EVALUATION OF WATER CURRENT TURBINES IN SOUTHERN SUDAN

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INTRODUCTION

1. In the past 6 years, ITDG has developed a turbine powered by water current and has tested prototypes in the UK and at Juba on the River Nile in Sudan. This work has confirmed the suitability of such a device for water pumping and suggested its possible suitability for electrical power generation, particularly in the more remote rural locations where more conventional power systems are less suitable.

2. This brief report is the result of a 2-week visit by ITIS Economist, Ken Marshall to Juba Boatyard in Sudan, the objectives of which were:

   2.1 To assess the market for the turbine in Southern Sudan.

   2.2 To assess the socio-economic implications of the turbine (in Southern Sudan).

3. The main body of this report comprises an assessment of the economic viability of the turbine in various applications and of the likely market for such a device (as per 2.1 above). Various aspects of its socio-economic importance are also considered (as per 2.2 above). In addition, Appendix 1 considers the economics of irrigation for vegetable growing in more detail, as this is thought to be the major area of application for the technology at present.

4. This report is intended as a companion to the technical report by Peter Garman (ITDG) entitled "Final Report to the Royal Netherlands Government on Overseas Testing of Prototype Run of Stream Turbine".

5. All amounts in the report are expressed in Sudanese pounds, denoted by S£. The February 1982 official exchange rate was: S£1 = US$1.1

6. 1 Feddan = 1 Acre

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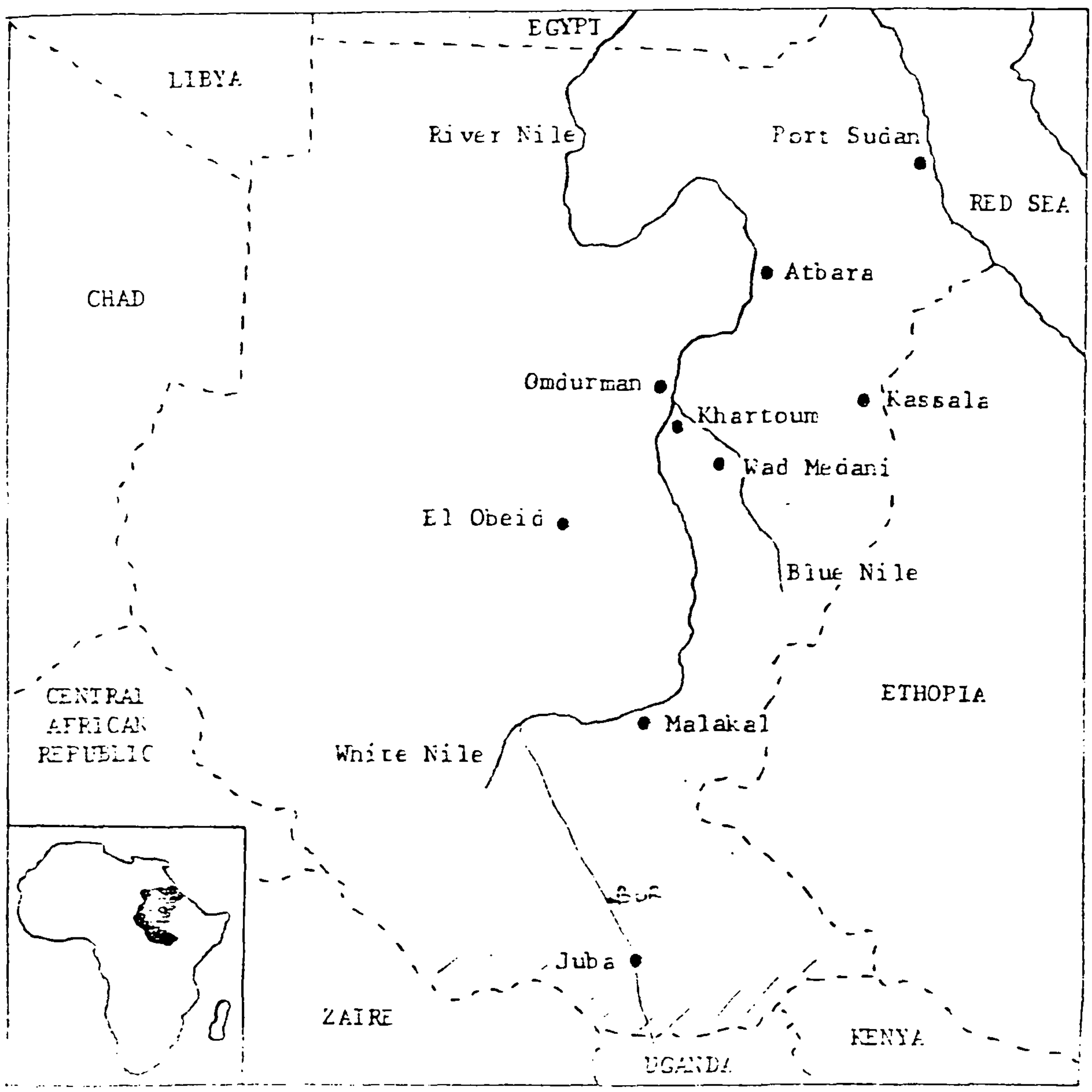
SUDAN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LIBYA
River Nile
Port Sudan
RED SEA
CHAD
Atbara
Omdurman
Khartoum
Kassala
Wad Medani
El Obeid
Blue Nile
ETHOPIA
Malakal
CENTRAL AFRICAN REPUBLIC
White Nile
Juba
ZAIRE
KENYA
UGANDA

Plate 1

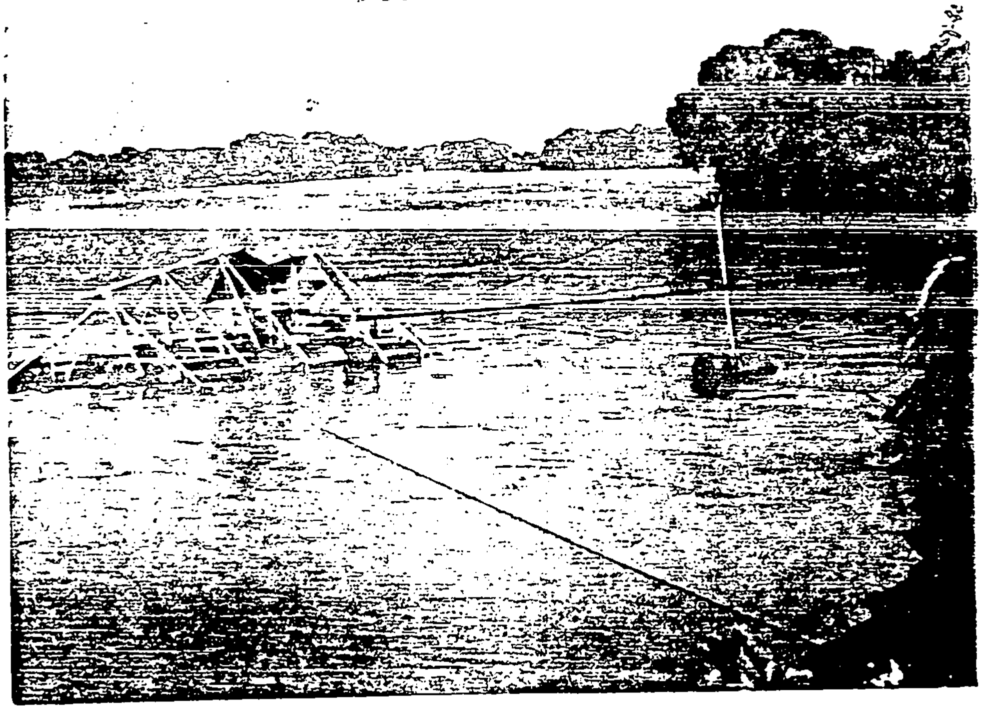
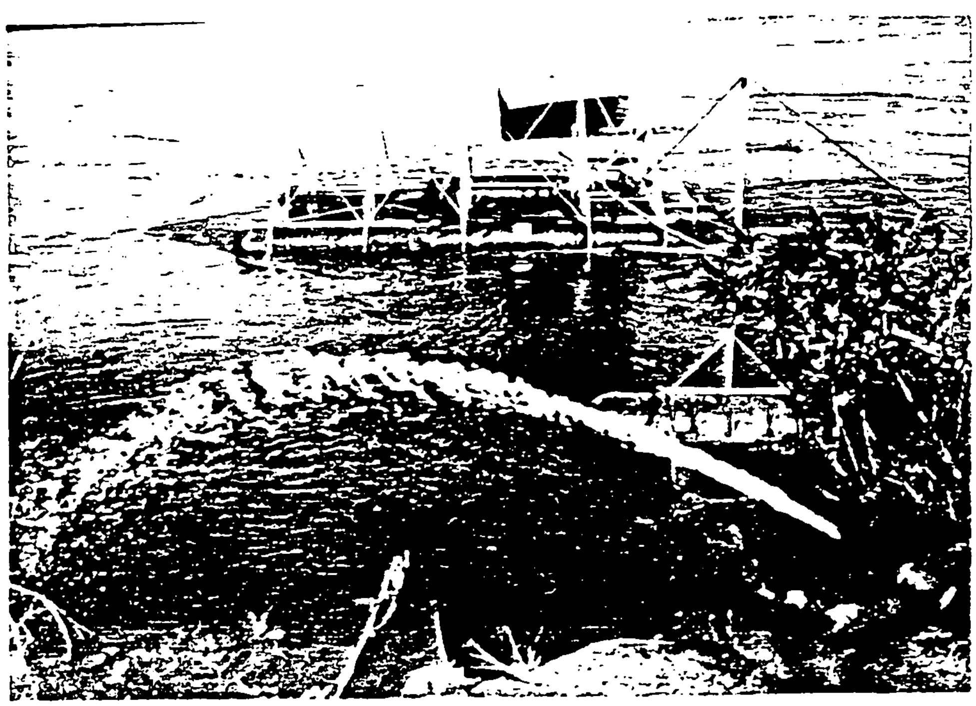


Plate 2



Plates 1 and 2

Prototype (3.75m^2 swept area) vertical axis turbine under test at Juba in Southern Sudan, pumping irrigation water from the River Nile. The comparative economics of this device and 5 HP diesel pumpsets are analysed in chapter 5. Smaller (25m^2 swept area) machines were also built for field testing in Southern Sudan and are reported in chapters 5 and 6.

1. SUMMARY

1.1 Field trials to date of various configurations of the water current turbine technology have shown its potential for pumping water from the River Nile in Southern Sudan. In typical dry season flow conditions (speeds of 0.8-1.0 m/sec), two sizes of turbine have pumped water through a head of 5 metres at the rate of approximately 1-2 l/sec, adequate with 8-hour operation to irrigate at least 1-2 Feddan of vegetables. Higher river currents improve WCT output and, hence, improve its cost-effectiveness relative to diesel sets, particularly in times of diesel shortages which result in market prices (considerably higher than controlled prices) becoming effective. WCT economics also improve if utilisation rates rise beyond those applying to diesel sets. However, field trials suggest that the additional time required of fieldmen using turbines in comparison with higher discharging diesel sets may be socially unacceptable and so a constraint on their adoption.

1.2 The turbines are capable of local manufacture at Juba Boatyard - under expatriate management - at a cost of S£2,070 for the smaller (2.5m^2 swept area) machine and S£4,500 for the larger (3.75m^2 swept area) machine. Further development work is necessary, particularly to reduce the capital cost of the larger machine.

1.3 The most promising end-use for the turbines is for water pumping to horticultural gardens, with a potential for some 70 machines in and around Juba.

1.4 Introduction of this number of machines would require maintenance and servicing back-up from the Boatyard, and provision of credit to potential users. Institutional credit is unlikely to be forthcoming in the absence of a programme to demonstrate the technology more widely.

1.5 The computed returns from vegetable production suggest that the payback period for smaller turbines irrigating 1 Feddan would be 1.5 seasons (of 6 months or so). This is likely to prove attractive to turbine users, even after allowing for a fall in vegetable prices due to increased availability.

1.6 Increased vegetable production in the dry season would reduce seasonal shortages, bringing benefits to 10,000 or so households in Juba in the form of improved supply and reductions in unit prices.

1.7 The smaller turbine - capable of irrigating up to 1 Feddan of land in dry season river flow conditions - is well-sized to the needs of the majority of vegetable growers, who own less than 1 Feddan of land. Their horticultural activity is largely confined to the wet season due to lack of access to water pumping technology in the dry season.

2. BACKGROUND

2.1 For several years the ITDG Power Programme has been working on applying the principle of the Darrieus wind turbine to extracting energy from river or canal currents for water pumping or electricity generation. This type of turbine is intended for use in situations where there is no 'head' of water readily available to drive a conventional turbine.

2.2 Despite the lack of attention to flowing water as an energy resource, ITDG felt that many rivers, canals and tidal streams existed with currents averaging over 1m/s in sufficiently close proximity to appropriate points of use, and which could in many cases represent the most cost-effective and reliable source of power - if suitable energy conversion technology were available to tap the kinetic energy of flowing water. Many large rivers such as the Nile, Niger, Zambesi, Zaire in Africa, the Euphrates or Tigris in the Middle East, the Indus, Ganges, Brahmaputra, Mekong, Yangtse Kiang in Asia, Amazon in Latin America, plus many lesser-known rivers, flow through regions where economic development is hampered by a lack of power resources, yet possess very adequate current velocities to perform useful tasks.

Many of these regions are arid, (or have long dry seasons). Pumping river water through a few metres head for irrigating fertile soil on their banks is not at present possible, because conventional power sources, such as diesel engines or mains electricity, are generally uneconomic in remote areas. Yet if irrigation could be introduced, it would make a major contribution to the development of the region.

People living alongside rivers have been aware for generations of the rivers' potential for enriching their land; in the Middle East large wooden undershot water-wheels have been used for many centuries to lift water. But these are too inefficient and large in relation to their power output to be constructed economically today. In China, small bamboo water wheels are still used to lift water from irrigation canals into rice paddies, but their output is very small and they are only viable for very low water lifts. There are, in fact, numerous appropriate and important applications for energy derived from flowing water currents and these are detailed in Chapter 3, Section 5.

2.3 For the last 100 years or so, virtually all efforts directed towards advancing the technology for tapping power from rivers have concentrated on impounding water, (behind dams or by using fortuitous topography), to create a head which could subsequently appear as concentrated kinetic energy at the runner of a relatively small turbine.

These efforts have generally been geared to large-scale schemes for electricity generation (or for gravity irrigation through large canal systems), covering wide areas. Such projects are enormously expensive, often create serious negative environmental effects, usually only have a finite useful life due to gradual siltation of the water catchment system and can only be established at the limited number of locations with both the correct topography for impounding the water sufficiently economically and with a large enough market within economic reach for the energy produced.

Since virtually no development effort has been directed either towards up-grading traditional practices or introducing new small-scale low cost techniques for tapping river or marine current kinetic energy, ITDG decided to institute a programme to investigate the utilisation of this interesting renewable energy resource.

2.4 This programme, initiated in 1976 under a grant from the Hilden Charitable Trust (UK) consisted of the construction and testing of small vertical-axis turbine rotors on the River Thames near Reading. Considerable knowledge of the characteristics of kinetic energy turbines running in free-stream water current conditions was gained by suspending model rotors (of about 1m diameter) over the bows of a small motor boat. The programme indicated that attractively high conversion efficiencies were attainable from devices of this kind and that such turbines could be designed that would be both simple and effective.

In April 1980, the Royal Netherlands Government provided the Group with a grant for a two year programme to build and test a full-scale working prototype system, to pump irrigation water and/or generate electricity under field conditions.

A unit with a 3m diameter vertical-axis rotor was designed, and the more complex mechanical components were constructed, and laboratory tested, at the ITDG's facility at Shinfield near Reading (UK). These components were then transferred to Juba in southern Sudan, where the Group in collaboration with the Sudan Council of Churches had established a boatyard which manufactures 25 tonne ferro-cement motorised river barges. Juba was chosen as a testing site as it offered the unique combination of a construction and repair facility well-known to the Group and in a location with a wide fast-flowing river typical of the kind where the technology under development might be applied.

The 3m diameter prototype was first started up in November 1980. It performed to expectations and has operated virtually without fault for some 6,000 hours of continuous running, pumping irrigation water.

2.5 Local interest developed in Juba, particularly from aid agencies and local farmers, and it was apparent that there was scope for producing smaller and simpler devices for pumping irrigation water onto quite small land holdings, (of less than 1ha), since the output of the larger unit, if stored over the 24 hours so that it could be fully utilised, would give enough water to irrigate landholdings of between 3 to 6 ha depending on river speed. Also the boat yard management expressed a serious interest in manufacturing such a smaller system for the local market as a new product in conjunction with barge production.

2.6 Therefore the Royal Netherland Government, who had provided the funding were approached in mid-1981 with a request for supplementary funding to permit the building of four prototype irrigation pumping turbines to be manufactured in Juba specifically for extended field trials. This request was granted and work is currently in hand.

2.7 ITDG has, therefore, demonstrated the technical and economic feasibility of a new renewable energy technology using a previously neglected resource. This report seeks to analyse the economic value of the systems developed.

3. DESCRIPTION OF THE TECHNOLOGY

3.1 The water current turbine developed by ITDG has been designed to be driven by the flow of water from rivers, canals or tides (without the need for a head of water). It consists of a turbine with symmetrical hydrofoil blades made of metal, wood, ferrocement or similar suitable materials joined to a hub by cross arms, (as shown in figure 2.) The cross arms are connected to a vertical shaft supported in bearings, allowing it to rotate about an axis perpendicular to the direction of the current. This unit can be suspended from a floating pontoon (as shown in figure 3) or from a structure bridging the water source.

3.2 In the case of the water pumping unit developed and tested in Southern Sudan, the position of the pontoon is adjusted by winch and mooring cables (as shown in figure 4) and carries both the turbine assembly and a water pump. The latter can be driven either directly off the rotor shaft in the case of a reciprocating pump or indirectly by way of step-up belt drive in the case of a centrifugal pump.

3.3 Tests to date show that as much as 25% of the available river power passing through the blades of such a turbine can be converted into useful shaft power. The faster the river speed and the greater the rotor area under water (i.e. the greater the turbine's swept area), the greater is the power output.

3.4 Power output is particularly sensitive to changes in river speed, such that the power output of the rotor increases by the cube of any increase in river speed. In other words, if the river flow is doubled, the turbine power output increases 8-fold. This is illustrated graphically in figure 5 for a turbine with a swept area of $3.75m^2$ and a rotor efficiency of 25%.

3.5 The turbine can be used for the following possible end-uses:

Pumped Water

Irrigation
Water Supply
Dewatering (for land recovery)
Desalination (by reverse osmosis)
Flooding of salt pans

Electrical Power

Lighting (domestic and communal)
Small power tools
Telecommunications
Medical equipment
Small scale refrigeration *
Icemaking *
Crop processing *

* (these are also feasible by means of direct mechanical power).

3.6 Fieldwork in Sudan has already demonstrated the feasibility of pumping irrigation water (as a direct replacement for diesel and petrol sets in the range up to 5 HP)

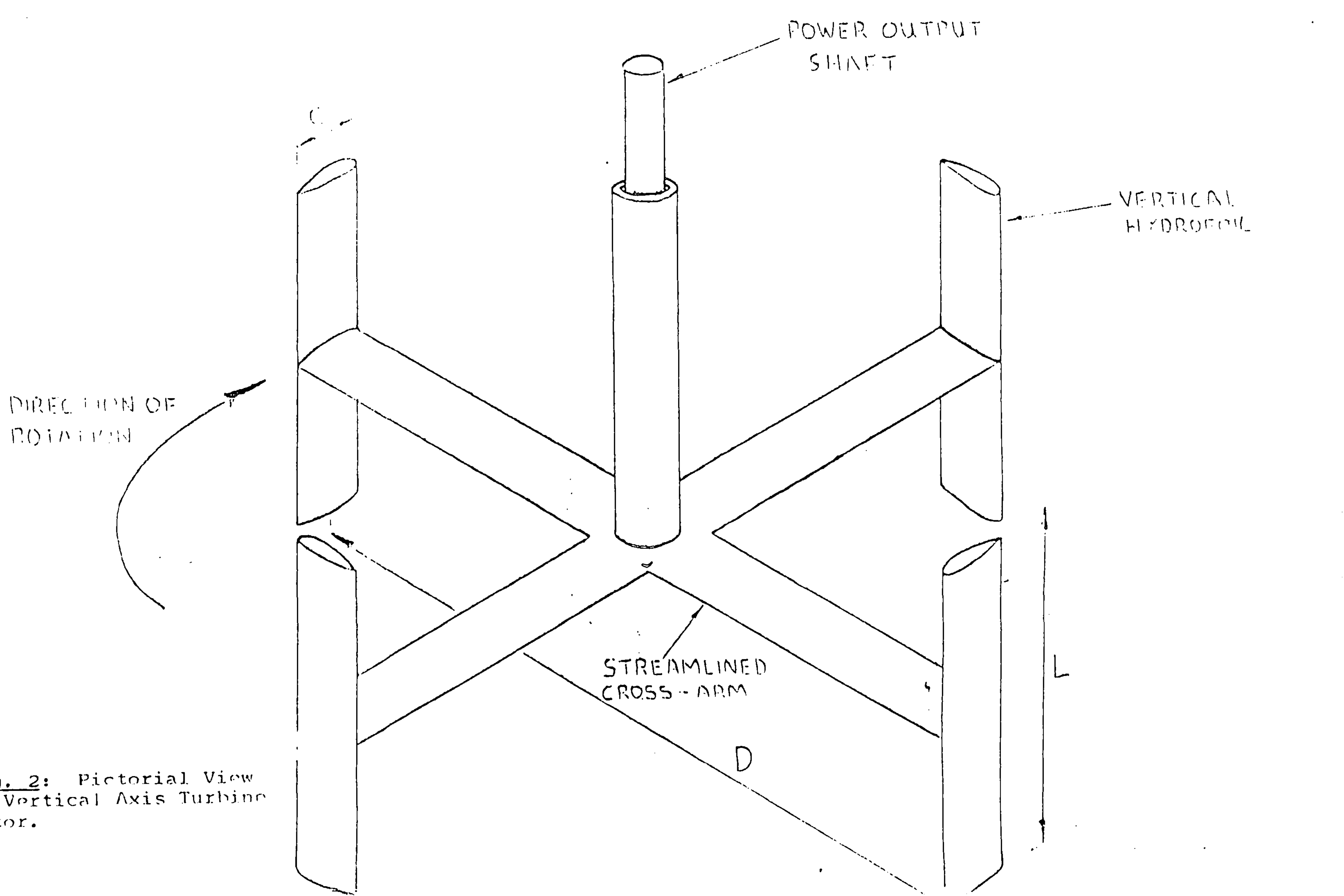


Fig. 2: Pictorial View of Vertical Axis Turbine Rotor.

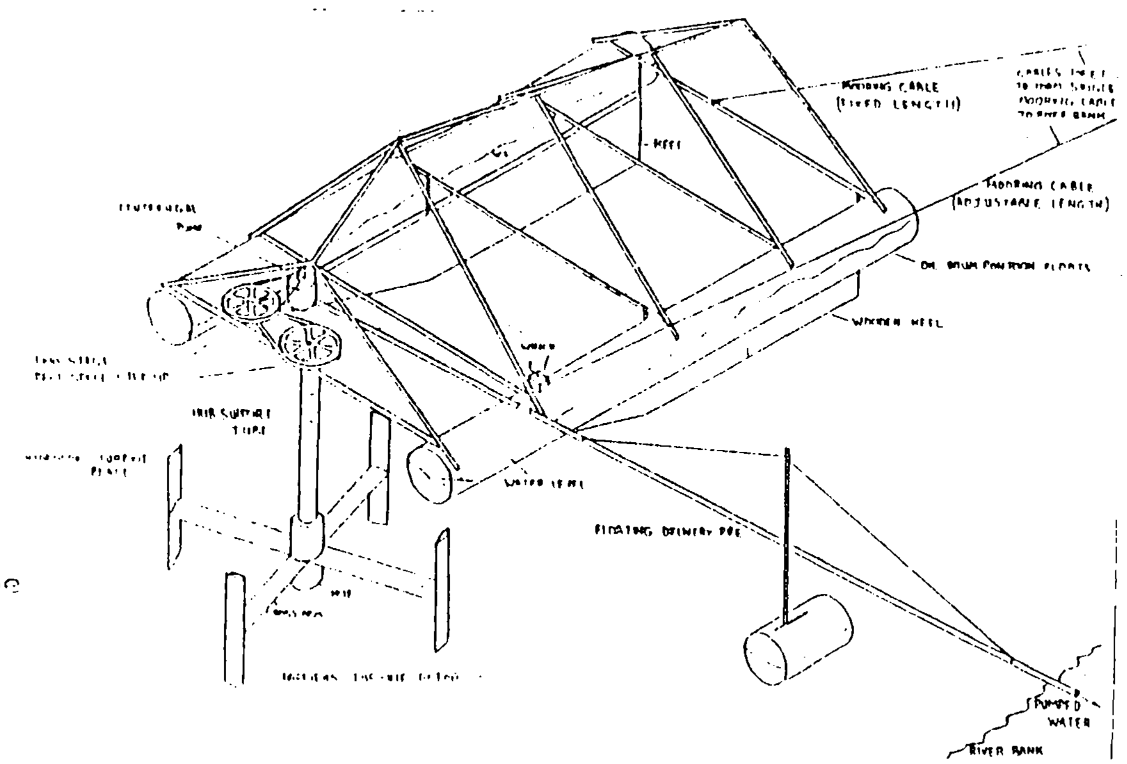


Fig. 3: ITDG's Prototype
River Turbine

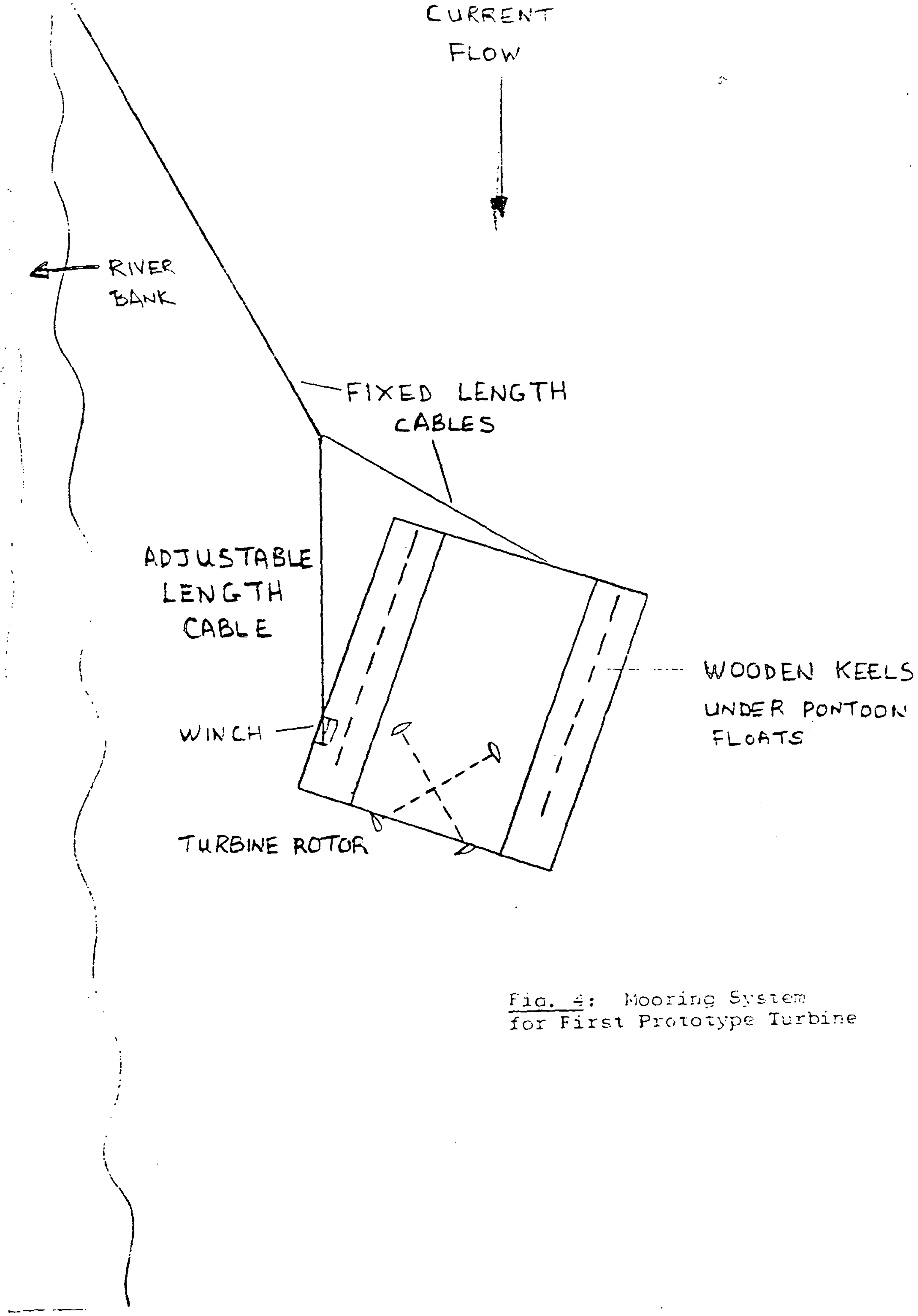
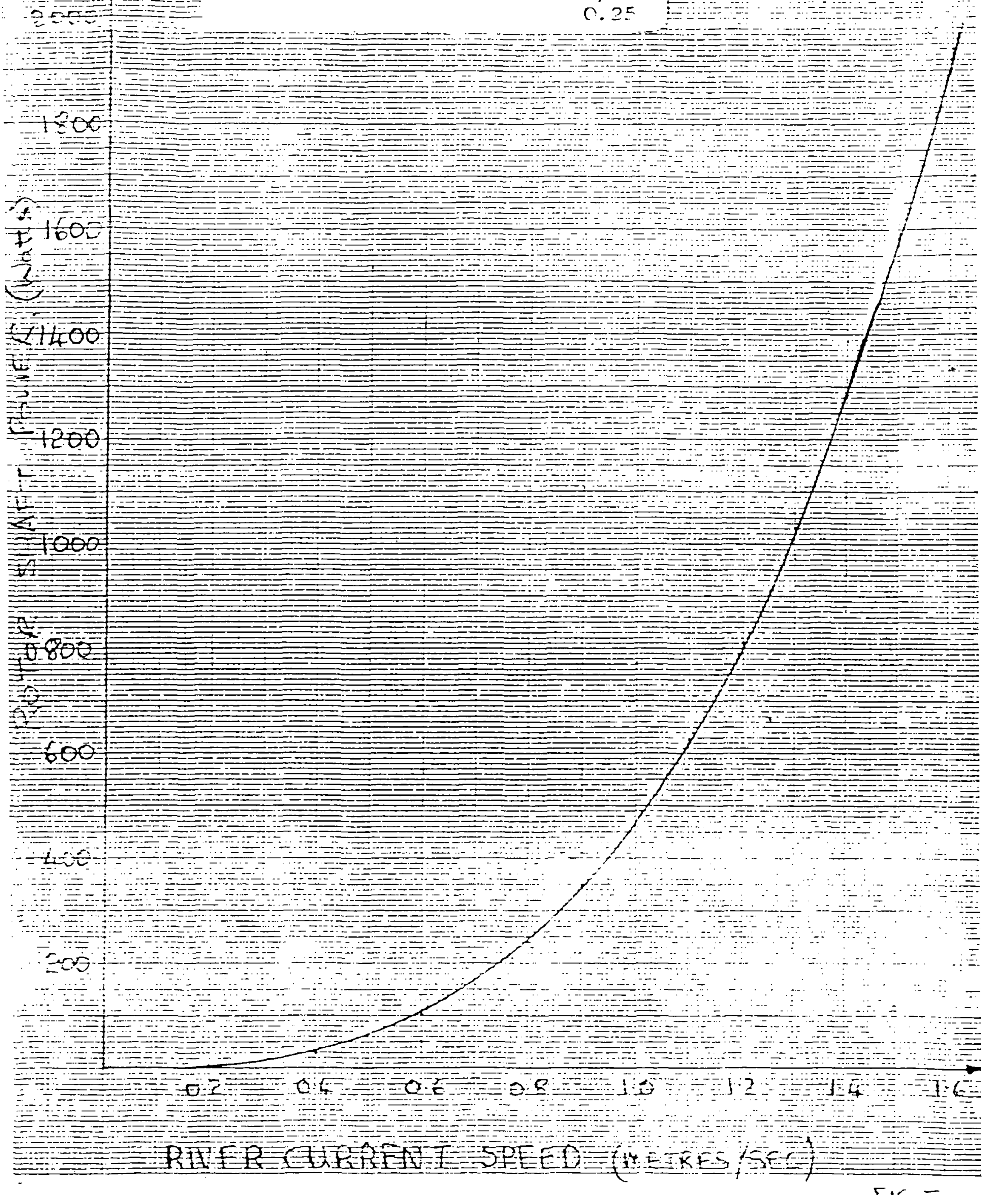


Fig. 4: Mooring System for First Prototype Turbine

Fig. 5: Graph Illustrating
Turbine Rotor Power
Characteristics vs.
River Speed
- Turbine Swept Area = 3.75m^2
- Coefficient of Efficiency = 0.25



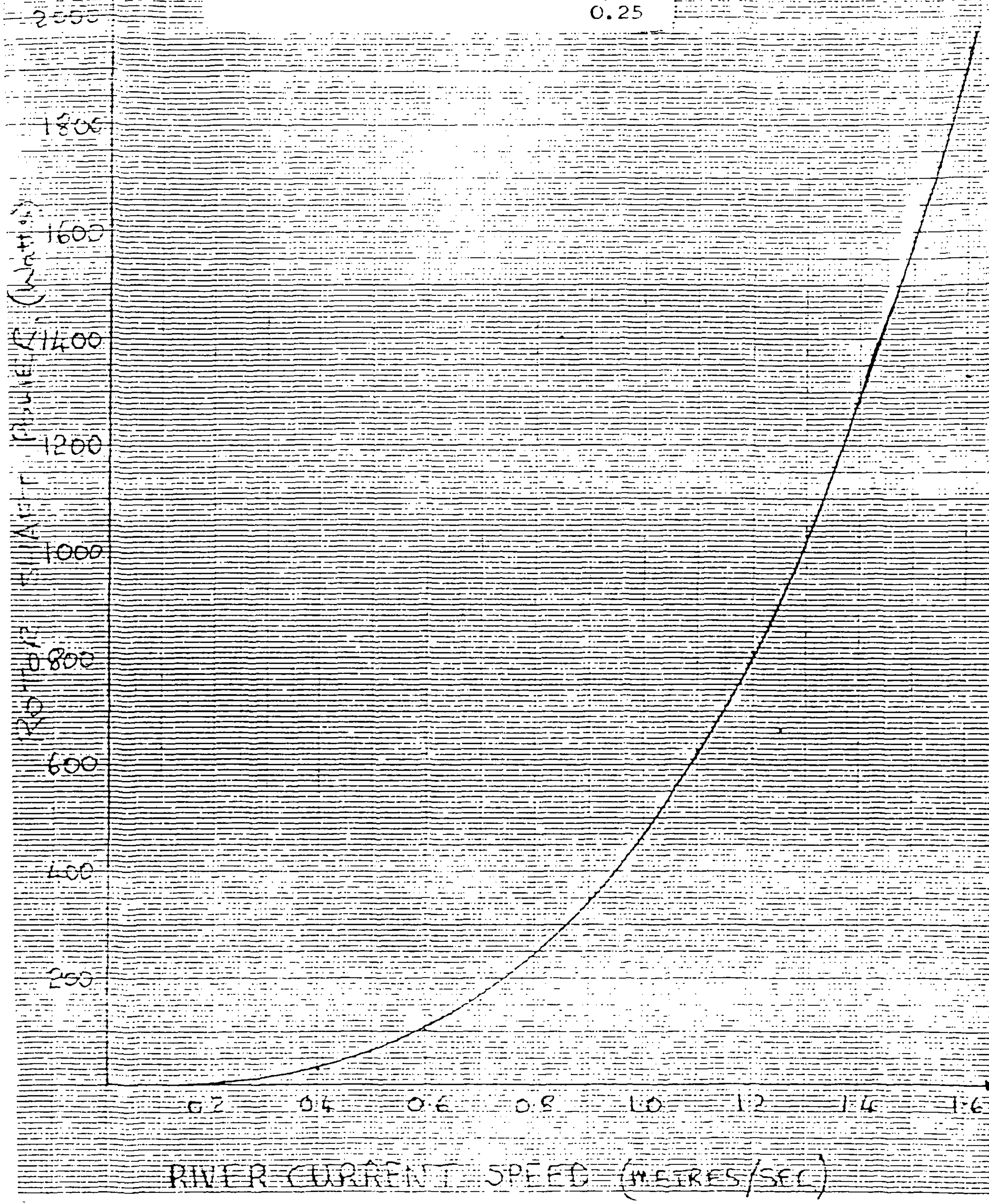


Fig. 5: Graph Illustrating
Turbine Rotor Power
Characteristics vs.
River Speed
- Turbine Swept Area = 3.75m^2
- Coefficient of Efficiency = 0.25

4. SOME ASPECTS OF TURBINE MANUFACTURE

4.1 Location

The only unit in Southern Sudan with the necessary skills, equipment and regular power supply to manufacture turbines is Juba Boatyard. It would also be able to provide necessary repair and maintenance services.

4.2 Source of Materials

These are presently imported by Juba Boatyard - by way of Kenya - including all steel, cement, bearings, etc. Only timber is available from local sources, although secondhand (vehicle) parts are available at Juba for manufacture of low-cost pumps. Allowing for occasional supply interruptions, Juba Boatyard is the only industrial undertaking with such regular (duty-free) supply lines. (See 4.4 "Local Value Added").

4.3 Cost of Manufacture

The direct cost (of labour and materials) was calculated by ITDG's Project Officer for manufacture of 2 sizes of vertical axis river turbines - of swept areas $2.5m^2$ and $3.75m^2$, capable of pumping approximately 1 and 2 l/sec in a current speed of 1 m/sec, typical of the Sudan dry season. (The head considered is 4-5 metres).

Allowing for overheads, the likely selling price of each machine (including Boatyard overheads) can be calculated (at January 1982 prices) at:-

$2.5m^2$ machine	S£2,070	($2,280)
$3.75m^2$ machine	S£4,500	($4,950)

The $2.5m^2$ machine incorporates locally made pump and transmission which have yet to be proven totally reliable. The $3.75m^2$ machine incorporates expensive imported pump and transmission of proven reliability. As these costs relate to one-off production prototypes, further cost reductions can be expected, however.

4.4 Local Value Added

Calculation of local value added for the smaller $2.5m^2$ swept area machine is shown overleaf in Table 1:-

Table 1: Estimated Cost of Producing 2.5m^2 Swept Area Turbines (£Sudanese)

ITEM	LOCAL S£	FOREIGN EXCHANGE S£	TOTAL S£
Materials (1)	81	934	1015
Labour:			
Skilled Operatives (2)	300	-	300
Supervision (3)	100		100
Overheads (4)	-	655	655
	----	---	---
	481	1589	2070
	----	----	----
%	23	77	100

NOTES:

(1) Labour requirements including cutting, filing, drilling, welding, plastering and assembly based on approximate time for prototype of 3 manmonths (72 mandays).

(2) Calculated on basis of contribution towards workshop supervisor's time, costed as 1 manmonth.

(3) Calculated on basis of Juba Boatyard overhead: labour cost ratio of 1:1 (at budgetted £S400,000 turnover). Shown as imported item, as most overhead items (expatriate salary, fuel etc.) are imported.

The two important advantages of instituting local manufacture in Juba are creation of a local capability for repair and maintenance of the turbines, and of an element of local value added (as high as 23% for the smaller machine), which increases the spin-off benefits of the turbine for the local economy in comparison with wholly imported diesel and diesel sets.

5. COMPARATIVE ECONOMICS OF ALTERNATIVE TECHNOLOGIES

5.1 The principle realistic alternative to the turbine at present in South Sudan for waterpumping is the 5 HP diesel pumpset. The following section considers the relative characteristics (advantages and disadvantages) of these two options, describes the methodology used for an economic comparison of these alternatives, and presents the results and conclusions of this analysis for Juba.

5.2 Comparative Features of Water Current Turbine and Alternatives

The advantages of the river turbine over the diesel pumpset alternative are:

1. uses a renewable energy source - the kinetic energy of flowing water
2. is independent of unreliable fuel supplies
3. avoids costly transportation of diesel
4. avoids rising fuel cost (in real terms)
5. can be locally manufactured, increasing local value added
6. (arising from 5) can be locally repaired
7. is less dependent on imported spare parts
8. is easier to maintain, avoiding need for lubricating oil and other consumables.
9. is likely to have a longer life
10. is less liable to catastrophic damage through neglect or lack of attendance, with unattended operation a possibility.

The disadvantages are:

1. has higher first cost
2. is dependent on water flow rates which vary over time making output unpredictable.
3. needs minimum water flow of 1 m/s to provide significant useful quantities of power (although the machine can operate at lower current speeds down to 0.75 m/s).
4. is liable to choking by debris in the water course.
5. does not presently enjoy a second-hand market

as diesel sets do.

5.3 Methodology of Economic Analysis

The analysis which follows compares the cost-effectiveness in Juba of a 3.75m^2 water current turbine as tested in Sudan with a diesel pump set of 5 HP (this being the minimum size generally available). It should be noted that this is a comparative cost study of two alternative methods of waterlifting. It implicitly assumes that the decision to pump water has been made and so does not necessarily indicate a positive cost-benefit ratio. (That is, it does not imply that the incremental crop value from a waterpumping application will necessarily exceed the incremental costs).

The analysis is presented in two modes:

private - in terms of comparative costs to the consumers (turbine user)

social - in terms of comparative costs to the national economy, using shadow prices to adjust for distortions to market prices.

The comparative analysis is presented in terms of the present value (pv) of costs over the assumed 10 year life and also in terms of the cost per m^3 of water pumped, using first year;s operating costs.

The analysis is based on critical assumptions which are adjusted by way of a sensitivity analysis to assess their importance to the conclusions. The main assumptions are:-

1. pumpset lives are 10 years
2. the opportunity cost of capital is 10% p.a.
3. nil residual value for equipment at year 10
4. all designs need manning

It should be noted that this analysis concentrates exclusively on the water-pumping potential for the device. It also compares WCT and diesel pumping technology for identical duty cycles, on the assumption that (as Sudanese evidence suggests) field labour is reluctant to work longer hours with a lower discharge machine. Use of storage tanks is unlikely to improve WCT economics, as the savings in WCT costs (from using a smaller unit) are offset by the costs of constructing a storage tank and by lost production from ground area given up to a low-cost earth/brick tank. (Raised steel tanks in Sudan are prohibitively expensive).

5.4 Base Data

The values of basic parameters are as follows:

Water Current Turbine (WCT)

Capital Cost:	S£4,500	Based on cost of an imported one-off production prototype of $3.75m^2$ swept area.
Life: 10,000 operating hours giving:	10 years	(assuming 1,000 hours per annum operation in a 1.2 m/s current)
	6 years	(assuming 1,730 hours per annum operation in a 1 m/s current)
Maintenance:	S£180 p.a.	Based on 4% of capital cost
Labour:		Costed at S£0.25/hour for a pump attendant, working:
	a) S£250 p.a.	1000 hours for a turbine in a 1.2 m/s current
	b) S£430 p.a.	1,730 hours for a turbine in a 1 m/s current.

Diesel Set (5 HP)

Capital Cost:	S£2,650 (private)	Calculated on basis of 5 HP diesel set imported from Kenya at US$2,000 (before 40% import duty), giving pumpset cost of S£2,550 plus 200 litres of diesel at S£0.5 per litre as working capital.
	S£2,080 (social)	Being private cost less import duties, making no allowance for foreign exchange scarcity, plus fuel at S£0.8/litre. (for an explanation of fuel prices, see "Fuel" below).
Life:	10 years	Calculated on the basis of annual use of 1,000 hours, and a maximum useful life of 10,000 hours. (This life is also a function of maintenance).
Maintenance:	S£102	Calculated at 4% on pumpset capital costs (excluding fuel stock), being equivalent to 12 mandays p.a. and an equal amount for parts and lubricants
Fuel:		Calculated on 0.8 l/hour diesel consumption for a typical duty cycle of 1,000 hours p.a. (Fuel consumption is based on field observations for a 4 year old set in Sudan and so is regarded as a reasonable average for a pumpset over its entire life).

	S£2,320 (unsubsidised private)	at S£2.9/litre, being the present free market price for diesel, assumed not to increase in real terms to the farmer.
	S£400 (subsidised private)	at S£0.5/litre being the present controlled price for diesel, assumed not to increase in real terms to the farmer.
	S£640 (social)	at S£0.8/litre, being the shadow price for diesel, calculated on the basis of ex-Kenya bulk delivery price, assumed not to increase in real terms to the economy.
Labour:	S£250 p.a.	Costed at S£0.25/hour for a pump attendant.

Opportunity Cost of Capital

	10%	a real social opportunity cost (or discount rate) of 10% is assumed; allowing for inflation, capital cost subsidies, preferential interest rates, etc. the private cost to the farmer is likely to be less than 10% in fact.

5.5 Results of the Analysis

Present Value (PV) Analysis

5.5.1 Table 2 overleaf summarises the results of the analysis, which indicate that the most cost-effective pumping solution to farmers (as measured by both social and private PV) is the water current turbine at river speeds in excess of 1.2 m/sec. It is significant that WCT capital costs are based on a one-off production prototype, yet to be subject to value engineering which could be expected to reduce costs, as would batch production. By contrast, diesel pumps are a mature, mass-produced technology, unlikely to fall in real price terms.

The analysis is based on WCT performance in a 1.2 m/s current, pumping water at the rate of 3.2 l/sec. through a 5 metre head. A 5HP diesel set was measured in tests in Southern Sudan at an equivalent output. This assumes a duty cycle of 1000 hours p.a. for both options, giving a relatively low load factor of 11% for WCT (load factor is defined as total hours in actual annual operation divided by total potential hours - i.e. 1,000 hours ÷ 8,760 hours p.a. = 11%). To pump an equivalent amount of water, the WCT must operate for longer duty cycles in slower current speeds. At the indicated speed of 1.0 m/s, the WCT must

TABLE 2: Summarised Results of Economic Analysis

Technology Option / Variable	WCT (1m/s current) S£	WCT (1.2m/s current) S£	Diesel (5 HP) (controlled price for fuel) S£	Diesel (5 HP) (uncontrolled price for fuel) S£
First Cost (1)	4,500	4,500	2,650	3,130
PV: (at 10% discount rate)				
PRIVATE	10,555	7,140	7,350	19,630
SOCIAL	10,555	7,140	8,080	-
Unit Cost of Water (S£ per m^3)	0.101	0.143	0.103	0.269

operate for 1,730 hours p.a. (at a load factor of 20%). Its performance is inferior to that of a diesel set at controlled fuel prices, but superior at market (uncontrolled) prices for fuel.

5.5.2 These results can also be ranked (according to the criteria of cost-effectiveness, 1 being least-cost, 4 being highest cost) as below in Table 3:

<u>Table 3: Ranking of Results of Economic Analysis</u>

Technology Option	WCT (1 m/s)	WCT (1.2 m/s)	Diesel (5 HP) at controlled fuel prices	Diesel (5 HP) at uncontrolled fuel prices
<u>First Cost</u> (1)	3	3	1	2
<u>PV</u>: PRIVATE	3	1	2	4
SOCIAL	3	1	2	-

5.5.3 Adjustments also made by way of sensitivity analysis marginally effect the conclusion. As shown overleaf in Table 4, the rankings (in brackets) for NPV using <u>private</u> costs change marginally favouring the diesel set at controlled fuel prices, if the discount rate is raised to 20% or if capital costs of both technologies are increased (by 50%).

Clearly, the level of fuel prices and considerations of fuel availability effect the analysis. At free market fuel prices, however, the WCT technology remains a cost-effective alternative to diesel sets even in slower (1m/s) currents, and even at 50% higher capital costs and a discount rate of 20%. Likely reductions in WCT capital costs (as it becomes a mature technology) further improve its cost-effectiveness rating.

<u>Unit Cost Analysis</u>

5.5.4 Table 2 and figure 6 also indicate the unit cost per m^3 for water pumped by WCT in two current speeds and by a 5 HP diesel set assuming fuel at controlled and market (uncontrolled) prices. The analysis shows the unit cost of water is similar at S£0.1/m^3 for WCT in relatively fast-flowing (1.2m/s) current conditions and for diesel sets at controlled fuel prices.

The results are sensitive to fuel prices and river speeds and so a range of these variables is illustrated in table 5 and graphically in figure 6.

TABLE 4: Results of Sensitivity Analysis

Adjustments / Technology Option	WCT (1m/s current)	WCT (1.2 m/s) current	Diesel (controlled fuel)	Diesel (Uncontrolled fuel
Base Data (Private PV over 10 years at 10% discount rate)	S£ 10,555 (3)	S£ 7,140 (1)	S£ 7,260 (2)	S£ 19,540 (4)
Increase in discount rate to 20%	7,975 (3)	6,300 (2)	5,800 (1)	14,310 (4)
50% fall in WCT costs (at 10% discount rate) *	7,152 (2)	4,339 (1)	7,260 (3)	19,540 (4)
50% fall in WCT costs (at 20% discount rate) *	5,100 (2)	3,673 (1)	5,800 (3)	14,310 (4)
50% increase in capital cost (at 10% discount rate) *	13,960 (3)	9,945 (2)	8,859 (1)	20,655 (4)
5% real fuel price rise	10,555 (3)	7,140 (1)	7,965 (2)	23,445 (4)

(* Maintenance costs are assumed as unchanged at £180 p.a. on WCT and £102 pa on diesel pumpsets.

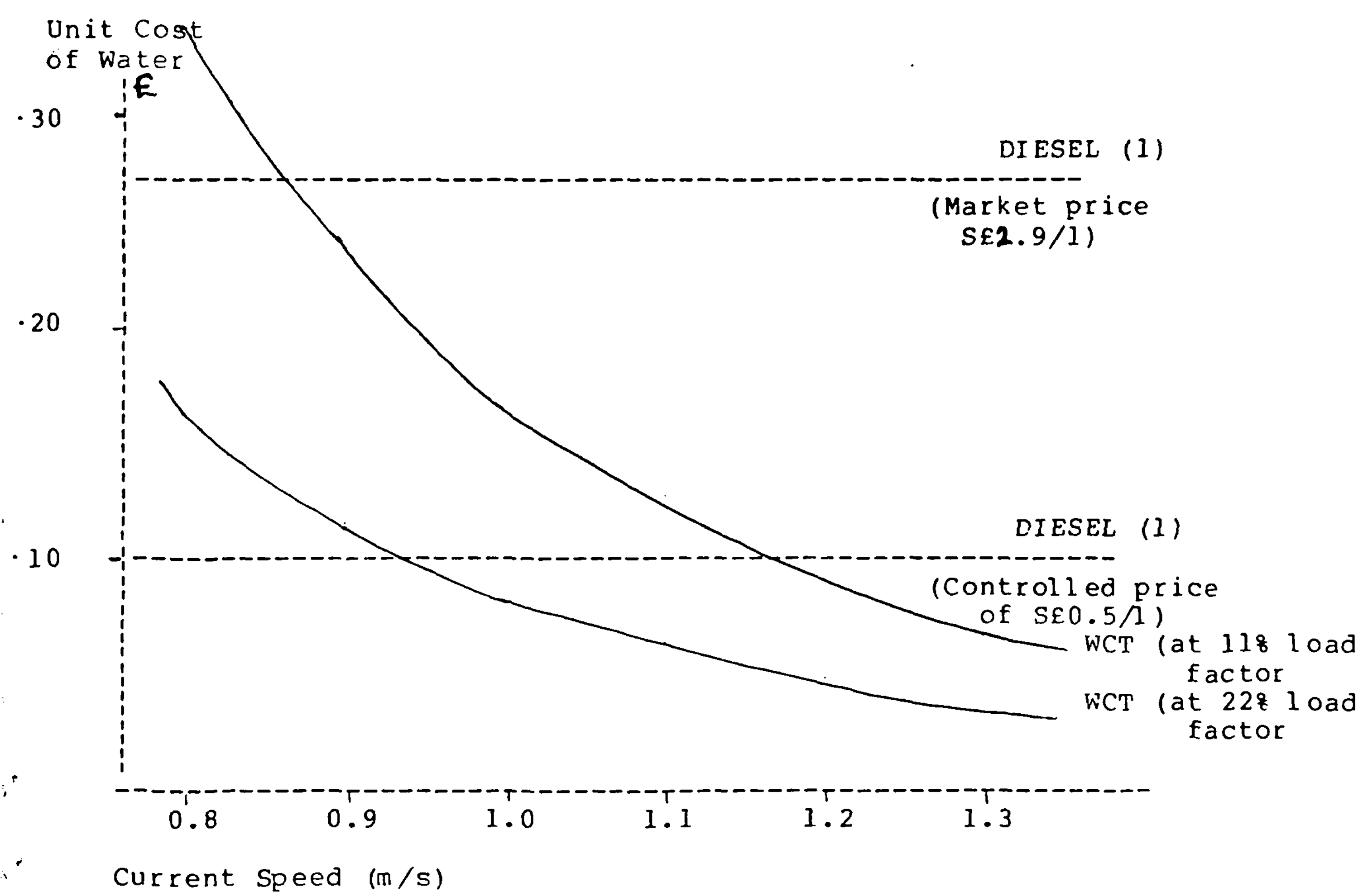
Table 5: Unit Cost of Water Pumped through 5m Head

Current Speed	Pumping Rate	m^3 pumped in 1000 hrs	Annual Cost	Unit Cost
(m/s)	l/s	m^3	S£(1)	S£/m^3
0.8	0.95	3,420	1162	0.34
0.9	1.35	4,860	1162	0.24
1.0	1.85	6,660	1162	0.17
1.1	2.46	8,860	1162	0.13
1.2	3.20	11,520	1162	0.10
1.3	4.07	14,650	1162	0.08

Note: (1) Annual cost is based on a capital cost of S£4,500 discounted at 10% over 10 years, giving:

	S£
annual capital cost	732
maintenance	180
labour (1,000 hours)	250
	S£1162

Fig. 6: Graph Illustrating Unit Water Cost at Various Current Speeds and Fuel Prices



Note: (1) Diesel costs are based on Table 2.

The higher are diesel prices, the more cost-effective the WCT technology becomes, even at lower river currents. In addition, as the WCT can operate unattended, it is capable of being left to operate for longer periods than the diesel set, further reducing unit water pumping costs. The effect of this is illustrated on the graph, which shows the effect on unit water costs of increasing annual operating hours to 2,000 (giving a load factor of 23% - i.e. 2,000 hours actual operation p.a. divided 8,760 hours possible p.a.) (Note: in the calculations, it is assumed that no additional operative time is required to attend to WCT beyond the 1,000 hours originally budgetted.)

Clearly, high utilisation rates for WCT technology are important in reducing the unit costs. Whether this is socially acceptable at present is difficult to judge. Limited Sudanese experience to date suggests not. In addition, in the absence of water storage (costly in Sudan in terms of a storage area and the opportunity cost of lost production from this area), Sudanese practice shows the need for operatives to be in attendance to control water flow and direct this along earth channels to small, bunded areas.

5.6 Conclusions

The conclusions of the analysis can be summarised as follows:

5.6.1 The optimal technology choice to the user (as defined by private NPV) is the water current turbine at a real interest rate of 10% (and indeed at rates up to 12%), where river flows are in excess of 1.2 m/sec.

5.6.2 The optimal technology choice to the national economy (as defined by social NPV) is likewise the water current turbine at marginally lower river speeds (in excess of 1.1 m/sec) or at marginally higher real interest rates (up to 18%). Allowing for a margin of error, when dealing with such uncertain data, however, the preference for the turbine over diesel set is not significant, provided diesel set users can be guaranteed access to fuel at controlled prices. In a region of regular fuel shortages, however, the latter is not considered a reasonable assumption.

5.6.3 The turbine offers considerable advantages to pump users - over the diesel option - at free market fuel prices.

5.6.4 Sensitivity analysis only marginally alters the conclusions, in favour of diesel sets at controlled fuel prices, when capital is costed at 20% (in real terms). Otherwise WCT technology is the most cost-effective pumping option.

5.6.5 As turbine capital costs are based on a one-off prototype, significant reductions in this figure can be expected, unlike the more mature diesel technology. This serves to improve the economics of WCT technology at higher discount rates and at lower river speeds.

5.6.6 WCT technology locally manufactured and, hence, serviced appears to be a cost-effective waterpumping alternative to diesel sets. The latter suffer from five major disadvantages, namely:

- irregular fuel supply, resulting in periodic non-availability
- irregular fuel supply, resulting in sharp increase in open market prices above controlled prices.
- lack of maintenance and repair skills, particularly outside of an institutional setting and in rural areas.
- lack of ready access to spare parts
- 100% importation which consumes scarce foreign exchange and limits local value added.

5.6.7 The cost-effectiveness of the smaller $2.5m^2$ swept area turbines is likely to be even more significant bearing in mind that it has an output performance rated at 67% of the larger machine (of $3.75m^2$ swept area) and a capital cost of 46% of the larger machine. It is, therefore, cheaper to buy (in terms of first cost) than a diesel set and is better suited to the water requirements of smaller landholdings (defined as less than 1 ha.), displaying a higher utilisation factor. The smallest diesel sets are oversized relative to the needs of smallholders and so represent considerable over-investment in underutilised capacity.

5.6.8 WCT may be capable of unattended operation, further increasing its cost-effectiveness by enabling it to be used for more hours/season than a diesel set, thereby reducing its unit pumping cost further.

5.7 Water Flow Considerations

The above analysis has directly compared a prototype 3.75 m^2 turbine with a 5 HP diesel set. Performance data for a 4-year old set from Juba (Sudan) show that the latter would typically pump 3-4 l/sec of water (taken in cost analyses as 3.2 l/s) through a head of 5m (allowing for engine derating, friction losses etc.)

A turbine with a swept area of $3.75m^2$ would have the following performance based on data from field trials in Sudan.

Water Pumping Rates (in l/sec) for a 3.75m2 Turbine Pumping through 5m head

Current Speed (m/s)	Pumping Rates (l/s)
0.8	0.95
0.9	1.35
1.0	1.85
1.1	2.46
1.2	3.20
1.3	4.07

This is based on a likely overall system's efficiency of 5% (taken as the potential energy of water pumped divided by the kinetic energy of the water intercepted by the rotor per unit of time). Tests on the prototype in Juba have given efficiency as high as 5.8%.

Clearly for the WCT option to be a direct substitute for a 5 HP diesel set assuming diesel availibility at controlled fuel prices, it needs application in water regimes where flow rates exceed 1.2 m/sec. Improved pumping rates could also be achieved by way of:-

- increasing system's efficiency beyond 5% (which is unlikely)
- increasing the turbine swept area, (which would increase capital costs and reduce the cost-effectiveness of this option).
- increasing daily usage (in terms of hours of operation) which is likely to be acceptable (based on Sudanese field experience to date), unless expensive recourse was made to storage tanks to allow unattended pumping.

However, as shown in Sections 5.5 and 5.6, with diesel supply erratic and prices consequently high, the turbine is a cost-effective alternative to diesel sets at lower river speeds. Dry season river flow data from Southern Sudan show current speeds of 0.8-1 m/s. When fuel supply is interrupted or market prices operate, the WCT is a cost-effective alternative to diesel sets at river speeds in excess of 0.85 m/sec. (as shown in figure 6). Clearly, in the absence of increased WCT utilisation rates (beyond the assumed 1,000 hours p.a.), the critical variables in assessing the alternative technologies become fuel price and river current. Further data collection is clearly necessary.

6. MARKET FOR TURBINES

6.1 Likely End Uses - Market Summary

The most likely end use for the turbine in Southern Sudan is considered to be water lifting for horticultural production at major urban centres like Juba and Bor and for fodder production. While there is a practical need for electricity generation for fish drying and freezing, dura (sorghum) grinding and workshop facilities, the lack of a ready institutional mechanism for developing these particular end uses and the absence of a proven, reliable technology (using WCT) makes this at best a theoretical market. The electricity generation option is, therefore, not considered a technology of immediate to short-term potential in Southern Sudan.

The following sections analyse likely demand for WCT technology both for waterpumping and - briefly for electricity generation - and predict an immediate market for 10 such devices (in the size range 2.5 - $4m^2$ swept area) and a longer-term market of 70 water-pumping WCT's.

6.2 Horticulture:

6.2.1 The economics of irrigation for horticulture (analysed in more detail in Appendix 2) suggest a present wet season gross yield of S£2,000/feddan (0.4 ha.) and a dry season gross yield of S£4,000/feddan. The main vegetables grown are local greens (riggla and kudra), aubergine, okra and onions. Cabbage, cucuberates and potatoes are less successful because of pests, high water needs and soil conditioning requirements.

Increased dry season cultivation using turbines could be expected to reduce shortages and hence prices to wet season levels. Consequently, the ensuing analysis shows reduced dry season gross yields per feddan of S£2,000, using a small ($2.5m^2$ swept area) turbine costing S£2,070. Such a turbine operating in a 1 m/s current has been shown to pump water through a 5m head at 1 l/s. This gives 5,200 m^3/season, assuming 8 hours per day operation, which meets the water requirements of a least 1 feddan of vegetables. With labour requirements of 3/feddan, the net yield per dry season feddan (0.4 ha) can be calculated as:-

	S£
Gross yield	2,000
Labour (at S£30/month)	540
Inputs (seeds etc)	100
Net yield	1,360 per season
Turbine investment	2,070
Payback Period	9 months

With credit terms being 12% interest on a 3 year loan, annual repayments of S£860 could be covered 1.6 times from net yields.

6.2.2 Demand for turbines is analysed in terms of:

- diverted demand (i.e. switched from diesel to turbines)

- generated demand (i.e. new demand for pumps)

The market for the smaller (2.5m^2 swept area) turbine in the Juba area is estimated at:-

Diverted 5 - to replace existing diesel sets used privately

Generated 70 - among existing wet season horticulturalists with less than 2 feddan.

6.3 Fodder Production

The FAO/Min.Ag. (MAFAO) "Small Holder Development Outreach Programme" plans to establish 25 mixed farming units (dairy - poultry - vegetables) near Juba, with a total of 250 head of cattle and 750 pullets. In addition, 50 TPA feed will be grown - estimated on the basis of 0.2 TPA per head of cattle - which will require 13 ha. of land with double cropping of improved sorghum varieties. Water requirements will be in excess of 500m^3 per day or 5-6 l/sec - requiring 5 machines (assuming crop water needs of 5,000 m^3/ha/season and 24 hours/day turbine operation).

The scheme will be managed by Min.Ag., FAO and the farmers, with produce (milk, meat, eggs and vegetables) marketed through traders in Juba (travelling out to collect produce). The annual profit per farmer is calculated as being in excess of S£1,000 after debt repayment. How far new farm management practices can be successfully introduced, and household members can meet increased labour requirements, are unknowns at this stage.

Market

Initially, the 2.5 year scheme covering 400 h.a. of riverine land requires 5 turbines. Successful demonstation of both the turbine and the overall scheme could open up a possible market for 2 turbines p.a., assuming the existence of at least 1 such scheme at any one time at similar river locations in Southern Sudan. The budget of US$25 million per scheme and the limited management potential for undertaking such schemes suggests that this may prove an optimistic projection.

6.4 Domestic Water Pumping

Most villages are set back from the river to avoid mosquitoes and so provision of a turbine pumped water supply to the bank would only marginally reduce time spent collecting water. However, use of a filter (and a tank) would purify water reducing the incidence of water-borne diseases, if no cultural preference presently attaches to cloudy water and its flavour. Such a system would need to be installed at a cost met from sources outside the village, which will limit this possible market. However, it is a supplementary use of the system which in the long term might merit consideration as a night-time load where other end uses have been established.

6.5 Fish Drying, Freezing

FAO estimates that initially scope exists for a 1 kW turbine to provide power to drive fans for improved ventilation to solar fish drying units. In addition, fish freezing units at isolated, point-of-catch locations are considered feasible. Typical catches of 30T are likely, making power requirements per unit in the region of 10 kW. No schemes as yet exist and further data on river flows in the swamp fishing areas is necessary, before the market potential can be gauged.

6.6 Workshops

Workshop facilities established in remote locations are a possibility which could only be realised in limited locations with outside financial intervention. A mix of hand and small power tools (drills, grinder and sander) would require 1-2 kW of power. Again no such schemes presently exist - but 1 unit per village would create a market for 10-20 units around Juba.

6.7 Dura Grinding

Another possible mechanical or electrical end use for turbines is for dura (sorghum) grinding to produce flour. Presently available in Juba, using diesel as the power source, units charge S£0.75/kg of dura ground. The location of such units at the river and so 1-2 km from the market will limit the market for turbine driven units in Juba but could be placed at village locations. Power requirements would be 1-2 kW. Presently, however, sorghum is ground in these villages by hand (pounded by women) at no cash cost to the village. The benefit to the household of labour released for other activities is difficult to assess in the absence of more information on household economics. Again the market is difficult to assess.

6.8 Market Summary

The market potential is clearly difficult to gauge in the absence of rural development programmes and with the emphasis of most ngo's on relief aid. The electricity generating option in particular using the water current turbine is not considered a technology of immediate to short-term potential in Southern Sudan in view of the lack of institutions to implement and manage such schemes.

	Immediate	Long-term
Horticulture	5	70 (at Juba)
Fodder production	5	2 p.a.
Domestic water pumping	-	?
Fisheries	-	?
Workshops	-	10-20
Dura grinding	-	?

6.9 Likely Beneficiaries

6.9.1 The smaller pumps (of $2.5m^2$ swept area) as funded by the Dutch government suit the needs of small and marginal vegetable growers with less than 1 hectare (or 2.5 feddan) of land (see Appendix I). However, this group - presently practising only wet season cultivation due to lack of pumping technology - would need favourable credit arrangements to acquire turbines. Present dry season vegetable growers - who constitute an immediate market for the turbine - have access to cash savings to acquire turbines, although the smaller ($2.5m^2$) unit would not meet all the water needs of their above-average size plots and they could be expected to be interested in purchasing larger turbine sets.

6.9.2 In addition, improved vegetable availability would benefit most households in Juba, including the lowest-income groups by way of reducing dry season shortages and so prices.

7. CONSTRAINTS ON TURBINE INTRODUCTION

This chapter briefly analyses a number of factors which are likely to act as constraints on successful adoption of WCT technology in Southern Sudan.

7.1 Markets for End Products Arising from Turbine Use

Apart from horticultural produce which enjoys a ready market in Juba, the market for the end uses identified in previous sections is limited in terms of cash available to households to pay for services. Dura grinding and domestic water lifting would in fact need to be an unpaid service, releasing household time for other activities. As these latter became established and profitable (in cash terms), then charges could be exacted for turbine-derived services. Turbine adoption for non-irrigation uses is, therefore, unlikely in the absence of institutional support and a subsidy programme.

7.2 Management and Ownership

This is the major constraint on executing schemes using the turbine for non-irrigation purposes. The willingness and ability of government and pvo's to promote turbine-using programmes would be an essential prerequisite to introduction of the technology with necessary training components built in (as in the case of the MAFAO Cattle Scheme). The most promising route for turbine adoption is through private ownership by horticulturalists at present. Leasing arrangements are unlikely to appeal to the private sector (as a business proposition), however.

7.3 Maintenance

The only unit capable of building and maintaining the turbines at present would be Juba Boatyard. Its present break-even turnover from boat building is S£400,000 - a figure yet to be reached - suggesting the small proportion of its turnover turbines costing S£1,600 to S£45,000 would account for.

7.4 Financing

Financial support would have to be secured from official development assistance sources (such as UN, ODA, DANIDA) and from pvo's own sources. Sudanese public funds are already heavily overspent and development programmes dependent on foreign aid, whilst the rural communities could not realistically be expected to make a major financial contribution.

Until October, 1981, there was only one Savings Bank in Juba and this did not give agricultural credit. Since that date, an Agricultural Development Bank (ADB) has been established but has given no loans to date.

Based on credit models from the North, ADB requires considerable form filling (8 pages), security (in the form of property and/or land registered at the survey department) and - for equipment - access to agents (based in Khartoum) for a proforma invoice needed before financial approval for the loan can be obtained. Loans of varying maturity will be available, ranging from short term (1 year mortgage loan against crop production), to medium term (2-3 years against pumps) and long term (7 years against ploughs). Loans for pumps will be repayable over 2-3 years at 12% interest (no grace period being available). However, the position as regards validation of new technology is unclear but it seems likely that an ADB engineer would need to travel from Khartoum to see new devices in action before certificating the technology as eligible for loan financing.

The possibility of using Bank financing is, therefore, regarded as negligible at this stage, particularly for farmers and farming groups outside of Juba. While institutions and some individuals can fund the purchase of equipment from own resources (using goverment budgets and private savings respectively), the majority of farmers will only gain access to the technology through aid financing - from donors (FAO, ODA, etc.) and pvo's (Accord, etc). These farmers are considered high risk for institutional lending, particularly as few have registered rights to land. (Interestingly, this land is held by individuals - according to the Planning Unit of the Ministry of Agriculture - and is not held under the traditional protection of the village chief as in many other African societies.)

APPENDIX I

ECONOMICS OF HORTICULTURE

A1. Juba town in Southern Sudan faces seasonal shortages of vegetables, although the barriers to entry into wet season production are low - all that is required being simple tools for land preparation and weeding, and seeds (in addition to land). Production in the dry season is constrained by a widespread inability to irrigate plots in the absence of low-cost water lifting technology and of credit and institutional mechanisms for promoting such technology. This note considers the economics of horticultural production and analyses the implications for the design and introduction of new technology.

Fruit production is not considered as its introduction on an organised, ordered basis calls for investment of resources 2-3 years ahead of first yields. Apart from institutions (such as Prisons, FAO, Scouts, Police and the University) and a small number of entrepreneurs, fruit growing on any other than an informal basis is therefore, not practised.

A2. GROWERS - Types

Vegetable growing is dominated by private growers and institutions, with a marked absence of co-operative or joint farmer schemes (in spite of official government policy). Individual areas given over to vegetable production range from 1/2 feddan (or 1/2 acre) to 10 feddan. A survey of growers on the West Bank, (or Juba side) of the Nile showed the following:

Size of garden	No.	(No. with pumps)
- 1 feddan	17	(3)
1 - 2 "	12	(2)
2 - 3 "	5	(2)
3 - 4 "	2	(-)
4 - 5 "	3	(-)
5 - 10 "	2	(-)
	---	---
	41	(7)

(Source: Ministry of Agriculture, Juba, Southern Sudan, 1982)
Less than 20% owned pump sets, the majority relying on rainfed production which limits dry season cultivation to pump users.

Another Ministry of Agriculture survey suggested the existence of a further 45 small wet season gardens, mostly at Luri, each less than 1 feddan and employing no pump sets.

A3. LOCATIONS

The main production locations are said to be:

Location	No of growers	%
Luri	39	45
Rejaf E	13	15
Juba Island	9	11
Gumba	9	11
Rejaf W	8	9
Gondorokoro	3	3
Jebel Lado	3	3
Others	2	3
	86	100

Areas cultivated are typically less than 1-2 feddan (1-2 acres) with institutions cultivating larger areas of between 4 and 10 feddan. These latter include the Prison Department, FAO, Scouts and Guides organisations and Juba University.

A4. SEASONALITY

Production is highly seasonal, comprising approx. 130 feddans of fruit and vegetable in the wet season, and approx. 20-25 feddan during the dry season. The result is a marked shortage of vegetables during the dry season (November-March, in particular), which raises prices and chokes off demand. Interviews in low-income Juba households suggested that the availability and variety of vegetables was adequate in the wet season, but not so in the dry season suggesting the need to increase dry season supplies by bringing a further 100 feddan or so into production.

A5. PRODUCTS AND PRICES

Products include:

Local Greens: riggla, kudra
Brassica: cabbage
Beans: adzuki, green grain, pigeon pea, cowpeo
Root crops: sweet and irish potatoes
Cucuberates: cucumber, squash etc.
Bush crops: aubergine, okra, tomatoes, peppers
(Fruits include:mango, banana, orange, pawpaws, pineapple, lemon and lime).

Prices are uncontrolled and market-determined. Data from the Min.Ag. suggest that they fluctuate widely over the year. (Prices in piastre/kg. 100 piastre = S£1).

Item	Average (1981) Price/kg	Range	Above Average Months
Okra	201	98(Sep)-416(Apr)	Jan-April
Onion	113	37(Apr)-192(July)	Jan,Jul-Dec.
Egg Plant	52	40(Sep)-71(July)	May-Aug.
Beans	74	50(Nov)-93(Sep)	Feb,June-Oct.
Green grain	146	53(Mar)-625(Jun)	May-July
Pigeon Peas	82	71(May)-100(Oct)	N/A Jan-Apr.
Cow Peas	86	67(Feb)-115(Sept)	N/A Mar-Apr.
Sweet Potatoes	51	30(Jan)-94(May)	May,Jul,Sept.
Irish Potatoes	112	43(Aug)-260(Sep)	Feb,Jul,Sept.
Tomatoes	117	28(Apr)-198(Dec)	Feb,May,Jul, Nov. Dec.

(Source: Ministry of Agriculture, Juba, Southern Sudan, 1982).

These data only partly suggest dry season price rises reported in interviews, and must be treated with caution as they do not indicate product quality or the effect of general inflation on price-levels (which will rise between January and December partly at least disguising periods of shortage). In addition these data were collected throughout the year and there is no indication of the basis for collection (including number of traders interviewed, time of day, etc.)

With production uncoordinated and heavily dependent on seasonal rains, there is a wide fluctuation in prices to equate seasonal supply with demand. Interviews conducted in lower income households suggested that many items are unobtainable during part of the dry season, and when available sell out quickly. Rainy season supplies, by contrast, were seen as adequate and prices as more reasonable.

A6. YIELDS

6.1 There are few systematically collected data on yields for agricultural produce, least of all vegetables. Table A1 below shows crop yields for certain cereal, root and leguminous crops for 2 zones - zone 1 (the hill areas) and zone 2 (the flatlands), as shown on the map overleaf. (Fig.7). These yields are at best indicative, as they were collected by the planning unit (PDU) of the Ministry of Agriculture from various outstations, where local and improved varieties were grown under rainfed conditions on small plots (less than $10m^2$ typically).

SUDAN

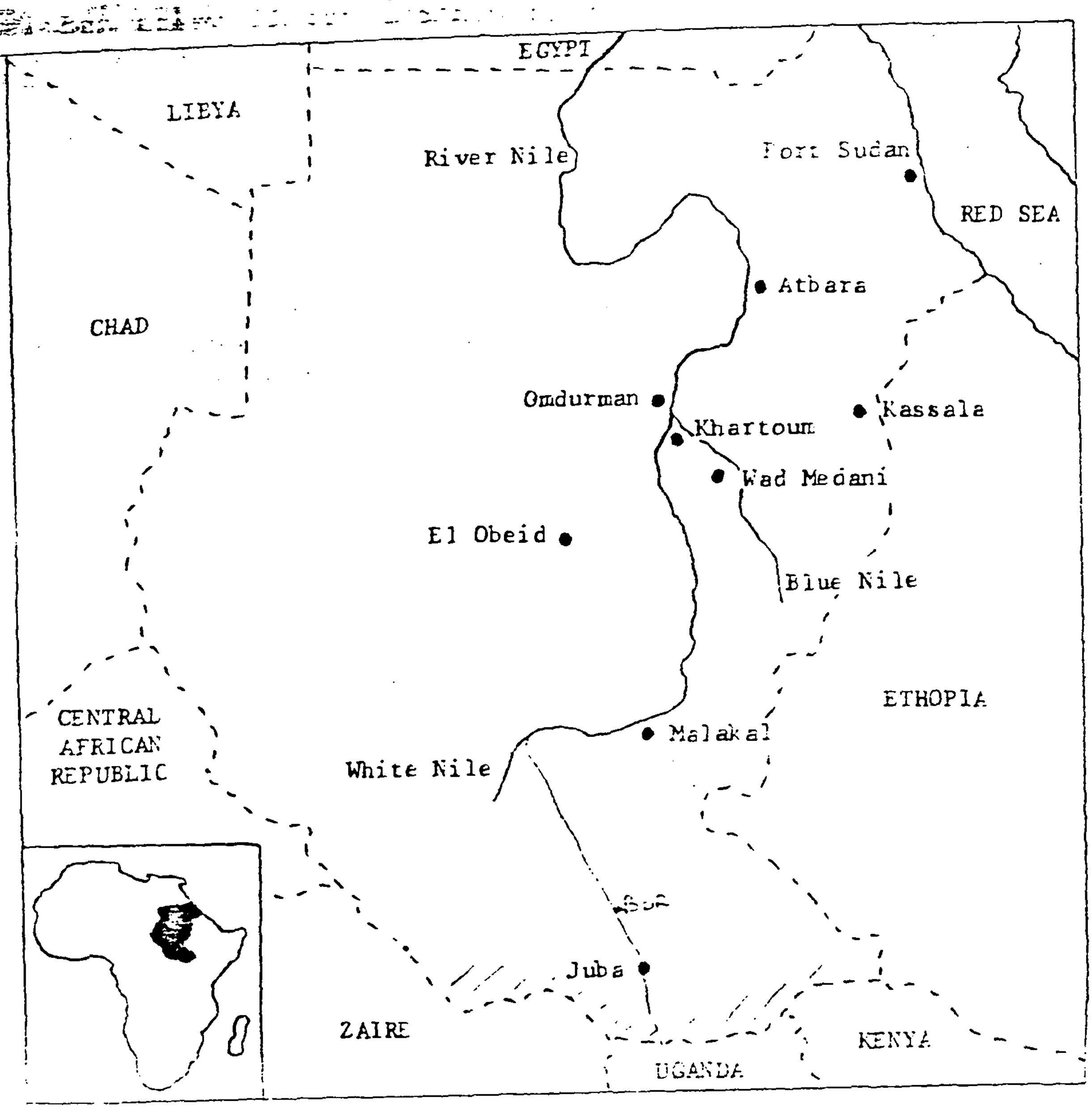

EGYPT
LIBYA
River Nile
Port Sudan
RED SEA
Atbara
CHAD
Omdurman
Khartoum
Kassala
Wad Medani
El Obeid
Blue Nile
ETHOPIA
CENTRAL
AFRICAN
REPUBLIC
Malakal
White Nile
Juba
ZAIRE
UGANDA
KENYA
Hills

Fig. 7

Table A1: Yields in Southern Sudan

(Yields in T/ha)

	ZONE 1		ZONE 2	
	Local Variety	Improved Variety	Local Variety	Improved Variety
CEREALS				
Maize	3-5	3-5	0.3-1	1-2
Sorghum	2-4	2-4	<0.7	0.7-1.5
Pearl Millet	0.5	1-2.5	0.5-0.7	0.7-1.5
Finger Millet	1.5-2	N/A	1.5-2	N/A
Rice	3-4	N/A	N/A	N/A
LEGUMES				
Groundnuts	1-2	1.5-4	0.5-1	1-2.5
Soybean	1	2-3	--	1-2
Pigeon Pea	<0.8	0.7-1.5	N/A	0.4-0.7
Beans (adzuki, greengram)	1	N/A	N/A	N/A
OIL CROPS				
Sesame (local)	0.8	N/A	N/A	N/A
Sunflower	1	1	N/A	N/A
ROOT CROPS				
Irish Potato		5	N/A	
COTTON*		2	N/A	

*(25% unstained lint, 75% unstained seed cotton)

(Source: Ministry of Agriculture, Juba, Southern Sudan, 1982).

Otherwise, no data are available. The conclusions to be drawn from these data and other reports made available by the Ministry were:-

- irrigated cereal production is unlikely to prove economic based on present cereal prices and likely irrigation costs (using diesel pumps).
- legumes, particularly, suffer from disease and drought, although beans (except chickpea) offer good yields.
- oil crops in the hills look promising.
- root crops are highly vulnerable to drought and disease and are better suited to hill (or altitude) production.
- improved varieties from African sources (Nigeria and Uganda, especially) look promising, but involve disease problems, which limit immediate applicability.

6.2 However no data on vegetable yields are available.

Reports from two major fruit and vegetable projects highlight this paucity of data. The Dutch government - funded Pengko Pilot Project at Bor (200m from Juba) reported in 1981 that its garden "performed well" while the FAO garden near Juba produced "negligible yields" because of "no transplanting of seedlings" and the ravages of rats.

6.3 So some indicative fieldwork was undertaken by the author of this report to assess likely yields for different vegetables. Individual plots on the irrigated prisons farm (by the Boatyard) measure 4m x 4m, and allowing for water distribution channels, 1 feddan (approx. 1 ac.) equals 200 plots. Yields for 3 vegetables were, therefore , assessed by sampling individuals plots and extrapolating the data.

The results are as follows:

Vegetable	Growing Season	Yield per Feddan	Present Price	S£/season (6 mnths)
Aubergine		100,000/season	5p	S£5,000
Okra		160,000/season	2.5p	S£4,000
Kudra *	21 days	10,000	5p/bundle	S£3,000

(* taken as bundles/month)

A7. REVENUE

The data in Section 6 tend to confirm hearsay evidence that vegetable growers can earn £200-300/feddan per month. The FAO garden of 3-4 feddan, for example, at Rejaf claimed to have grossed £400-500/month (although this failed to cover labour costs).

A8. CONSTRAINTS

Yields obviously vary according to a number of factors, including plant spacing, soil types, seed varieties, fertiliser and water application and pest control. Particular constraints on vegetable production are:

8.1 Inputs

Seeds are available on an irregular basis from the Ministry of Agriculture and the main market and on a more regular basis from the Sudan Council of Churches (the source being imports from UK, specially packed for the tropics). In addition, part of a previous season's crop could be left to go to seed. Prices vary, being highest for tomatoes at US cents 15 per 1,000 seeds.

Otherwise, no further inputs - fertiliser, lime pest control chemicals, and so forth - are available. Occasional use of animal dung as a fertiliser is practised, but competes with other uses for the material (such as fuel). The chemical composition of the soil is, therefore, difficult to balance, being highly acidic due to addition of ash after burning the bush for clearance.

8.2 Pests

Apart from aubergines, okra and indigenous greens (such as kudra and riggla), most vegetables are highly prone to pest and disease attack, particularly the cucuberates (cucumber, squash, etc.). Without expensive pest control, the latter are difficult to grow.

8.3 Water Supply

Rains supply 10,000m^3/ha of water in the Juba area (rising to 13,000m^3 in hill areas of Yei) concentrated heavily into a 6-7 months period with peaks in April, July and October.

Rainfall (mm)

400

300

200

100

J F M A M J J A S O N D

TYPICAL RAINFALL PATTERN

Hills (Yei)

(Kajo Kedi)Plains

During this season, water availability/ha varies from a monthly average of 40m^3 per day to 90m^3 per day. Based on daily water needs of 50-100m^3/ha in the dry season, shortfalls occur (based on Kajo Kedi data for the plains) for May and June (of at least 50m^3) and August and September (of at least 30m^3 p.d.), as well as the dry season (October-March). Clearly, introduction of low-cost pumping technology to such riverine locations as Juba would increase dry season horticultural activity.

8.4 Land Ownership

This has restricted the access of more progressive immigrant groups to land. In addition, few individuals have title deeds to land, which are necessary for securing credit to acquire inputs and equipment. Land is individually held, rather than collectively or traditionally by elders or village headmen.

8.5 Farm Management

There is very limited knowledge of irrigation in the area which suggests that introducing vegetable production - particularly of disease and drought - prone items - is an exercise which will require considerable back-up by way of training and familiarisation. Competing dry season activities will also cause labour bottlenecks. Such activities including house repairs, ceremonies and hunting. In addition, night-time irrigation is unlikely to be acceptable, limiting turbine use to some 8 hours per day, in the absence of expensive investment in water storage tanks.

8.6 Financing

There is little possibility of small farmers - individually or collectively - obtaining credit at present for working or fixed capital purpose (see Section 7.5 in the main report on "credit"). This not only limits take-up of pumps, but also prevents investment in improved water channels to reduce field delivery losses.

8.7 Marketing

Markets for vegetables are heavily concentrated in such urban areas as Bor, Mangalla and Juba. Outside these conurbations there is limited cash to buy vegetables. Within these areas, wet season vegetable production are regarded as adequate for present needs, suggesting the need for an equivalent 100 feddan of dry season, irrigated vegetable area, additional to the wet season area.

However, no organised distribution channel exists or is presently likely to be created to get fresh vegetable quickly to the market. Hence, the scope for vegetable production away from Juba is limited. Although traders acting as middle-men would allow production to move marginally further from Juba, they are constrained by transports costs and fuel availability. The present method of carrying vegetables to market by basket and basin is likely to remain the optimal solution for the time being, in terms of giving growers maximum share of market revenues and avoiding middle men shares. However, production is likely to remain sporadic in these circumstances.

The organisational potential for cold stores, etc., is not considered promising.

8.8 Soil Fertility

Soil fertility - particularly south of Juba - is limited and double cropping could be expected to reduce fertility dramatically. Consequently, existing wet season vegetable growers - who already have some knowledge of growing conditions and practices - would need to be encouraged to utilise further (presently unused) land area for dry season, irrigated cropping.

Experience at Juba Boatyard suggests that introduction of local villagers to irrigation, particularly where they presently grow few, if any, wet season crops, is a difficult task. The most promising route for promoting horticultural activity is through existing dry season growers (who use diesel pumps) and wet season growers.

8.9 Others

A final constraint on major horticultural activity is cattle, which destroy unfenced cultivated plots in their search for fodder. Two solutions to the problem are fencing which is an additional cost, or retaliation which often leads to fights with the herdsmen.

(Handtools are available in Juba market and should not be a constraint on production).

A9. MARKET FOR VEGETABLES

A survey of households near Juba market suggested average household expenditure of S£0-5/day on vegetables. This suggests an annual turnover for vegetables of S£1.5 million for the 10,000 or so households in Juba. Yields per feddan in the region of £400 wet season and £800 dry season/feddan/month - or £5-10,000 approx. p.a. - suggest there is scope for up to 100-200 feddan of land dedicated to vegetable production. At present, some 130 feddan are cultivated during the wet season, and as few as 30 feddan during the dry season. As few interviewes complained of wet season vegetable shortages, the upper limit of 200 feddan identified above can be considered optimistic, and so the lower figure is used in computing demand for additional area to be cultivated. There is, therefore, a production shortfall during the dry season, equivalent to the output of some 70 feddan or so. This presents the few existing dry season growers with high returns and offers potential for pumped irrigation of vegetable gardens in the dry season. With lower prices due to increased supply, yields per feddan could be expected to fall to £400/feddan/month or £2,000/feddan for the season.

A10. ECONOMICS OF WATER CURRENT TURBINE USE

With gross yields per feddan of S£2,000, labour requirements for land preparation, seeding, watering, harvesting, etc., of 3/feddan (and costing S£1 per person per day), the net yield per feddan can be calculated as:

	S£
Gross yield	2,000
Labour	540
Inputs (seeds, etc)	100
Net yield	1,360
$2.5m^2$ Turbine Investment	2,070
Payback Period	9 months

The above example of projected smallholder, horticultural production economics is based on a $2.5m^2$ swept area water current turbine as funded by the Dutch government and field tested at the Prisons Department garden in Juba. Output is dependent on river currents but prototypes (of both reciprocating and centrifugal pump types) were found capable of pumping 1 l/sec of water through a typical head of 5m in typical dry season currents of around 1 m/s. This quantity of water was found adequate to irrigate a little over 1 feddan (1 ac.) of land on an 8 hour basis.

A11. MARKET FOR PUMPS

As shown above, the water needs of up to 1 feddan of vegetable could be met by the $2.5m^2$ swept area machine (costing S£2,070) at a river speed of 0.9-1 m/sec. This would generate revenue sufficient to pay back the investment in 9 months, or a little over one season of production, net of labour costs for 3 garden attendants.

As detailed in Chapter 6 of the main body of this report, an initial market for 70 smaller diameter pumps can be identified.

Presently, pumped irrigation is not practised because of:-

1. Lack of cash (credit) to buy pumps.
2. Shortage and high costs of fuels (diesel and petrol).
3. Absence of equipment supply in Juba.

In view of the likely profitability of turbine use, a market potential for such a device exists, provided credit is made available to would-be purchasers. Benefits would flow to smallholders in particular and to some 10,000 households in Juba which purchase vegetables. The existence of a local manufacturing unit with repair and maintenance facilities suggests that the turbines are an appropriate device to promote in Juba, although further investigation of the economics of manufacture are necessary.

A12. FARMER TYPES

This section briefly records the experience of 4 horticultural enterprises - one private owner, one pvo, and two government institutions. The range of products grown and profitability vary widely.

12.1 Aquilino Wani

An ex-government employee, of the Lacoyo people, Wani has 3 wives and 21 children (14 girls, 7 boys - some working). He produces citrus fruit, mangoes, pawpaws, and sugarcane on a 4 feddan garden, the revenue from which is sufficient to cover food, educational and health costs of his family (no indication of amount willingly given). Vegetable growing is limited to sweet potatoes and Okra and Kudra (latter when market prices are high due to shortages from January - April).

Water was previously pumped from a well to the garden using an Indian petrol-kerosene set bought in 1973 for £S200 (mark 12/2 HSPP, with no plate to indicate power output, which is thought to be 4 HP approx.) Fuel shortages had resulted in abandonment of pumping after 2 years, during which time no breakdowns had occurred. The only operational problem in fact, was dirt in the fuel. Petrol prices per gallon have risen over the period from £S1.50 in 1973 to £S10.00 plus in 1982. Wani thought that such a pump would cost at least £S1,000 in 1982.

During the rains, vegetables were in plentiful supply, so pumping was restricted to approx. 4-5 months p.a., giving 480-900 hours pumping at 4-6 hours p.d., part in the morning, part in the evening. 10-20 plots were watered every day. (Each plot is approx. 100ft^2). On a 3-day cycle, giving 30-60 plots in all, an area of 0.1-0.2 feddan is irrigated.

Each plot could gross as much as £S5 for fast-growing (short-maturity) kudra during the dry season, particularly January - April. With a growing cycle of 21 days, up to 6 harvests per dry season would be expected, giving a gross return to 30 plots of £S900 or as much as S£9,000/feddan per season.

Fuel consumption was estimated at 4 gallons per 24 hours, or a total of 80-150 gallons p.a. (assuming 500-900 hours pumping per season) costing £S800-1,500. With family labour to clear and prepare land, weed and harvest, a net profit of £S7,500 was possible for each dry season feddan.

12.2 An FAO vegetable and fruit garden of only 4ha. and using 6.6HP diesel pumps grossed monthly income of £S400-500, which does not even cover direct labour costs of £S840 (40 employees at £S21 per head p.m.) Heavy labour inputs are required particularly for weeding, and in view of public sector rates of pay and - what is seen as - low labour productivity, this results in high labour costs. The demise of 2 diesel sets in 2 years saw the vegetable garden closed and efforts switched to fruit growing, which requires minimal labour inputs, except at harvesting time and which still has a diesel pump operational. However, citrus trees do not yield in first three years or so of planting, which gives rise to a serious cash flow constraint for smallholders (q.v. experience of fruit tree planting schemes in Uttar Pradesh Hill Area, India).

12.3 The Scout and Guide garden at Rejaf near Juba similarly has abandoned vegetable growing in favour of longer-term fruits (citrus, pawpaws, in particular) in view of the "low return" to vegetables. Transport costs to Juba market (10 miles per round trip) alone totalled £S3 p.d. (for 1.5 gallons of fuel) which all too often exceeded the daily revenues, particularly if there was a seasonal glut of a particular crop (Okra being the most recent example). An unknown investment in 2" PVC pipe laid underground had been made to reduce pump-to-tree water losses on an area of approx. 4 ha.

12.4 The prison garden (located lm from Juba) is presently in the happy position of being able to minimise labour costs by using 7 prisoners at nil cost and 9 local girls at £S16 per head per month. Selling largely Kudra at 5-10 piastre per bunch, it grosses S500-1,000 per month in the dry season. A 3HP diesel set operates consuming

0.8 litres of fuel/hour (at an overall fuel:pumped water efficiency of 2.5%) when fuel is available. This unit has been using both larger (3.75m^2 centrifugal pump) prototype turbine and the smaller 2.5m^2 turbine. It considers the smaller machine at S£2,070 a sound investment and would consider buying the larger machine if the price of S£4,500 could be reduced.

A13. CONCLUSIONS

13.1 The market for the river turbine for water pumping in the Juba area is limited primarily to private entrepreneurs, suggesting a market for 5 or so devices to replace diesel sets, and for up to 70 or so to permit increased dry season cultivation of vegetables.

13.2 Wider spread dissemination of the technology is limited by demand factors. In particular, the growth potential in vegetable and fruit demand particularly away from Juba, limits the size of the future market for water current turbines.

13.3 Sets could be marketed to a small number of individuals who have cash savings from employment in Juba, but the majority of vegetable growers would require credit.

13.4 On the supply side - while Juba Boatyard possesses the technical competence to manufacture and repair turbines - there are presently no credit or HP facilities available to farmers marginal to the cash economy, for buying equipment and this would need to be designed into any turbine extension programme.

13.5 Investment in a turbine (of S£2,070 for the smaller unit and S£3,500 for the larger unit, assuming value engineering of present designs) is a cost-effective alternative to diesel sets (particularly where fuel is not available at controlled prices) and at river speeds in excess of at least 1 m/s. Where diesel is available at controlled prices, the turbines are cost-effective alternatives to diesel sets if river speeds increase towards 1.2 m/s, which can be considered high for many dry season sites. However, smaller (2.5m^2) turbines are likely to prove competitive, as they are cheaper than diesel sets and better matched to the pumping needs of smaller farmers, for whom minimum diesel set sizes of 5 HP represent investment in significant overcapacity which is rarely used, therefore. The returns computed from using the turbine for horticultural production show a short (9 month) payback.

13.6 Introduction of turbines for horticultural purposes would increase the income of small/marginal farmers and improve vegetable supply (and hence reduce dry season prices) to Juba's urban population, a significant economic benefit.

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