The potential for small-scale solar-powered irrigation in Pakistan

by Michael Howes

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THE POTENTIAL FOR SMALL-SCALE SOLAR-POWERED IRRIGATION IN PAKISTAN

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SUMMARY

1 Early in 1981, Intermediate Technology Industrial Services (ITIS) purchased a small number of solar-powered irrigation pump sets from Solar Electric International (SEI) for field testing, under a programme organised in collaboration with the Agricultural Development Bank of Pakistan (ADBP). The tests were set up with the assistance of engineers from the Hydraulics Research Station, Wallingford (HRS) and began in March 1981. In February 1982, at the end of the first year of trials, ITIS commissioned me to visit Pakistan for two weeks in order:

- to compare the solar pumping system with alternative existing forms of irrigation;

- to determine the socio-economic impact of the new system in terms of likely endusers and effects upon the distribution of income;

- to determine the size and location of demand for the solar pumping system.

I was accompanied to Pakistan by Graham Pallett, an irrigation engineer from HRS, and my own report should be read in conjunction with his, which deals with the technical aspects of performance under field and experimental station conditions.

2 During the course of my trip I was able to visit ten of the fourteen sites where field testing is being carried out, but for a number of reasons, the data collected proved inadequate as a means of investigating the issues laid out in my terms of reference. In order to proceed, it therefore became necessary to make a number of rather crude assumptions about pump performance, and likely patterns of use. As such, my attempts to compare solar and other systems; to anticipate social consequences; and to predict demand; must be regarded as preliminary and tentative, serving at best as a foundation upon which more adequate analyses may be built as better data become available.

3 A further complication is introduced by the fact that the present $6200, seven panel system (henceforth system A), is almost certain to be superceded in the near future by more powerful, more efficient, but less costly alternatives. These are system B, with 8 panels, costing $3900, system C, with 12 panels costing $5850, and system D, with 16 panels costing $7800. An attempt has been made to incorporate these systems into the analysis, but it should be borne in mind that their

superior efficiency has still to be properly demonstrated under field conditions.

4 The likely performance of the different systems is compared with the traditional ox-drawn Persian wheel and with a one cusec diesel-operated deep tubewell (DTW). In terms of cost per unit of water, these are the most expensive forms of irrigation currently in use in Pakistan, and therefore the most likely to be displaced by solar pumping in the short run. Irrigation water from canals and electrically operated tubewells is much cheaper (for the end user at least), and there was therefore little point in including them in the analysis at this stage. Calculations are made which show the extent to which the price of solar systems would need to fall before being able to compete with the Persian wheel and the tube well, with allowance also being made for an additional 'uncertainty' factor on the part of potential adopters, and for the various levels of subsidisation which the ADBP is likely to make available.

5 In the comparison with the Persian wheel it is concluded that:

- none of the systems is yet cheap enough to compete with the Persian wheel under even the most favourable conditions where fixed capital items (equipment and oxen) would have to have been replaced immediately, and where no allowance was made for uncertainty;

- system A, which has already been subjected to a year of field testing, would not appear attractive to present Persian wheel users even if the highest level of subsidisation considered by the ADBP ($3000) were to be made available;

- where Persian fixed capital items were due for replacement, then the minimum level of subsidisation ($1500) would be sufficient to make system B attractive both before and after uncertainty had been taken into account, and system C attractive before it had been taken into account. System D, before uncertainty, could compete at the second level of subsidisation (2400), but could not be made attractive after uncertainty;

- where fixed capital items had been replaced, system B could be made attractive both before and after uncertainty at the second level of subsidisation, but even the highest subsidies failed to bring C or D within the acceptable range against either of these assumptions;

- all of these results are calculated at a 12 per cent level of discount. The effect of adopting a 20 per cent level would be to further increase the subsidies required by a modest factor in all instances.

6 In the comparison with purchased DTW water, it is concluded that :

- system A appears less attractive than in relation to the Persian wheel;

- systems B and C would require high levels of subsidisation in order to be able to compete here;

- system D could not be made attractive even at the higher subsidy level contemplated by ADBP.

7 The results presented in points 5 and 6 above suggest that there is never likely to be any demand for system A, and that system D is fairly unlikely to ever become attractive. B and C, however, could start to compete with Persian wheels with fairly small reductions from their present price levels, and with purchased DTW water if rather more substantial reductions were to prove possible. Thus, although there would be no demand for any solar system at present prices, it seems worthwhile to explore what demand might be if such reductions could be achieved. This potential demand is measured at four different levels:

- in three areas already identified by ADBP where there is a high incidence of Persian wheel use, but few DTWs (11,600 sets);

- among open well users in the ten districts with the heaviest concentration of open wells nationally (56,000 sets);

- among diesel DTW water purchasers in the same ten districts (436,000 sets);

- among diesel DTW water purchasers nationally (957,000 sets);

There would appear to be reasonable prospects for tapping demand at the first level fairly soon; whilst the second, third and fourth levels raise progressively greater difficulties and could only be approached after increasingly lengthy periods of time, if at all.

8 The final section of the report deals with the likely social and income distribution implications of the

introduction of solar pumping technology. It is argued here that the major beneficiaries are likely to be farmers with landholdings in the 5-25 acre range, and that the majority of farm households, with holdings of 5 acres or less, are likely to be excluded. At the same time it is pointed out that this need not necessarily be the case, and various measures are discussed whereby access on the part of the smallest farmers could be improved.

9 Throughout this report it is emphasised that the results presented are all highly tentative, and that particular caution is required in interpreting findings relating to systems B, C and D, which have only been tested very recently. Outstanding issues which could only be resolved through further and rather more systematic farm-level trials than have hitherto proved possible, are listed in an appendix.

GLOSSARY

Barani:	Areas where rainfall exceeds 50" per year; rain-fed areas.
Kharif:	The summer season; approximately from April to September
Rabi:	The winter season; approximately from October to April

ABBREVIATIONS

ADBP:	Agricultural Development Bank of Pakistan
B'stan:	The Province of Baluchistan
DTW:	Deep tubewell
HRS:	Hydraulics Research Station, Wallingford, UK.
ITDG:	Intermediate Technology Development Group
ITIS:	Intermediate Technology Industrial Services
NWFP:	Northwest Frontier Province
PARC:	Pakistan Agricultural Research Council
SCARP:	Salinity Control and Reclamation Project
SEI:	Solar Electric International

UNITS

1 cusec	= 1 cubic foot per second=28.3 litres per second
$1	= 10 rupees

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INTRODUCTION

The cost of photovoltaic cells, which convert solar insolation into electricity, has fallen very rapidly in recent years; and a point is now being approached where solar energy may be able to compete effectively with existing conventional energy sources in certain areas at least (Halcrow/ITDG, 1981). Potential is greatest where temperatures are high and cloud cover low, and of the many applications of the new technology which may prove possible, the lifting of relatively small amounts of water for irrigation and other purposes, is generally regarded as the most promising.

For a number of reasons, Pakistan appears to offer a particularly favourable environment in which to explore the feasibility of solar pumping. Insolation is high and rainfall low, and over extensive areas of the country regularly recharged aquifers are available within a few feet of the surface. In addition, there are a large number of small farms, most of which lack adequate access to modern forms of irrigation.

Taking these factors into account, and encouraged by a preliminary report prepared by Stephen Allison of Solar Electric International (SEI) (Allison 1979), the Agricultural Development Bank of Pakistan (ADBP), decided in 1981 to embark upon a programme of field tests designed to determine the performance of prototype pumping systems under farm conditions. The pump sets were supplied by Intermediate Technology Industrial Services (ITIS); and the field testing programme was complemented by the Pakistan Agricultural Research Council (PARC), who undertook to carry out more detailed sets of investigations on their own research stations.

This report, which has been commissioned by ITIS, is based upon a trip which I made to Pakistan in February 1982, at the end of the first year of the programme. It has three main objectives:

- to compare the solar pumping system introduced by ADBP in 1981, and others now following in its wake, with alternative existing forms of irrigation;

- to determine the socio-economic impact of the new system in terms of likely users and effect upon the distribution of income;

- to determine the size and location of demand for the solar pumping systems.

Ideally it should be read in conjunction with the technical report prepared on the same visit by Graham Pallett of the Hydraulics Research Station (HRS) (Pallett 1982); and against the background of earlier assessments by Abernethy (1981) and Pallett (1981).

The central issues are addressed in section 3 below, but I start with two brief exercises designed to set the context for the discussion which follows. The first is an attempt to convey something of the diversity of physical conditions, agricultural practices and social relations which Pakistan exhibits;whilst the second takes the form of an account of the development and distribution of the established systems of irrigation which solar pumping will either have to compete with, or in some way to complement, if it is successfully to establish itself.

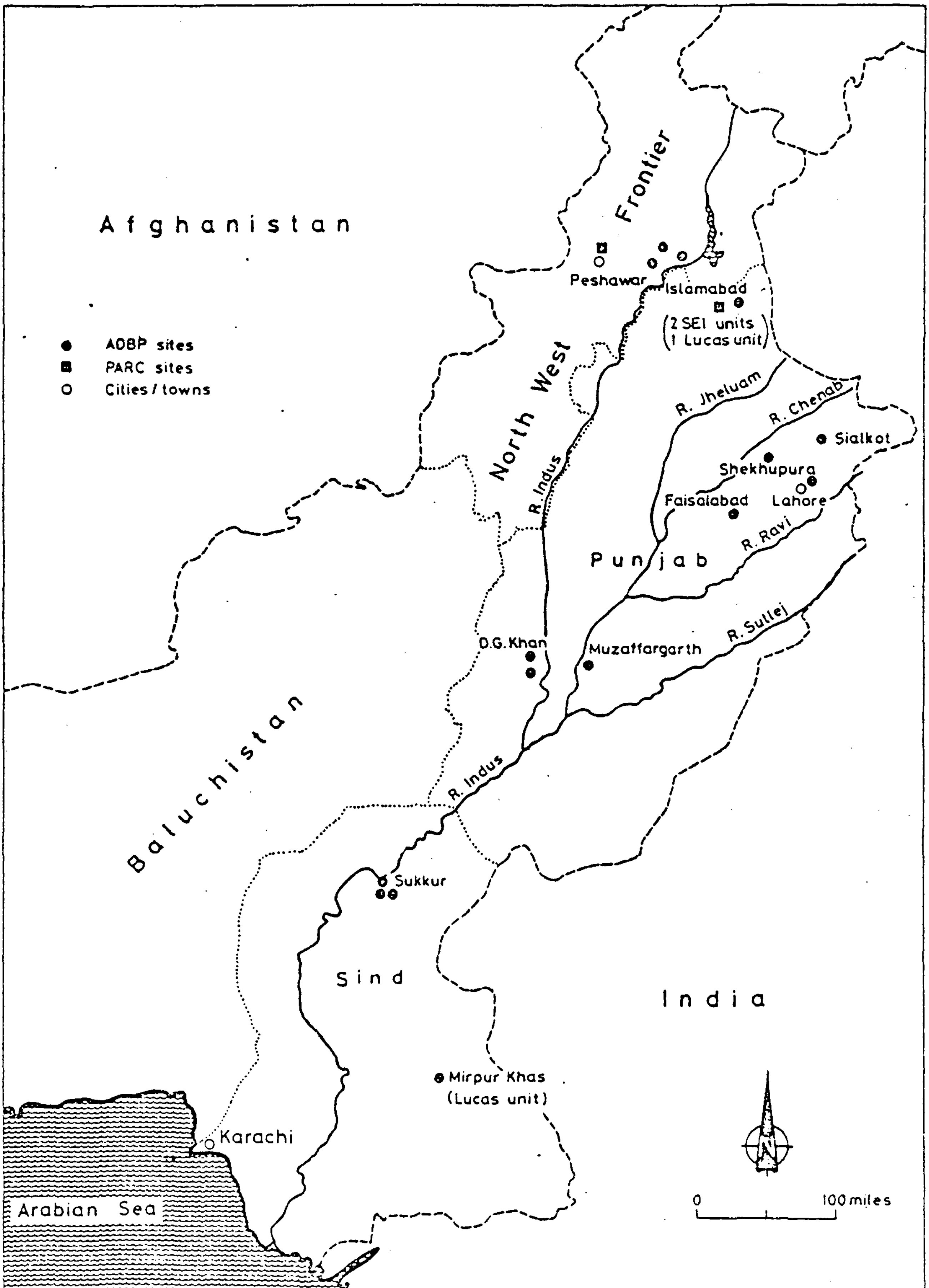
1 AGRICULTURE AND AGRARIAN RELATIONS

The greater part of Pakistan's land area - comprising the Baluchistan plateau in the west, the Himalayas in the north, and the Cholistan desert in the south east - is barren and largely uninhabited. Nearly all of the country's agricultural activity, and the bulk of its population are concentrated in the Indus basin which includes the Peshawar valleys of the NWFP, most of the province of the Punjab, and a part of the Sind.

In terms of its agriculture and social relations, the basin may be subdivided into two smaller units. The first and less important, are the barani areas; defined broadly by the 50" isohyet, within which rainfall is generally sufficient to support cultivation without recourse to irrigation. They stretch across the north of the Punjab and a small part of NWFP, and correspond approximately to the administrative districts of Lahore and Rawalpindi (the area immediately surrounding Islamabad in Figure 1). These are the oldest settled and most heavily populated parts of the country. Farm sizes accordingly, are well below the national average, and only small amounts of land are available for cultivation under tenancy arrangements.

Until the beginning of the twentieth century, the remainder of the Punjab and the greater part of the Sind remained the preserve of landlords who had acquired property rights in extensive parcels of land, but who were unable, in the absence of adequate rainfall, to put it to good productive use. This situation was transformed from the turn of the century onwards by the development of what was to become the largest continuous canal system in the world; and the establishment of the canal colonies. These were populated largely by migrants from the north, who in certain instances were able to purchase land directly from its previous owners, but more frequently had to settle for some form of tenancy agreement.

Figure 1



Location of the solar pumps in Pakistan

The comparatively recent settlement of the colonies is reflected clearly in the present structure. Landholding sizes are on average far greater than in the *barani* areas, many very large landholdings remain (although inevitably reduced from their original size by the passage of generations and population increase); and a very substantial proportion of the total cultivated area continues to be operated by tenants.

In the absence of detailed district level data on the distribution of landholdings, and the extent of tenancy agreements, it is difficult to specify the nature of agrarian relations in the *barani* and canal colony areas any more precisely than this. However, the fact that such a large percentage of the land under cultivation falls within the canal colonies means that the national level data presented in Table 1 below, give a fairly accurate impression of the situation here at least.

Table 1 Distribution of land ownership in Pakistan

Farm Category	Effective landholding acres	% of Farms
Small (below subsistence)	0-5	58
Medium (subsistence)	5-25	39
Large (surplus)	25+	3

Source: Alavi 1976: 192-3

'Effective landholding' expresses ownership and operation of land in combination. Thus the upper limit of the 'small' farm category might comprise either a household which owned five acres of land, or one which held ten acres in tenancy, on the assumption of a 50-50 sharing arrangement; and so forth.

The figure of five acres as the minimum necessary for adequate subsistence is an approximate average based upon conditions in the canal colony area. More than half of all farms fall within this category, suggesting that most rural households are forced to take land in tenancy where this is available, and to seek alternative sources of income where it is not. In this case they enter into competition with the landless, who comprised more than 10 per cent in the national labour force in 1961, and have almost certainly grown in relative importance since.

The 'medium' or subsistence band is defined in relation to the average area of 12.5 acres which can be ploughed by one pair of bullocks. With two pairs of bullocks being taken as the maximum which one household could operate itself, this gives an upper limit of 25 acres. Just over a third of all farms fall within this category.

'Large' farms, in excess of 25 acres, are taken as those which could not be operated on the basis of family labour alone (at least under circumstances where oxen must be used for ploughing); and where clear potential exists to obtain a surplus over and above domestic subsistence requirements. Only 3 per cent of all farms fall within this category, but they account for 19 per cent of the total land cultivated. Figures from 1960 indicate that a further 49 per cent of the farm area was tenant-operated, suggesting that something approaching 70 per cent of the total farm area was in the possession of either large farmers or non-cultivating land owners.

This highly uneven distribution of landholdings has important implications in terms of access to the benefits arising from the various forms of irrigation which will be discussed in Section 2.

2 PRESENT FORMS OF IRRIGATION

Table 2 gives a breakdown of the area irrigated by different sources in different provinces for the years 1971/2 and 1978/9. This provides a sufficient timespan to reveal several trends which are of significance as far as the possible introduction of solar powered irrigation is concerned.

The table shows that canals continue to provide by far the greatest amount of irrigation water, accounting for 74 per cent of the total area irrigated in 1971/2, and 76 per cent in 1978/9. But in spite of their overall importance, these have only made a relatively modest contribution to the spread of high-yielding varieties (HYVs). This is so for two major reasons: firstly, because of the unpredictability of water supply which canals provide in many areas(particularly those lying at the 'tail end' of systems); and secondly because of the shortage of water available from this source during the rabi season, when wheat, the major HYV crop, is grown.

The critical factor as far as HYVs are concerned, has been the introduction, from the 1950s onwards, of deep tubewell irrigation, which offers a far more controllable, and hence reliable supply of water. The major period for the introduction of deep tubewells was during the 1960s, and by the end of the decade they accounted for about 15 per cent of the area irrigated nationally; a figure which had risen to about 20 per cent by the end of the 1970s.

Table 2 Area irrigated by different sources 1971-2 and 1978-9 (mn acres)

Year / Source	Punjab	Sind	NWFP	B'stan	Total	%
1971-2						
Canal	15.83	5.83	1.36	0.62	23.64	(74)
Tubewell	4.89	0.17	0.07	0.05	5.19	(16)
Well	1.48	0.07	0.01	0.05	1.65	(5)
Other	0.46	0.54	0.07	0.52	1.60	(5)
Total irrigated	22.67	6.62	1.61	1.19	32.08	(100)
%	(71)	(21)	(5)	(4)	(100)	
Total cultivated	27.26	12.97	4.00	2.01	47.15	
%	(58)	(28)	(8)	(6)	(100)	
1978-9						
Canal	16.89	7.76	1.45	0.94	27.04	(76)
Tube well	6.77	0.10	0.05	0.10	7.01	(20)
Well	0.64	0.10	0.07	0.05	0.86	(2)
Other	0.10	0.12	0.10	0.22	0.54	(2)
Total irrigated	24.40	8.07	1.68	1.31	35.45	(100)
%	(71)	(23)	(5)	(4)	(100)	
Total cultivated	28.03	13.54	4.69	3.43	49.70	
%	(56)	(27)	(9)	(7)	(100)	

Source: Government of Pakistan 1979:66-7

(Totals may not add up exactly due to rounding)

Developments were confined largely to the public sector, with large electrically operated tubewells being installed under the auspices of the Salinity Control and Reclamation Project (SCARP) in areas of the Punjab and Sind where saline intrusion was leading to a reduction in the area available for cultivation. More recently, however, the emphasis has switched to smaller, privately owned tubewells, the most common of which are of 1 cusec capacity. About 20 per cent of these are electrically operated; whilst the remainder rely on diesel.

Table 2 indicates that tubewell irrigation has been concentrated very heavily within the Punjab, which accounted for about 95 per cent of the total area irrigated from this source in 1978/9. Within the province most wells have been installed in the canal colony region, with the districts of Jhang, Gujranwala, Sialkot and Multan taking the largest share; but the richer old settlement district of Lahore also has suitable groundwater conditions, and has figured prominently as well.

With the extensive adoption of deeptubewells, the traditional Persian wheel technology (which is ox drawn in most instances, but relies on camels in the more arid areas) has tended to be displaced. This is reflected in the decline in the amount of land irrigated by well from 5 per cent in 1971/2 to only 2 per cent in 1978/9. But in areas where there are fewer tubewells, the Persian wheel continues to be used. By far the most important of these is Muzaffargarh in the southern part of the Punjab. This will be of significance later in the report since it is thought likely that the new solar irrigation technologies will initially prove most successful in areas where traditional methods continue to be used.

The uneven geographical spread of canals in the period up to the 1950s led to considerable variations in the types of cultivation which could be practised in different places, and the introduction of tubewells has served to make these more pronounced. In the canal colonies and richer old settlement areas, high price grains, most notably wheat, can be grown extensively; whereas in other areas only coarse grains, such as maize, can be cultivated. Superior access to irrigation also gives favoured areas a large advantage as far as the cultivation of cash crops such as paddy and cotton are concerned.

But apart from increasing the gap between regions, the new irrigation technology, and the HYV package which it makes possible, have also served to deepen inequalities within them. Precise data are again difficult to obtain, but the indications are that as many as 90 per cent of all tubewells are located on the land of large farmers with 25 acres or more. This does not mean that others have been totally excluded; there are perhaps seven farms which purchase tubewell water for every one that has its own tubewell, and most of these would fall within the subsistence categories; but most purchasers have access only at a higher cost per unit of water than deeptubewell owners, and are far less able to obtain water in the quantities required, and at the most appropriate times.

The effect of this has been to further concentrate income and purchasing power into the hands of the relatively well off; which in turn has led to increasing demand for consumer goods and imports, and a high rate of inflation which has eroded the living standards of the majority of people.

Superimposed upon this, and serving to widen inequalities further, have been the effects of the rapid introduction of tractors. These have greatly outstripped even tubewells in terms of the share of formal institutional credit which they have been able to attract. One machine can do the work of perhaps a dozen pairs of oxen, and like the tube well, tractors have mainly been adopted in the canal colonies, where landholdings are larger. As a result, tenants have been evicted from most holdings of less than 100 acres, and only relatively small numbers have been retained on larger farms. Those that do remain have been forced to accept less favourable terms as competition for land has increased, and pressure on all small landholders has grown as those with land in the 25-100 acre range have sought to consolidate their holdings in order to take full advantage of the new technology. The small farmers, at best largely bypassed and at worst adversely affected by developments in irrigation, therefore find their livelihoods directly threatened. Many have already become landless, and many more will join their ranks if present trends continue.

Part of the problem has been the unavailability of 'divisible' technologies suitable for use on small landholdings. The picture has recently begun to change with the introduction of smaller Chinese tractors; and proponents of solar irrigation systems have argued that their low command areas and zero energy costs might provide a base from which small farmers could begin to resist the pressures which have recently been brought to bear against them. Whether this in fact will prove to be the case, and whether the various systems will be able to compete effectively against other irrigation methods are matters which will be explored in some detail a little later in the report. But first of all, it is important to say a little more about solar technology itself, and the way in which it is currently being tested.

3 SOLAR IRRIGATION

The Technology

The pumpsets tested in the programme were all purchased from SEI by ITIS and have been described as follows:

> There are three principal components. The first is the solar array, consisting of 7 panels each to $0.3m^2$ in area, mounted in sets of 4 and 3 respectively, upon two lightweight wheeled frames. The second is the maximum power controller, which takes in the roughly constant d.c. voltage and varying current that is generated by the panels, and adjusts these continuously to match the pump load in such a way as to maximise the power utilisation. The third is the submersible pump and motor, suspended in the well from a spherical polystyrene float.
>
> The solar array uses silicone cells and is designed to generate 250w in standard bright conditions, defined as an insolation or incoming radiation of $95mW/cm^2$ ($950\ W/m^2$) at 30^oC ambient temperature.
>
> The pump is a vertical-axis single-stage centrifugal unit, close-coupled to a brushless d.c. motor, whose nominal operating point is 300 rpm at 60v. The pump is manufactured by KSB of Germany: it is not a standard design, but has been adapted by the manufacturers for this specific application under low heads.
>
> (Adapted from Abernethy 1981)

Pumpsets of this kind can currently be obtained in small numbers for about $6,200, and were the only ones being tested in Pakistan at the time of my visit. Since then however, three additional systems have been proposed as alternatives to that presently in use, and subjected to some preliminary field trials. These have been designed by Stephen Allison (now of Solar Enterprises Inc.), and operate on the same principle as the present system (which will henceforth be known as 'A'). They are however, both more powerful, with 8,12, and 16 panels respectively; and, according to Allison, more efficient. They will subsequently be referred to as systems 'B','C' and 'D'.

The price at which B, C and D can be made available in the event of a sizeable order has proved the subject of some controversy. Allison himself claims that it will be possible to market them at $3,500, $4,500 and $5,500 respectively, but others regard these figures as unrealistically low. To be on the safe side, we have costed the alternative systems at the rather higher and more generally acceptable level of $15 per peak watt. The outcome of this calculation and the essential characteristics of systems A to D are outlined in Table 3, below.

Table 3 Characteristics of alternative solar pumping systems

	Systems			
	A	B	C	D
Price ($US)	6,200	3,900	5,850	7,800
Number of modules	7	8	12	16
Peak watt capacity	250	260	390	520

Field Trials

The location of the 14 type A SEI pump sets used for field testing is shown in Figure 1 above. In the course of a ten day trip, we visited ten of the sites; previous enquiries on the part of ADBP representatives having indicated that little useful purpose could be served by going to the remaining four.

At each site visited farmers' records of solar pump use were examined, and interviews carried out to check these, and to determine in more detail how the new system had been used.

Information was also collected about other methods of irrigation used prior to the introduction of solar pumping or in conjunction with it. The outcome of these enquiries is largely self -explanatory and is laid out in Appendix Table A1.

Whilst it has proved possible to base at least part of those aspects of our analysis which deal with alternatives to solar irrigation on our own primary data, the information gathered from test sites on solar system A has proved more difficult to apply directly. This is so for a number of reasons:

- some sets had only been moved to their present location quite recently;
- some of the locations selected (eg on the farms of very large landholders, or in rain fed areas) were unsuitable;
- some pumps had developed mechanical faults which meant that the system could not be used;

- some users had proved unable to maintain adequate records of pump use;

- the fact that users lacked previous experience of the system, meant that results obtained during the first year were unlikely to provide an accurate indication of the final pattern of use;

- the widespread practice of irrigating individual pieces of land conjunctively with other methods, made it very difficult to assess the performance of the solar pump.

In view of these difficulties it has been necessary to make a large number of assumptions regarding the performance of solar systems. Whilst I am confident that few, if any, of these will prove wildly inaccurate, it is important to bear in mind that many parameters will need to be modified as better information becomes available; and that all of the figures presented subsequently should be reported and used with caution. This is particularly important in the case of data presented in relation to systems B, C and D, which had not been field tested at all at the time of my visit to Pakistan, and which have been subject to only the most preliminary testing since.

Assumptions and Procedures

The first major assumption is that the various solar systems will be used as an exclusive means of irrigation. This departs from reality in that most, if not all adopters of the new systems, appear likely to use them jointly with water from canal and/or other sources; but offers a means of comparing solar directly with available alternatives, and seems unlikely to distort the nature of such comparisons.

The next step is then to determine the amount of water which the various solar systems could lift at different times of the year, and to go on from there to see what area of different crops they could actually be used to irrigate. We shall look first of all at system A, about which rather more information is available.

The best way to measure systems capacity is to attach a flow meter to the irrigation device, from which periodic readings could then be taken in conjunction with measures of the height over which water is being lifted. But unfortunately no such devices were available for the field trials, and even if they had been they would not necessarily have been very helpful since inexperienced farmers could not have been expected to utilise the system to its full capacity.

The alternative method used has been adapted from Pallett (1982) and will only be presented in outline here. Essentially it involves:

a) calculating the amount of effective insolation available on an average day in each month in $KwHr/m^2$, from radiation data collected at a Research Institute in Multan (which is at the centre of the region where solar systems are most likely to prove viable);

b) estimating the efficiency of the solar system on the basis of field and experimental station data;

c) calculating the volume of water which could be lifted each month at a head of 4 metres (the minimum level specified by ADBP) on the assumption that all effective insolation would actually be utilised for pumping;

d) allowing for 40 per cent of water loss in the form of water seepage and deep percolation;

e) devising a cropping system where as much of the water available as possible is used, but where the crop water requirement in any particular month (after allowing for evaporation and effective rainfall), does not exceed the amount of water available.

The outcome of these calculations is summarised in Table 4 below which shows that system A should be capable of irrigating about 2.6 acres of berseem, wheat, potatoes and sugar in the rabi season, and 1.15 acres of sugar, cotton and fodder in kharif.

Before going any further it is important to make explicit some of the major assumptions which underlie the procedures leading to this conclusion. This will enable readers to interpret the results which follow and to assess how these might have to be modified in the light of more reliable data becoming available at a later stage.

System efficiency b) above was arrived at by dividing energy output by energy at a lift of 3 to 4 metres. Energy input was defined as the amount of insolation x the actual area of photovoltaic cells; and energy output, as the head at which water was lifted x discharge measured under experimental conditions x g (gravometric constant) x weight of water.

Step c) assumes both that the system will not break down, and that labour will always be available to connect it up/ move it as necessary, during periods of effective insolation (with one exception which is discussed below).

Table 4 Crop Water Requirements and Sun Pump Capacity at 4m Pumping Lift in $m^3 \times 10^2$

Rabi Crops	Area (acres)	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Berseem	0.67	2.16	2.09	1.82	1.75	2.29	3.97	14.08
Wheat	0.67	1.82	1.21	0.94	1.75	2.69	2.69	11.10
Potatoes	0.67	-	-	0.74	0.94	1.41	-	3.09
Sugar (perennial)	0.67	2.16	1.21	-	-	-	0.81	4.18
Total requirement[1]	2.68	6.13	4.51	3.50	4.45	6.40	7.48	32.45
Water available at field[2]		8.14	7.73	7.48	6.83	6.41	7.48	44.07
Water available at pump		13.56	12.89	12.46	11.39	10.69	12.46	73.45
Water surplus to requirements		2.01	3.22	3.98	2.38	0.01	-	11.60
Kharif Crops	**Area (acres)**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Total**
Fodder	0.24	0.27	0.74	1.09	0.79	0.79	0.42	4.08
Cotton	0.24	-	0.42	1.36	1.72	1.38	0.99	5.87
Sugar	0.67	4.45	5.79	5.79	4.71	4.71	3.50	28.95
Total requirement	1.15	4.72	6.95	8.24	7.22	6.88	4.89	38.90
Water available at field[2]		8.24	9.42	8.87	7.22	8.26	7.87	49.88
Water available at pump		13.73	15.70	14.78	12.04	13.76	18.12	83.13
Water surplus to requirements		3.52	2.47	0.63	-	1.38	2.98	10.98

1 Crop water requirement calculated using evaporation-effective rainfall data.

2 Assumed 40% is lost by seepage and deep percolation. Totals may not add up exactly due to rounding.

Manufacturers claim that the system should be virtually maintenance-free , and it may be that difficulties experienced in the first year are simply teething troubles which may subsequently disappear. To the extent that they do not - a matter about which it is far too early to make any sensible judgement at present - then the performance of the solar systems and their capacity to compete with existing forms of irrigation are subsequently overstated. The same applies if labour is not available, although it should, at the same time, be pointed out here that the amount of labour required to carry out the operation in question is very small.

Step e) rests upon two assumptions which may have the effect of cancelling each other out. The first is that cropping patterns will be adopted which enable the highest percentage possible of the water available to be utilised. To the extent that this does not prove to be the case, and other considerations such as economic return or the satisfaction of household needs lead to deviation from this 'optimum'; then permutations might have to be altered and overall acreages reduced. The second assumption, on the other hand, is that what is sometimes described as 'peak load matching' must take place (i.e. that the scale of cultivation should be adjusted such that the amount of water required in any month must be met from water pumped within that month). In practice this means that the amount of water available in every month but one during the season will actually have to exceed that required in order for matching to occur in the remaining month (see Table 4). This means that only 74 per cent of the water available in _rabi_ and 78 per cent of that available in _kharif_ can actually be used. But if, as Pallett has argued (Pallett 1982, point 5.3.3.4) it is possible for surplus water to be stored in the plant route zone until it is required, then the area irrigated increases accordingly. Again this is a matter which cannot be resolved through _a priori_ reasoning, but requires further empirical investigation. Intuitively, however, it seems unlikely that all water theoretically available at given levels of insolation and system efficiency will actually be utilised, and that the utilisation factor of 76 per cent employed here might not be too wide of the mark.

Returning to the procedures adopted in evaluating the performance of the solar systems, the next step was to establish an index facilitating the comparison of system A with B, C and D; about which rather less was known. This was calculated on the basis of the peak flow of water obtained from different systems under test conditions at a standard lift of 4 metres. The results of this calculation are summarised in Table 5 below. It should be noted in passing that there is no direct correspondence between peak watt capacity (which has been used to determine price) and the actual amount of water lifted; indicating that the systems perform with varying degress of efficiency. System B (with 8 panels) performs best, followed by system C (with 12 panels) and system D (with 16 panels). The original 7 panel system A comes quite a long way behind.

Table 5 Comparing Indices of Solar Pumping Performance

	System			
	A	B	C	D
Peak watt capacity	250	260	390	520
Peak flow (litres/ second at 4m lift)	1.65	3.00	4.00	4.80
Index figure[1]	1	1.82	2.42	2.91

1. Expressed as multiple of peak flow of system A

To the extent that relative peak flows diverge from relative total flows over extended periods of time, these indices will need to be adjusted; but in the absence of any actual recordings of the latter there is no alternative at present to using the former as a basis for calculation.

With these indices established, further calculations can be carried out to establish the amount of water which could be lifted in a year, the amount which could be available at the field, the amount actually utilised, and the area irrigated in different seasons in the case of systems B, C and D. The relevant results are presented in the upper part of Table 6 below.

Having dealt with the question of the performance of different solar systems the next problem to arise concerns which of the existing types of irrigation they should be compared with, and how this comparison could be effected.

There would be little point in comparing the cost of solar with canal irrigation for two reasons. In the first place, solar systems can only be used effectively where water is available close to the surface, which means in turn, that they can really only function in areas where aquifers are recharged regularly by canal water. In this sense the two forms of irrigation could never really be regarded as alternative to each other. The second is that where canal water is readily available as a direct source of irrigation it is much cheaper than water from solar sources could be in the foreseeable future. Given present levels of subsidisation the same applies to water from electric tubewells.

There does, however, seem to be a good chance that solar pumping can shortly begin to displace the traditional Persian wheel, where irrigation costs are mugh higher; and at a rather lower price level it might also start to attract farmers who currently purchase water from diesel-operated deep tubewells; although consideration of scale and convenience make it unlikely to appeal to many deep tubewell owners. Data have therefore been collected on the amounts of water typically lifted in a year by ox-driven Persian wheels and by a 1 cusec diesel DTW, as well as upon the costs involved. Details of the way in which costs have been calculated are presented in Appendix 2, and performance figures have been incorporated in the lower part of Table 6 below, and used as a basis for assessing the power of the systems by comparison with solar pumping. (It should be noted here that all water available at the field is assumed to be used, since operators, by contrast with those of solar pumps, can exercise control over when they are used and when they are not.)

Using these figures, calculations have been made, against different assumptions, to assess the reductions which would be required from present solar price levels before they could start to become economically viable as alternatives to these two types of irrigation. To do this, farms equal in size to the <u>rabi</u> command of systems A-D, at a head of 4 metres have been assumed (2.68, 4.88, 6.69, and 7.80 acres, respectively). The next step is then to take account of the uncertainty which farmers would feel vis-a-vis the new technology, and to identify the rather lower price levels required before potential adopters themselves would believe it to be in their interests to change to the new systems. The first set of calculations is then completed by examination of the likely effects of different levels of subsidy which the ADBP is contemplating as a means of encouraging the early adoption of solar pumping. The minimum level being considered at present is $1,500 per set, and the higher figures of $2,400 and $3,000 were also mentioned in discussions with Bank officials.

<u>Comparing solar costs with the Persian wheel and purchased diesel tubewell water</u>

Detailed explanations of the assumptions and methods used in arriving at the results presented in this section may be of little interest to certain readers and are therefore relegated to Appendix 2. In outline, it has been assumed that the solar system will last for 15 years, and that once the initial fixed capital investment has been made, the only

Table 6 Comparison of performance of solar and other irrigation systems

(1) Method of irrigation	(2) Lift in metres	(3) Amount lifted in year ($M^3 \times 10^2$)	(4) Water to field ((3) x 60%)	(5) Water used	(6) Area irrigated (acres) Rabi	Kharif	Average	(7) As multiple of system A
A. Present solar system	4	157[1]	94	71	2.68	1.15	1.92	1
B. New SEI solar system (8 modules)	4	286[1]	171	129	4.88	2.09	3.49	1.82
C. New SEI solar system (12 modules)	4	380[1]	227	172	6.49	2.78	4.65	2.42
D. New SEI solar system (16 modules)	4	457[1]	274	207	7.80	3.35	5.59	2.91
E. Persian wheel with two oxen	4	130[2]	78	78	2.94	1.26	2.11	1.10
F. One cusec diesel tube well (16 H.P.)	20	3013[3]	1808	1808	68.24	29.28	48.89	25.46

1 Theoretical figure based on the assumption that all available effective radiation will be used for pumping.

2 Figure based on our own recordings and interviews which suggested that Persian wheels would on average lift 2.5 litres/second x 4 metres and be used for 8 hours a day and 180 days a year.

3 Derived from Chaudhary (1978).

additional expenditure required will take the form of a sum set aside annually for repair and maintenance. With the Persian wheel, a larger number of factors must be taken into account: the initial outlay on materials and on oxen, and their 'scrap values', annual repair and maintenance costs, the opportunity cost of the land on which the oxen are grazed (adjusted downwards by 20 per cent to allow for the average amount of time which animals spend on work other than irrigation), and the opportunity cost of supervisory labour time. Similar allowances are made in the case of the DTW for initial expenditure, scrap values, repair and maintenance, operator's wages and fuel.

Two levels of discounting have been used: 12 per cent - which reflects the approximate opportunity cost of capital to institutions such as the ADBP, and 20 per cent - which reflects more closely the opportunity cost to potential adopters. Both sets of calculations are presented in Appendix 2 but for reasons of simplicity only the 12 per cent level will be used in this discussion. In interpreting figures, the reader should remember that a lower rate of discount favours the solar systems, since a much higher proportion of total expenditure occurs as fixed capital outlay in year one here than with alternatives, where recurring fuel and other costs are much more significant.

i) Solar systems and the Persian wheel

The results of the comparison between the costs of irrigation by Persian wheel and the four alternative solar systems are presented in Table 7 below.

The upper part of the Table shows the price at which solar systems need to be made available in order to become attractive to a Persian wheel owner at the point at which both equipment and oxen would need to be replaced. Given an assumed equipment life of 30 years, and an assumed oxen working life of 10 years, the first of these two assumptions would only apply to one thirtieth, and the second to one tenth of all irrigators in year one of any scheme. The second part of the Table presents a situation where both equipment and oxen have just been replaced, and where both are assumed (somewhat artificially) to have no resale value. The figures represented here thus show the level at which all Persian wheel irrigators would be encouraged to switch immediately to solar. With the passage of time, increasing numbers of irrigators would arrive at the point where they would wish to adopt a solar system at the higher price levels. Conversely, reductions in prices from the first towards the second level, would have the effect of telescoping the time which would need to elapse before all irrigators would be advised to adopt a new system.

Table 7 Price reductions required in various solar systems in order to displace the Persian wheel ($ 12% discount)

	Solar Pumping System			
	A	B	C	D
Present price	6200	3900	5850	7800
Level to which price would need to fall where fixed capital items would otherwise have had to be replaced immediately				
- not allowing for uncertainty 1	1709	3422	4575	5490
2	(72%)	(12%)	(22%)	(30%)
- allowing for uncertainty 1	1367	2738	3660	4392
2	(78%)	(30%)	(37%)	(44%)
Level to which price would need to fall where fixed capital items have just been replaced				
- not allowing for uncertainty 1	999	2130	2857	3423
2	(84%)	(45%)	(55%)	(56%)
- allowing for uncertainty 1	799	1704	2286	2739
2	(87%)	(56%)	(61%)	(65%)

1 Price to which solar pumping systems would have to fall to displace the Persian wheel

2 Level of subsidy which would be required to justify immediate switch to solar pumping

Both of these basic calculations are then revised to allow for the need to overcome the uncertainty which potential adopters would feel towards the new technology. This has been done by making the crude assumption that a reduction of a further 20 per cent in price levels would be required to account for this factor. Figures 'not allowing for uncertainty' therefore represent the point at which different solar systems become economically viable, whilst those 'allowing for uncertainty' reflect the levels at which farmers themselves would perceive this to be the case.

Finally, two pieces of information are presented for each of the four subsections. The first in each case is the price level to which different solar systems would have to fall in order to displace the Persian wheel. The second is the subsidy level, expressed as a percentage of present price, which would be required to make the alternative system immediately competitive from the farmer's point of view. The results arising from this exercise may be summarised as follows:

- none of the systems is yet cheap enough to compete with the Persian wheel under even the most favourable conditions where fixed capital items (equipment and oxen) would have to have been replaced immediately, and where no allowance was made for uncertainty;

- system A which has already been subjected to a year of field testing, would not appear attractive to present Persian wheel users even if the highest level of subsidisation considered by the ADBP ($3,000) were to be made available;

- where Persian fixed capital items were due for replacement, then the minimum level of subsidisation ($1,500) would be sufficient to make system B attractive both before and after uncertainty had been taken into account, and system C attractive before it had been taken into account. System D, before uncertainty, could compete at the second level of subsidisation ($2,400), but could not be made attractive after uncertainty;

- where fixed capital items had been replaced, system B could be made attractive both before and after uncertainty at the second level of subsidisation, but even the highest subsidies failed to bring C or D within the acceptable range against either of these assumptions;

- all of these results are calculated at a 12 per cent level of discount. The effect of adopting a 20 per cent level would be to further the subsidies required by a modest factor in all instances.

The overall conclusion to be derived from this exercise is therefore that system B and C appear likely to attract a small proportion of present Persian wheel users immediately, and a growing number as time elapses and existing fixed capital is used up, with a relatively modest reduction in the price levels which have been used here. It lies beyond the scope of this report to comment whether such a reduction may occur in practice, but if it is deemed likely, then modest levels of subsidisation would appear justified. The fact that the prices quoted by Allison would, if achieved, make make system B, C and D, immediately competitive against some assumptions at least, might be taken as a factor pointing in this direction. On the other hand, however, it should be remembered that no allowance has been made here for the fact that solar systems are imported at a cost for the foreign exchange budget of the country, whereas Persian wheels are locally manufactured and repaired.

ii) Solar systems and the purchase of diesel tubewell water

The comparison between the Persian wheel and the solar pumping systems was relatively straightforward, since in all instances the head over which water is being lifted is much the same, and at the smaller end of the solar scale at least, discharge volumes and areas irrigated are of the same order of magnitude. The comparison between solar systems and diesel deep tubewells is more complicated for a number of reasons. In the first place, although it is a relatively simple matter to compare costs per unit of water pumped, this does not allow for the fact that the low discharge from a large number of solar installations may, on some cases, require much more labour on the part of fieldmen than in the case of the deep tubewell. Secondly, differences in discharge might lead to differences in the extent of water transmission losses in the case of the two systems (although what solar systems lose by virtue of the time which they take to transmit water a fixed distance, may to some extent be counteracted by the greater distances which deep tubewell water has on average to travel). Thirdly, in instances where tubewell water purchasers wished to switch to solar pumping but did not already have an open well, then the additional cost of making a boring into which the solar pump could be placed would need to be taken into account.

Given these difficulties, each of which could substantially alter the point at which solar pumping systems could become attractive, but none of which can adequately be dealt with here, the results presented below should be treated with considerable caution.

A further problem concerns the very large difference in scale between the diesel tubewell, which at the 1 cusec level used here can irrigate about 49 acres, and even the most powerful solar system considered (system D), which

Table 8 Price reductions required in various solar systems to displace the purchase of diesel DTW water ($ & 12% discount)

	Solar Pumping System			
	A	B	C	D
Present price	6200	3900	5850	7800
Level to which price would need to fall with diesel prices remaining constant in real terms				
- not allowing for uncertainty 1	1327	2727	3651	4378
2	(79%)	(30%)	(38%)	(44%)
- allowing for uncertainty 1	1062	2181	2921	3502
2	(83%)	(44%)	(50%)	(55%)
Level to which price would need to fall with diesel prices increasing by 10% per annum in real terms				
- not allowing for uncertainty 1	2204	4323	5773	6930
2	(64%)	(-)	(1%)	(11%)
- allowing for uncertainty 1	1763	3458	4619	5544
2	(72%)	(11%)	(21%)	(29%)

1 Price to which solar pumping systems would have to fall to displace the Persian wheel.

2 Level of subsidy which would be required to justify immediate switch to solar pumping.

will only cover 6 acres. The convenience and economy to a large landowner of being able to rely upon one device as opposed to 5 or 6, with all of the extra labour which this would entail, means that solar prices would need to fall very much further than calculations carried out on the simple basis of the cost of water at the well, and equal transmission losses from all irrigation systems might suggest.

Nevertheless, the comparison is worth making since, for every deep tubewell owner there are perhaps 7 purchasers of deep tubewell water, and for them the cost of water to the owner should define the minimum price at which they will hope to be able to purchase (the maximum being defined as the cost of irrigating the area by a solar system by Persian wheel). In the absence of hard data, it seems reasonable to assume that the larger landowner will be able to obtain deep tubewell water at something close to its cost price (since if he were asked to pay much more than this he would simply obtain a deep tubewell himself), whilst the smaller landowner will have to pay something approaching the Persian cost. As the price of solar falls through the relatively narrow band separating Persian and deep tubewell costs, it may therefore be assumed to become attractive to progressively larger farmers.

Proceeding on this basis, Table 8 suggests that further reductions in solar prices will be required beyond the level where they can compete with the Persian wheel, before they will be able to appeal to purchasers of diesel DTW water. In more detail it suggests that:

- system A appears less attractive than in relation to the Persian wheel;

- systems B and C would require high levels of subsidisation in order to compete here;

- system D could not be made attractive even at the higher subsidy level contemplated by ADBP.

But all of this assumes that diesel prices will remain constant in real terms. The second part of the Table illustrates what would happen if, following the Halcrow ITDG Report, the alternative assumption of a 10 per cent per annum increase in costs in real terms is adopted. The picture to emerge here, is one where solar systems start to become competitive at much higher prices; and although it would appear perhaps to be unreasonable to expect a farmer to base an adoption decision on calculations of this kind, they may well be relevant to policy-makers in helping to justify an initial programme of subsidisation.

Demand Assessment

The analysis of the previous section indicated that there would be no demand for any of the different solar systems at their present price levels unless subsidies could be made available. At the 12 per cent level of discounting, and after the effects of uncertainty had been taken into account, it was found that falls to 22 per cent, 70 per cent, 63 per cent and 56 per cent of the present price levels of systems A,B,C and D respectively, would be required before any existing users of Persian wheels might begin to switch to solar irrigation. Furthermore, it was noted that the only Persian wheel users attracted to the new technology at these levels would be those whose fixed capital was due for immediate replacement, and that larger reductions to 13,44, 39, and 35 per cent of present price levels respectively, would be required to make the new systems immediately attractive to all Persian wheel irrigators. It was also noted that generally larger reductions to 17,56,50 and 45 per cent of present prices would be necssary to attract existing purchasers of diesel DTW water to the new system, under circumstances where diesel prices remained constant in real terms.

In this section, an attempt will be made to assess the potential levels of demand were such price reductions actually to come about. This, however, will not be entirely straightforward for two major reasons.

Firstly, it will only infrequently be the case that the capacity of available systems will precisely match the area which a farmer wishes to irrigate. This will mean, in many instances, that the entire farm cannot be irrigated from a single solar system, and that continued access to an alternative system will be required. This, in turn, may entail additional unit costs over and above those incurred on a farm where solar does cover the entire area, and wherever this is the case the price of a solar system will again need to fall further below the indicated levels before it can effectively start to compete. This constraint disappears if solar system owners are able to sell water in excess of their own requirements - but given the unpredictability of discharge at any particular point in time, and the relatively high water transmission losses consequent upon the low rate of discharge, this may well prove much more problematic than in the instance of either DTW or Persian wheel systems. Beyond noting this factor however, little can be done to account for its influence until rather more is known than at present about the way in which solar systems will actually be used under farm conditions.

The second complication arises as a result of factors operating on the supply side; namely the need, initially at least, for solar pump sets to be concentrated in relatively small areas where necessary credit and maintenance facilities could be provided. This will present rather less difficulty.

The procedure adopted here will be to assesss demand at four levels:

- firstly, within the three Persian wheel-using districts already given priority by ADBP, where there are few tubewells and where adoption is likely to occur earliest, if and when solar prices fall (Swabi sub-division in Muzarfargarh and in the Punjab, and Sukkur in Sind);

- secondly, among open well owners in the ten districts where these are most common (and where tubewells are available in larger numbers);

- thirdly, among purchasers of diesel DTW water within these ten districts;

- fourthly, among purchasers of diesel DTW water in the country as a whole.

The first potential category of demand will begin to be activated once solar prices fall to the levels indicated in the upper portion of Table 7; and the full potential of demand presented in Table 9 below will be realised at the level indicated in the second part of Table 7, where all Persian wheel operators should immediately find it worth their while to switch to solar systems.

The Table has been constructed from data presented in the 1972 Agricultural Census on the number of Persian wheel users by farm size, and excludes all present irrigators with farms of less than 2.6 acres - the Command of the least powerful solar option. It should, however, be borne in mind that further price reductions would serve to bring at least some of those initially excluded back within the solar fold, and that the cut-off point adopted here is both relative to the cropping pattern chosen for purposes of illustration, and subject to the assumption that water excess to requirements could not be sold.

On the other hand the inclusion of system A, which is similar in size to system B, yet at the same time less efficient and more expensive, is somewhat artificial. If, as would seem more likely, system B were the smallest to be made available, then the smallest viable farm size at the relevant price levels would be a little less than 5 acres, and the entire 'potential demand' for system A would be wiped out. (At the other end of the spectrum, the inferior economic efficiency of system D as compared to system B and C, might also well lead to its elimination; though in this instance the effect would be to distribute demand among existing systems rather than to eliminate it as such).

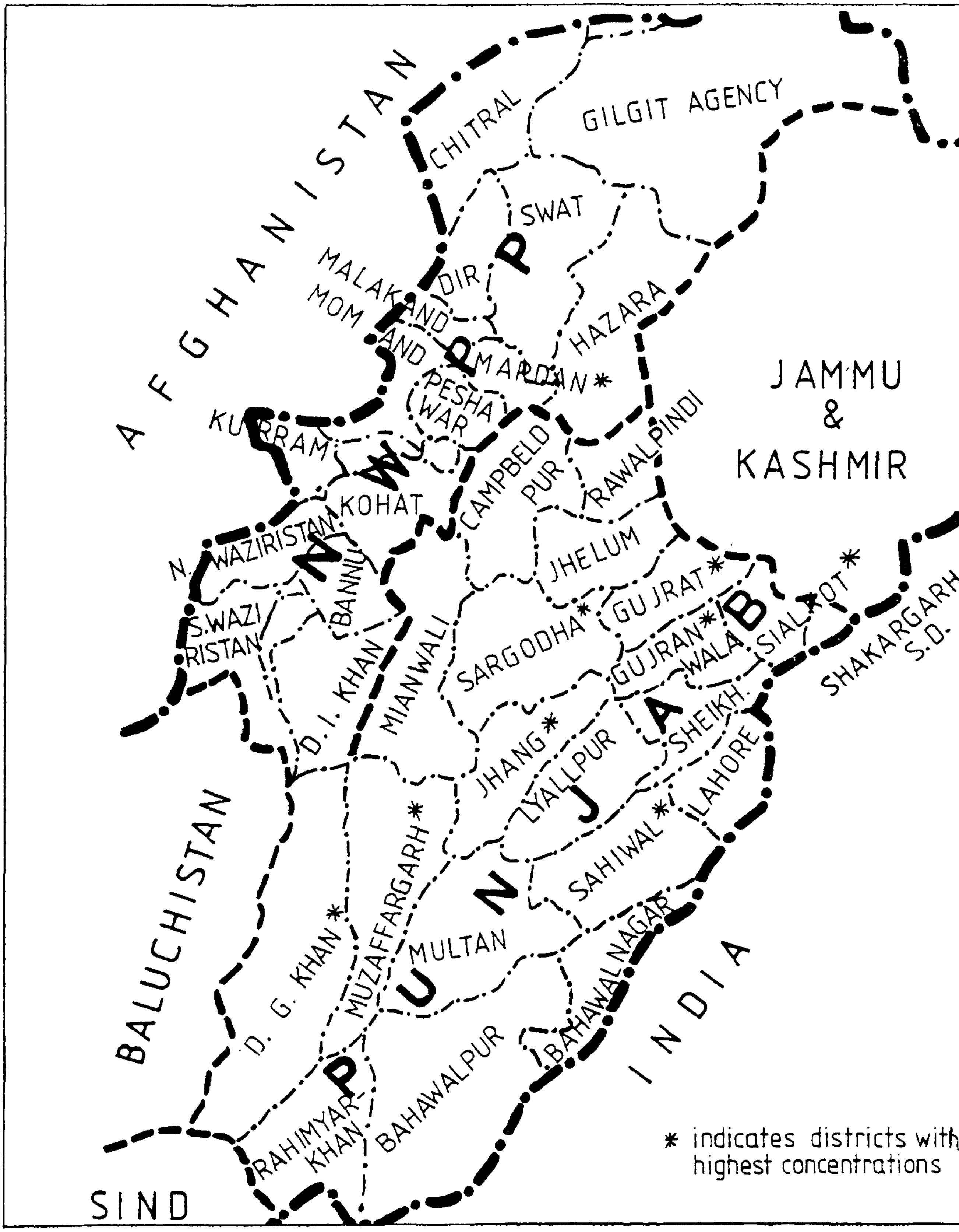
Table 9 Potential Demand for Solar Pumping Systems within the Areas favoured by ADBP

System	Farm size (acres)	Number of potential adopters Swabi	Leiah	Sukkur	Total
A	2.68-4.88	582	511	76	1169
B	4.88-6.49	327	681	104	1112
C	6.49-7.80	257	679	165	1101
D	> 7.80	787	8,230	376	9393
Total		1,953	10,101	721	12,775

The second category of potential demand encompasses all owners of open wells in the ten districts indicated in Figure 2 below, which account for about three quarters of all wells nationally. Many of these wells have been used with Persian wheels at some stage, but many would now have been replaced by DTWs. In assessing the level at which potential demand would be activated here, it is therefore safer to use the lower DTW water purchase displacement figures from Table 8, than the Persian wheel figures from Table 7. At this level, and leaving aside system A, for the reasons indicated above, there would be a demand for about 56,000 sets; broken down between B, C and D in the proportions indicated in Table 10 below, and including the 11,600 from the initial three areas.

But if prices were to begin to fall to this level, then all purchasers of diesel DTW water within the areas would become potential adopters (although with the proviso that some additional reduction in solar costs would be required in cases where no open wells were available and special borings had to be made for the installation of a solar system. This also assumes the availability of suitable aquifers close to the surface which could not always be guaranteed). This third potential level of demand could eventually amount to as much as 436,000 sets, although available statistics make it impossible to suggest how many of these would already be accounted for as part of level 2. Ultimately, and again subject to aquifer conditions, there could conceivably be demand for something approaching a million pump sets on a national scale.

Figure 2



Location of open wells

Table 10 Summary of Potential levels of Demand for Solar Systems B - D

System	Displacing Persian wheel		Displacing purchased DTW water	
	3 areas	10 areas	10 areas	nationwide
B	1,112	4,000	31,000	113,000
C	1,101	4,000	31,000	55,000
D	9,393	48,000	374,000	759,000
Total	11,606	56,000	436,000	957,000

Access to the benefits of solar irrigation

Having attempted to identify the likely levels of demand for solar irrigation technology, it now only remains to assess which types of farmer are likely to enjoy access to it.

System A - the one currently being tested - has been promoted at least partly in terms of its suitability for small farmers. In one sense this is not an unreasonable claim, since the technology does appear to lend itself to ownership and operation on farms which are at least smaller than those presently equipped with modern irrigation (a conclusion which stands even if one assumes the displacement of system A by system B). But by the same token, the discussion of demand has made it clear that the smallest farms will continue to be excluded. Simple interpolation from the figures presented in Table 1 above suggest, in fact, that more than 50 per cent of all farms would be of insufficient size to justify the adoption of system B, and this takes no account of land fragmentation.

There are additional reasons for supposing the exclusion of the smallest. Owing to the inadequacy of the data available, no consideration has been given to the likely influence of tenancy on adoption behaviour. Since a high proportion of small farms are at least in part dependent upon land which is not owned, and since insecurity of tenure must inevitably exercise an influence upon the decision of whether to adopt a new technology or not, it is difficult to avoid the conclusion that many small farmers who are not already excluded on other grounds, will be unable to take the risk of adoption.

Finally, here, in carrying out cost calculations, it has been assumed that farmers who previously used the Persian wheel would be able to give up their oxen when they switched to solar. This overlooks the fact that small farmers also use their oxen for ploughing and for transport, and in instances where tractors or other oxen are not readily available for hire, the solar pumping system could therefore be considerably less attractive than the earlier discussion suggested.

A further factor to be taken into account is the stated intention of the ADBP of promoting only systems with a capacity to discharge 4 litres per second at a head of 4 metres. This would have the effect of excluding those farms suited to system B; and of leaving only those with large enough contiguous areas of land to justify the adoption of system C and D.

The question of credit must also be considered, since few farmers will be able to adopt without it. The ADBP proposes, after subsidies, a 10 per cent down payment, a one year grace period, and then seven annual repayments. Allowing for 11 per cent interest, this would mean repayments of about $300 per year at the price levels anticipated. This, in itself, should not create insuperable difficulties but raises the question of who will have access to any credit which is available

The record of the Bank to date indicates a very strong tendency for loans to be concentrated in the hands of those with 12.5 or more acres of land. It is, however, argued that this reflected a situation where available technologies (notably tractors and tubewells) were inappropriate to the needs of small farmers; and that the new small farmer credit programme has already begun to redress this imbalance. The most recent statistics do indeed indicate a very substantial shift away from lending to large landholders, but the main beneficiaries have been farms falling within 5 to 12.5 acre category, with only an insignificant percentage going to the under 5 acre group who comprise the bulk of the rural population. So even where there is a demand from small farmers, and a capacity to repay - a question which cannot be adequately investigated until much more is known about the cropping patterns which will be adopted with solar pumping systems - then the indications are that they will still generally be excluded.

It is possible that those with less than 5 acres may be able to benefit through access to new sources of water for purchase and through additional employment opportunities on the land of others. At the same time, however, the prices of their produce are likely to fall, and the increased purchasing power of other groups is likely to push up the cost of consumer goods and agricultural inputs. Such an effect will only be experienced 'at the margin' but nevertheless there is a danger - which grows with the power of the solar system contemplated - of the smallest landholders thus being subject to a 'double squeeze'. It should also not be forgotten, in this context, that the displacement of the Persian wheel will remove an important source of employment for carpenters and blacksmiths, who tend to be drawn from the poorer strata of rural society.

This is not an argument for opposing a solar programme, from which many relatively small farmers can benefit: but it does point to the need for specific measures to ensure that the smallest farmers are not excluded. These might include:

- devising smaller systems than those presently anticipated so that farms which would otherwise be too small can participate; or of this were to prove impossible, then at least promoting system B and giving less emphasis to C and D. This would naturally entail lowering the minimum performance specification currently laid down by the ADBP, but could be justified in terms of the superior efficiency exhibited by system B in preliminary trials;

- recognising that the smallest farmers would generally not have open wells and would therefore need help in sinking borings for solar pump use. This would entail attaching at least a lower priority to the objective of displacing the Persian wheel;

- offering higher subsidies for smaller systems, and building in safeguards against their resale with profit to larger landowners:

- earmarking the greater part of the loans to be made available for landholders with less than 5 acres.

All this, of course, presupposes a fuller investigation of the influences of tenancy, new cropping systems and repayment capacity on the adoption behaviour of small farmers than is possible at this stage.

4 CONCLUSION

This completes the major portion of the report (although certain matters of less crucial importance are dealt with in Appendices which follow). In conclusion four points seem worthy of restatement:

1. On the basis of information currently available about the price and performance of different solar pumping options, it would be premature to make any hard and fast statements about their likely future viability;

2. It does, however, seem likely that relatively modest reductions in price (or modest increases in levels of subsidisation) would enable the more efficient solar systems to start displacing the Persian wheel in areas where no other form of lift irrigation is currently available.

3. Where other forms of lift irrigation (most notably, diesel deep tubewells) are available, then the magnitude of the solar price reduction required before adoption could be expected to take place on a substantial scale, would need to be considerably larger.

4. As things stand, if solar pumping technology does become established, then it is likely to benefit the smaller farmers who have thus far only been able to participate marginally in the benefits of the Green Revolution. But without some rethinking of current strategy, the smallest farmers will continue to be excluded and may indeed suffer a further deterioration in their living standards.

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RESULTS OF FIELD TRIALS

RESULTS OF FIELD TRIALS

Appendix 1:Table A1

FARMER'S NAME	LOCATION	LAND OWNED (acres)	LAND OPERATED (acres)	DEPTH TO WATER TABLE AT LOWEST POINT m	METHOD(S) OF IRRIGATION USED PRIOR TO SOLAR	SOLAR IRRIGATION: DATE FIRST USED	PERIODS WHEN NOT USED	REASONS FOR NON-USE	TOTAL DAYS USED	TOTAL HOURS USED	AVERAGE HOURS/DAY	AREA COMMANDED (acres)	KHARIF: METHODS OF IRRIGATION USED IN CONJUNCTION	KHARIF: MAJOR CROPS (ACRES)	RABI: METHODS OF IRRIGATION USED IN CONJUNCTION	RABI: MAJOR CROPS (ACRES)	COMMENTS
Sherwali	Peshawar	?	4	2 (July Aug.)	Persian Wheel	18.10.81	Odd days through period	Rainfall	65	311	4.8	2*	-	Maize (1) Fodder (1/4) Veg (1/16) Fallow (11/16)	-	Wheat (1½) Veg (1/4) To be followed by Tobacco Fallow (1/4)	*Also helped neighbour irrigate sugar
Faizalam	"	3¾	-	3.5 (July Aug.)	Persian Wheel	3.10.81	Apparently not at all after October		25(?)	164	5.7	5	-	Maize (5) Tobacco (2 3/8) (To come later)	Nothing so far may use later if necessary	Wheat (2½) Fodder (1/3)	
Manafjal	"	8⅛	8⅛	3.5 (June July)	Barani Area occasional use of LLP	1.3.81	Most of year	Rainy season	34	213	6.3	4¼	Little cultivation of any kind - too much rain	Maize (¾) Spinach (1/3) Sheftal (1/3)		Wheat (3¾) Spinach (½)	Bad location for pump
Zamiruddin	Muzaffargarh	9	9	3.5 (June July)	Public & private tubewell	15.9.81	22.12.81 to present		88	731.5	8.3	4-5	Public tubewell-land preparation private tubewell (1 hour/week)	Sorghum (1) Fodder (½) Paddy (½)/Sugar (3/8) Veg (½)/Mango (½)	Private Tubewell (2 hours/wk) Public Tubewell (4½ hours/wk)	Veg (1 5/8) Wheat (1½) Berseem (1) Mango 4 Sugar 3	Results don't mean much because of other irrigation used
Amanullah Khan	"	7	7	3.5 (May June)	Very little canal water available - small amount in summer only	5.3.81	Used most of time		283	2724	9.6	5	Purchased tubewell water negligible Canal water	Rice (2) Sugar cane (½) Veg (1/4) Fodder (1)	Purchased tubewell	Wheat (2) Berseem (2¼) Fallow (¾)	
Naubah Shah	"	2½	2½	3 (June July)	Persian Wheel	12.7.81	To Jan.	Pump broke down	77	?	?	2½	Persian wheel used until solar arrived	Rice (1) Fodder (1) Veg (½)	Persian wheel used after solar broke down	Berseem (2) Veg (½)	Reliable solar pump would lead farmer to switch to commercial veg cultivation
Suba	Sukkur																Pump broken down - no record
Aktab	"	20	29	4 (July Aug.)	Persian Wheel & canal	25.2.81	3.11 - 5.12.81	Pump broke down	?	851		2	Canal for 3 hours/week 5 acres/time	Bitter Gourd (1/4) Paddy (2)	Canal supply very poor and unreliable. Persian wheel	Onion (1 3/8) Brassica (1/8) Somf (1/3)	
Mahmood Bahir	Sialkot																Only used for one month - pump broken May, so no interview taken
Malik Masood	Shekhpura	180	180	4 (April)	Canal and tubewell	5.4.81	11.5 - 9.6 25.11 - 29.12 20.1 - present		151	?	?	7½	Canal and tubewell	Paddy (1)	Canal and tubewell	Peas (5) Berseem (1½) Radish (½) Spinach (½)	Irrigated area large owing to availability of other methods

APPENDIX 2

Methods Used for the Calculation of Irrigation Costs

1. All calculations are based on a 15 year period, with net cash flows discounted at 12 and 20 per cent. All calculations presented in the text use the former rate. The detailed tables which follow present results at both the 12 and the 20 per cent levels.

2. In arriving at the figures in Tables 4 and 5, which show the level to which the price of various solar pumping systems would have to fall, in order to displace the Persian wheel or the purchase of diesel tubewell water, the following procedure has been used:

a) calculate present discounted value of costs of the irrigation system with which solar is being compared;

b) multiply the result of a) by the relevant solar figure from column (7) of Table 6, and divide by the figure from the same column for the irrigation system with which solar is being compared. (This gives the cost of irrigating the same area as the command of the solar system in question with existing methods of irrigation);

c) subtract from b) the present discounted value of the imputed repair and maintenance costs of the solar system in question.

3. Persian wheel costs are based on my own interviews in the field and are made as follows:

a) Fixed Capital

2 oxen:$600 (slaughter value after 10 years:$200)
Materials:$315 (scrap value after 15 years:$158) (1)

b) Labour Costs

Annual repair and maintenance $30
Supervisory Labour(2).......................$130

c) Value of Land under Fodder Crops (3) $64

(1) Once constructed, open wells may be used for very long periods of time. Since virtually all Persian wheel users will have had wells for many years, and hardly anyone would now contemplate constructing a new well for irrigation, this cost has not been taken into account.

(2) Assumed to be ½ day x $1.45/dayx180 days

(3) Assumed as an average net return of $64 from crops grown on 0.3125 of an acre, basic return figures derived from Allison (1979)

4. Diesel tubewell fixed capital costs are based on Chaudhary (1978) and multiplied by 1.6 to allow for inflation since 1977 when these data were collected. Other costs were obtained from the ADBP. They break down as follows:

a) Fixed Capital

Centrifugal Pump, accessories ....$272 (life 10 years)
Diesel engine, accessories.......$2307 (life 10 years)
Pipes............................$554 (life 10 years)
Constructions .... $960 (life 30 years)
Other fixed costs .... $416 (life 10 years)

b) Circulating Capital

Annual fuel and lubricating costs $4434 (1)

c) Labour Costs

Annual maintenance costs $360
Operators wages $1200 (2)

Notes

(1) $1.5/hourx2956 hours

(2) $100/month

5. Solar costs follow Halcrow (1981) @ $100/year for repair and maintenance, and are then scaled up or down according to system size as follows:

System	Annual maintenance cost
A	68
B	78
C	100
D	122

Table A2.1 Price reductions required in various solar systems in order to displace the Persian wheel ($ at 12 and 20% discount)

		Solar Pumping System							
		A		B		C		D	
Present price		6200		3900		5850		7800	
Discount rate %		12	20	12	20	12	20	12	20
Level to which price would need to fall where Persian plant would otherwise have had to be replaced immediately									
- not allowing for uncertainty	1	1709	1350	3422	2671	4575	3569	5490	4284
	2	72%	78%	12%	32%	22%	39%	30%	45%
- allowing for uncertainty	1	1367	1080	2738	2137	3660	2855	4392	3427
	2	78%	83%	30%	45%	37%	51%	44%	56%
Level to which price would need to fall where Persian plant has just been replaced									
- not allowing for uncertainty	1	999	673	2130	1439	2857	1930	3423	2314
	2	84%	89%	45%	63%	51%	67%	56%	70%
- allowing for uncertainty	1	799	538	1704	1151	2286	1544	2739	1851
	2	87%	91%	56%	70%	61%	74%	65%	70%

1 Price to which solar pumping systems would have to fall to displace the Persian wheel

2 Level of subsidy which would be required to justify immediate switch to solar pumping

Table A2.2 Price reductions required in various solar systems to displace the purchase of diesel DTW water ($ at 12 and 20% discount)

		Solar Pumping System							
		A		B		C		D	
Present price		6200		3900		5850		7800	
Discount rate %		12	20	12	20	12	20	12	20
Level to which price would need to fall with diesel prices remaining constant in real terms									
- not allowing for uncertainty	1	1327	947	2727	1937	3651	2593	4378	3111
	2	79%	85%	30%	50%	38%	56%	44%	60%
- allowing for uncertainty	1	1062	758	2181	1550	2921	2075	3502	2489
	2	83%	88%	44%	60%	50%	65%	55%	68%
Level to which price would need to fall with diesel prices increasing by 10% per annum in real terms									
- not allowing for uncertainty	1	2204	1403	4323	2767	5773	3697	6930	4438
	2	64%	77%	-	29%	1%	37%	11%	43%
- allowing for uncertainty	1	1763	1122	3458	2214	4619	2957	5544	3550
	2	72%	82%	11%	43%	21%	49%	29%	54%

1 Price to which solar pumping system would have to fall to displace the Persian wheel

2 Level of subsidy which would be required to justify immediate switch to solar pumping

APPENDIX 3

Questions Outstanding

A short consultancy looking at a very newly introduced technology must inevitably leave a number of important problems unresolved. The following is an attempt to indicate areas where more detailed investigation would be useful.

A Solar Pumping Systems

1. How much will it cost to make borings for potential solar adopters who have no open well? How will this additional cost influence the price levels at which solar pumping systems become attractive?

2. How, in practice, will solar systems be used where other sources of irrigation - most notably, canal and tubewell water - are also available at certain times of the year? What cropping patterns will solar users adopt, and how will this influence their capacity to repay loans? How will patterns of conjunctive use and cropping systems relate to the area under solar command, and what impact will this, in turn, have upon the question of who will be able to adopt and levels of demand for systems of different capacities?

3. Will a market for solar water be available in instances where there is capacity in excess of a farmer's own requirements? Alternatively, what are the prospects for storing excess energy in batteries and putting it to other uses?

4. How much maintenance will solar systems in practice require? How will this effect their performance?

5. How extensive are tenancy relations in the areas where the ADBP intends to launch its programme, and how will these influence the adoption behaviour of small farmers in particular?

B The Comparison with Persian Wheels

1. How much labour is actually devoted to the operation of the Persian wheel, when the other activities of the person concerned are taken into account? Where labour is provided by the land operator's household and not hired, what is its opportunity cost? To what extent, in other words, will different types of farmer be able to substitute actual cash outlays on solar, for the labour currently provided by household labour with the Persian wheel?

2. Where a Persian wheel owner uses oxen for other purposes, at what cost may they be substituted?

3. What will be the effect on the income and livelihoods of blacksmiths' and carpenters' repair and maintenance of Persian wheels, is these are displaced?

4. What will be the effects at the national level of substituting an imported technology for one which is produced locally?

C The Comparison with Tubewells

1. How much do potential solar adopters actually pay for tubewell water at present? How reliable is the supply of water, and what influences do these factors have upon cropping patterns, net income and the viability of solar systems for different types of farm?

2. How do water transmission losses from tubewells differ from those from solar systems? Does extra field labour need to be employed with solar systems owing to the low rate of water discharge?

APPENDIX 4

Contacts

Agricultural Development Bank of Pakistan

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a) Technology Division

Md. Afzal Hussein	Director
Safdar Ali Gill	Joint Director
Abdul Rauf Khan Rao	Deputy Director
Mahmud Rafique	Assistant Director
Mansoor Ahmed	Assistant Director

b) Regional Managers

Md. Azam Khan	Peshawar
Saeed Ahmed Cheema	Muzaffargarh
M.R. Faridi	Sukkur
Md. Tufail Khan	Lahore
A.A.Alvi	Gujranwala

KSB Pumps Limited

Manzurul Haq	Managing Director

Farmers

Sherwali	Peshawar
Faizalam	Peshawar
Manafjal	Peshawar
Zamuruddin	Muzaffargarh
Amanullah Khan	Muzaffargarh
Naubah Shah	Muzaffargarh
Suba	Sukkur
Aktab	Sukkur
Mahmood Bahir	Sialkot
Malik Masood	Shekhpura