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SUSTAINABLE GROUNDWATER IRRIGATION TECHNOLOGY MANAGEMENT WITHIN AND BETWEEN THE PUBLIC AND PRIVATE SECTORS

Guidelines of good practice, based on the experiences of Bangladesh and Pakistan

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REFERENCE MANUAL
TECHNICAL FEASIBILITY

Findings of DFID funded research project (R6877) on 'Technology Transfer and Sustainable Rural Development' to develop guidelines of good practice for (a) technology transfer in relation to the full or partial transfer of tubewell irrigation from the public to the private sector, and (b) associated rural development, 1997-1999.

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1. INTRODUCTION

Objectives of 'Technical Feasibility' Guidelines:

- improving quality and performance of technology
- suggesting new technologies

The feasibility of groundwater technology as it is transferred to, or developed within, a particular sector is determined by the specifications, attributes, and practical management of the technology, and the physical environment in which it operates. The technical component of the guidelines is concerned primarily with ways of improving the quality and performance of existing technology and making suggestions for technologies or ideas which may be new to many. This applies either to the public or the private sector, or at the point of transfer from public to private.

Guidelines cover:

- well
- pump
- prime mover
- conveyance system

- selection
- installation
- operation

Almost all mechanised groundwater irrigation systems comprise the same basic components, but terminology for these components can vary widely. For example, many farmers, when referring to the pump, actually mean the pump and the prime mover (either engine or motor). For the purposes of these guidelines, the main components of a groundwater irrigation system are defined as: the well, the pump, the prime mover, and the conveyance system. These components are defined, and some examples given from Bangladesh and Pakistan, in Box 1. Each of these components will be looked at individually and, where appropriate, together. The quality of these components and the way of using each can affect the efficiency of power use and amount of water reaching the plants. Box 2 shows the process of delivering water from the ground to the plants and the ranges of energy loss at each stage of the process. The figure shows that there can be an enormous range of energy loss, from 55% in an efficiently operating system, to over 99% in an extremely poorly operating system. There are natural losses at each stage which cannot be avoided but losses can be reduced through correct selection, installation and operation of technology.

Two main different physical pumping processes are employed for groundwater extraction. These are called suction mode and force mode. These may be relatively new terms to many people but, nevertheless, have been chosen to differentiate between cheaper and more expensive technologies with different technical, economic and management requirements.

Suction mode is where the pump is above the groundwater level and literally lifts the water from the ground to the surface.

Suction mode is where the pump is above the groundwater level and literally lifts the water from the ground to the surface. The depth from which water can be lifted is influenced primarily by atmospheric pressure, but also vapour pressure, friction losses, and design parameters such as impeller design and rotation speed. As a result, limitations are imposed on the depth from which water can be lifted.

Force mode is where the pump is placed below the groundwater level and propels the groundwater to the surface.

Force mode is where the pump is placed below the groundwater level and propels the groundwater to the surface. The physical restrictions which are imposed on force modes are much fewer in number and less in extent than for suction modes. Force mode technologies may therefore pump water from much greater depths, the limits depending upon the amount of power used.

The suction mode technology is the cheapest in terms of the costs of the equipment required and for running costs and in most cases is preferred by private sector farmers. However, there are cases where suction mode is simply not feasible because the static water levels are lower than the suction limit of the equipment. Ways and means can be found of overcoming this, either through adapting the suction mode technology, or by change of mode.

Whilst static water level is an obvious constraint upon technology choice, there are many other less obvious physical and technical constraints to profitable groundwater irrigation, such as the level of power and water efficiencies that arise as a consequence of differences in the quality of construction and operation of the well, pump, prime mover and conveyance system.

The technical efficiency of the technology, and hence its feasibility and affordability, is measured in two key ways:

i) the technology's use of energy/power, and

ii) the technology's delivery of water.

This section of the guidelines will make observations about technology choice and management for the two modes and, for given environments, make recommendations for good practice in selection, installation, operation and maintenance of the technology. Priority will be given to suction mode technology as this is the dominant technology in the private sector under the technical responsibility of the farmers themselves. A separate section will deal with conveyance systems.

Box 1: Definitions of technology terms used in the guidelines, based on Bangladesh and Pakistan

Pumps

Suction mode: Centrifugal pumps with a suction limit determined mainly by atmospheric pressure, but also by vapour pressure, friction losses, and design parameters such as impeller design and rotation speed. Limit generally about 21 feet. Pumps placed on the ground surface or on the floor of a pit. Generally cheap and manufactured in-country.

Force mode: Turbine pumps (usually vertical line-shaft), generally set at depth below the groundwater level with the power unit on the surface. These pumps have higher pump heads and pump efficiencies. Often manufactured in-country, though some imported. Expensive and need for high standards of well verticality.

Submersible pumps, pump and electric power unit close-coupled and set below groundwater level. High pump efficiencies and less demands on well verticality than line-shaft turbine pumps. Mainly imported with consequent lack of spare parts.

Manual pumps: These are all suction pumps and include the hand Tara & Rower pumps and treadle pumps.

Prime movers

Suction pumps mostly driven by diesel engines, turbine pumps either driven by diesel engines or electric motors and submersible pumps only driven by electric motors.

Diesel engines: Bangladesh - mainly Chinese manufactured for low horse power suction pumps and mainly imported from Europe or India for high horse power turbine pumps.

Pakistan - mainly locally made high speed 'peters' engines. Tractor engines are also used to power suction mode pumps.

Electric motors: In both Bangladesh and Pakistan mainly restricted to imported high horse power engines, usually under projects rather than for individuals, or for the use of imported submersible pumps. Increasingly popular with individuals in Balochistan - locally made pumps, motors imported.

Wells

Shallow Tubewells: STWs are generally those wells which use suction mode pumps and which are in the region of 30-130 feet in depth. They are generally small in diameter and can be excavated using manually operated drilling rigs. Variations on the STW theme include:

Bangladesh - STW where the pump is set at the ground surface. Unlined Deep Set Shallow Tubewell (DSSTW) where the suction pump is set at the bottom of a manually excavated pit usually no deeper than 7 ft and lined DSSTW where the suction pump is set at the bottom of a manually constructed lined pit usually deeper than 7 feet.

Pakistan - most wells in this category are, according to the Bangladesh criteria, lined DSSTWs, since most pumps are placed at the bottom of lined pits in excess of 30 feet deep.

Deep Tubewells: DTWs are generally those which use turbine, 'force mode' pumps and are normally in the region of 100-500 feet deep. There are several different categories of DTW in Bangladesh and Pakistan:

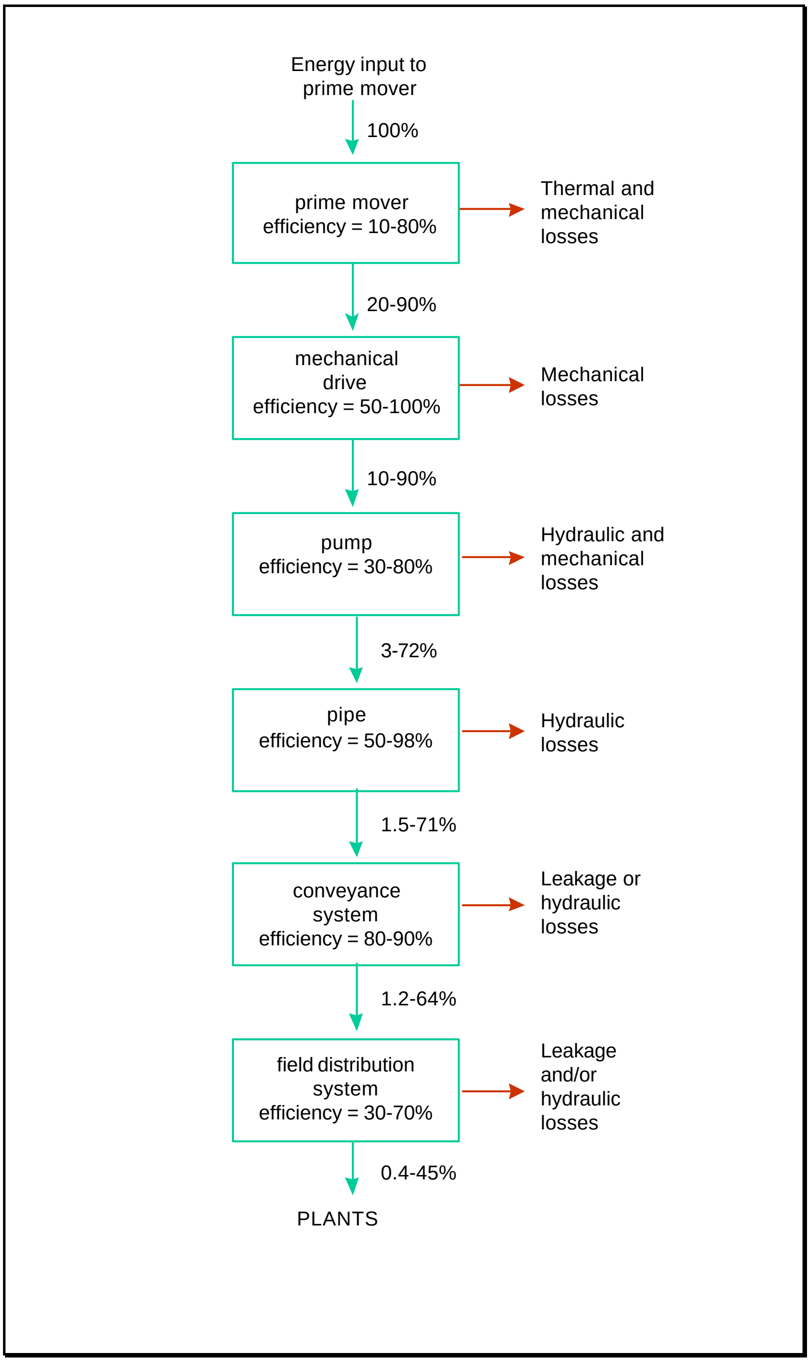
Bangladesh - wells for line-shaft turbine pumps which are wide diameter expensive wells requiring engineering expertise to maintain verticality, and wells for submersible pumps for which the issue of verticality is not so important.

Pakistan - these are the SCARP tubewells used for irrigation and drainage and the 'scavenger' wells of the Left Bank Outfall Drain project (LBOD) which house two pumps within one well, a turbine pump at depth for drainage and a suction pump near the surface for irrigation.

Conveyance System

These include lined canals, unlined canals and buried and surface pipe systems.

Box 2: Energy flow through a typical groundwater irrigation system



(after Fraenkel, 1998)

2. SUMMARY OF TECHNOLOGIES USED IN BANGLADESH AND PAKISTAN

There are many differences in the physical environment and, as a consequence, between the technologies used, in Bangladesh and Pakistan. Even where technologies are similar the terminology may differ. To clarify references to technologies later in the text, and to illustrate the main range of technologies available for different physical circumstances, a summary of the main types of well components in Bangladesh and Pakistan is shown below. Where appropriate, photographs or sketches illustrating the well components have been included.

2.1 Wells

For the purpose of these guidelines, wells will be defined in two major categories, these are Shallow Tubewells (STWs), which use suction mode pumps, and Deep Tubewells (DTWs) which use force mode pumps. DTWs are indeed generally deeper than STWs but there is no clear depth threshold where a STW becomes a DTW. The threshold relates to the technology used and the cost of the well. The main types of well in Bangladesh and Pakistan are illustrated in Boxes 3 and 4 below.

The most detailed and user friendly reference guide to pumps is 'Water Pumping Devices - A Handbook for Users and Choosers' by Fraenkel (1998). Many of the diagrams used in this section come from this handbook, and it is recommended for more detailed information on pumps and prime movers. (see under 'Guidelines Publications' section in the references).

2.2 Pumps

Mechanically driven pumps are basically divided into suction and force mode pumps. Most of the suction mode pumps are called centrifugal pumps where a casing holds a single impeller (or rotor) which spins the water into a circular path at high velocity and then releases the water away through an outlet. Fraenkel (1998) illustrates this with the image of a weight on a piece of string being flung away after being whirled around. The full term for this type of pump is a volute centrifugal pump. The main components are a water inlet, a snail shell shaped chamber, an impeller and an outlet (see diagram in Box 5). With accurate moulds these are relatively easy and cheap to manufacture. These are entirely made locally in both Bangladesh and Pakistan by large established and small new companies alike. The materials used and accuracy in design and manufacture vary greatly in each country and this affects the performance of the pumps considerably.

Box 3: Main well types in Bangladesh

Shallow Tubewells (STWs)

STWs are generally wells which use suction mode pumps and which are in the region of 30-120 feet in depth. They are generally small in diameter and can be excavated using percussion methods with manually operated drilling rigs.

STW
(pump at ground level (GL)

Unlined Deep Set STW (DSSTW)
(pump at bottom of unlined pit)

Lined DSSTW
(pump at bottom of lined pit

Deep Tubewells (DTWs)

DTWs are generally those which use 'force mode' pumps (usually housed in permanent structures) and are generally in the region of 200-500 feet in depth. There are different categories of DTW in Bangladesh: (i) wells for line-shaft turbine pumps which require engineering expertise to maintain verticality, and (ii) wells for submersible pumps for which the issue of verticality is not so important.

DTW (with header tank for partial buried pipe system)

Box 4: Main well types in Pakistan

Shallow Tubewells (STWs)

In Pakistan, suction mode pumps are either placed at ground level (GL) or at the bottom of lined or unlined pits in excess of 30 ft below GL. The equivalent definitions, in terms of the Bangladesh names given above, are STW or lined DSSTW. The pits in Pakistan tend to be much deeper and wider (up to 20 ft) to allow room for excavation and flat belt drive systems which are common in Pakistan.

STW

(pump at GL)

Lined DSSTW

(pump at bottom of lined pit)

Deep Tubewells (DTWs)

These are mainly the SCARP tubewells used for irrigation and vertical drainage and the 'scavenger' wells of the Left Bank Outfall Drain project (LBOD) which use two pumps within one well, a turbine pump at depth for drainage and a suction pump near the surface for irrigation. In addition, many government and private DTWs have been installed in Balochistan housing submersible pumps.

SCARP tubewell - Punjab

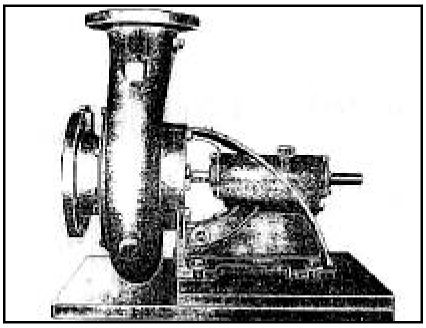
Submersible DTW - Balochistan

Box 5: Main pump types in Bangladesh and Pakistan

<u>Suction mode pumps</u>

Centrifugal pumps: Centrifugal pumps with a suction limit determined by atmospheric and vapour pressure, friction losses, and design parameters such as impeller design and rotation speed. Limit generally about 21 ft. Pumps placed at ground level or on the floor of a pit, sunk below ground level. Generally cheap and manufactured in-country.

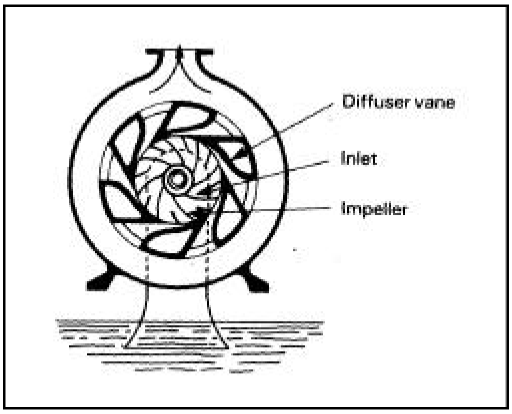
In Pakistan, in particular, borehole jet pumps are also used. The action is as with normal suction mode pumps but some of the discharge water is returned to the system to raise pressure in the rising main and increase the heads from which water can be lifted.

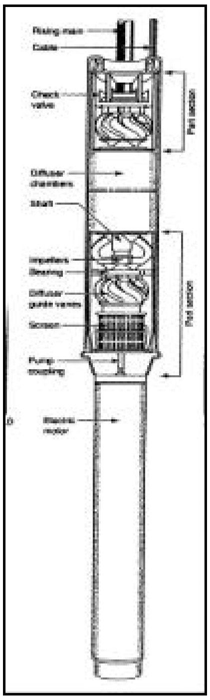


<u>Force mode pumps</u>

Turbine pumps: Turbine pumps (usually vertical line-shaft) generally set at depth below the groundwater level with the power unit on the surface. These pumps have higher pump heads and pump efficiencies. Often manufactured in-country, though some imported. Expensive and need for high standards of verticality.

Submersible pumps: Pump and electric power unit close-coupled and set below groundwater level. High pump efficiencies and less demands on well verticality than line-shaft turbine pumps. Mainly imported with consequent lack of spare parts.





<u>Manual pumps</u>

These are all suction pumps and include the hand Tara & Rower pumps and treadle pumps.

(after Fraenkel, 1998; NMIDP, 1994)

In the turbine pump, the pump is set below water level while the prime mover is at the surface. The prime mover and pump are connected by a vertical line-shaft. With the submersible, the close-coupled pump and motor are both set below the water level. In both cases the pumps consist of one or more stages. Each stage consists of an impeller housed in a chamber. The shape of the chamber and the addition of diffuser vanes cause the water velocity to slow down and consequently the water pressure to increase. The greater the pumping depth the greater the number of stages are needed. These two pump types are illustrated in Box 5 below. The engineering required for force mode pumps is of greater technical difficulty and tend (i) to be considerably more expensive than simple centrifugal pumps, and (ii) to be imported, particularly in Bangladesh. This has implications for affordability and availability of spare parts. Turbine pumps are manufactured in Pakistan, as are the pump component of submersible pumps (the sealed motor only being imported).

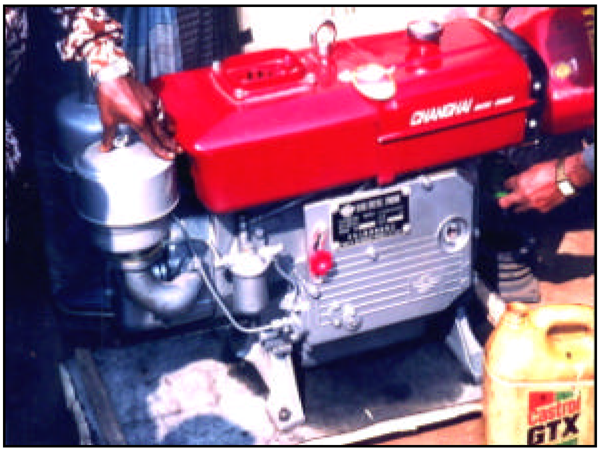
2.3 Prime movers

The prime mover private sector market mainly deals in diesel engines. In Bangladesh these are mainly two-stroke engines, whilst in Pakistan these vary from single cylinder low speed diesels with large fly-wheels, through two cylinder diesel engines, to tractors. The small field and farm sizes in Bangladesh largely preclude the use of tractors. Chinese engines now dominate the Bangladesh market (where almost all engines are imported) and did dominate the Pakistan market, although many local manufacturers are copying and making their own versions of the Chinese and older British engines, and are known as 'peters' engines. The main types of prime mover in Bangladesh and Pakistan are shown in Box 6.

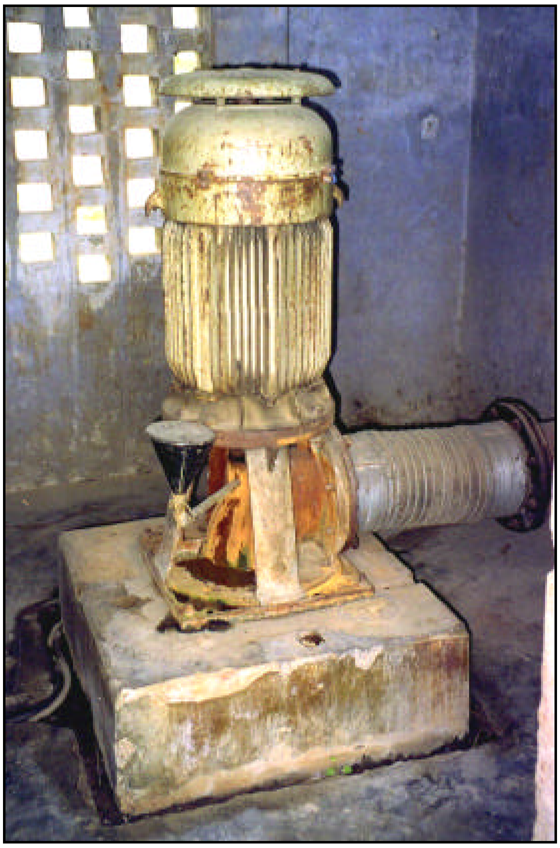
The power of the prime movers ranges typically from 3 Brake Horse Power (BHP) to 15 BHP for suction mode wells (for discharges of between 0.5 and 1 cusec) and from 22 BHP to 35 BHP for force mode wells (for discharges of between 2 and 3 cusecs). However, there are also examples of higher BHP for suction mode wells and lower BHP for force mode wells (for submersibles in particular).

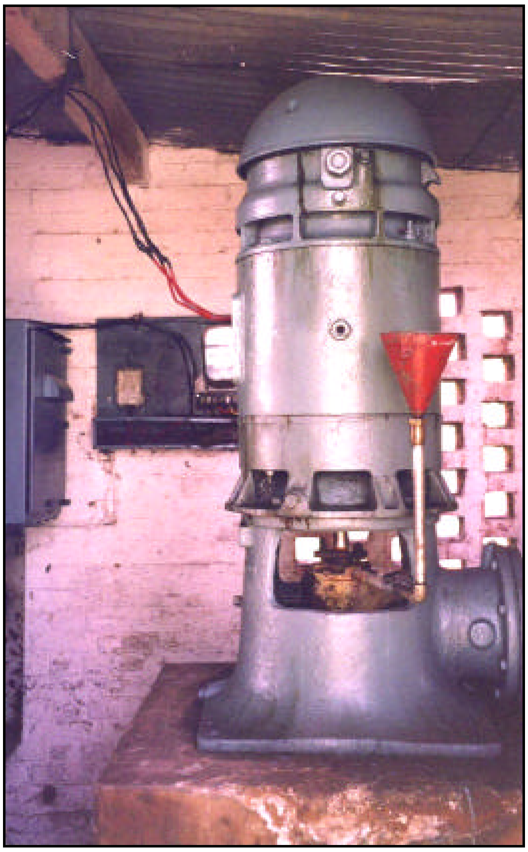
Box 6: Main prime mover types in Bangladesh and Pakistan

Diesel engines:	Bangladesh	- mainly Chinese manufactured for low HP suction pumps
		- mainly imported from Europe or India for high HP turbine pumps, although lower powered engines for small diameter turbine pumps are made locally..
	Pakistan	- mainly locally made high speed 'peters' engines. Still many British single cylinder low speed diesel engines being used. Tractor engines are also used to power suction mode pumps.



Electric motors: In both Bangladesh and Pakistan mainly restricted to imported high HP engines, usually under projects rather than for individuals, or for the use of imported submersible pumps.





2.4 Conveyance system

Bangladesh and Pakistan provide examples of a wide range of conveyance systems from the tubewell to the field. These include unlined (compacted and non-compacted) earthen channels, lined channels (lined usually with either bricks or concrete), buried pipe systems (concrete or PVC), surface pipe systems (HDP) (see Box 7). In Pakistan, groundwater irrigation in all except the 'barani' (rainfed) areas, is used to supplement surface irrigation, where the conveyance system is part of a large surface irrigation network maintained by irrigation departments.

Box 7: Main conveyance system types in Bangladesh and Pakistan

Unlined earth channel

Lined earth channel

Buried pipe system

Surface pipe system

3. SUCTION MODE TECHNOLOGIES

The STWs have been at the forefront of the development of privately owned groundwater irrigation. They are relatively cheap to install and operate and following the opening up of the markets in Bangladesh, Pakistan and India, cheap imports flooded into these countries.

This is an area of technology use which is now largely free from any government involvement. In Bangladesh, Government involvement has reduced since the removal of subsidies for electricity and import duties on machinery. In Pakistan, the diesel technologies have developed unchecked and require no imports. Electricity is still subsidised through flat rate charging but this is beginning to change. This is a vibrant area which has seen major development of small industries manufacturing groundwater irrigation technologies. In all three countries pumps are manufactured locally and, in Pakistan and India, diesel engines are manufactured too. In Bangladesh, the supply of diesel engines is now almost exclusively from China, largely replacing more expensive Japanese engines.

There is much scope for improvement in the efficiency of technology. Enormous amounts of energy and water are wasted through inefficient installation and operation, thus decreasing the affordability of groundwater irrigation in marginal areas.

In terms of units sold and volumes of water produced by STWs, the story of private sector development is one of considerable success (Box 8). However, there are areas for considerable improvement in the efficiency of the technology. Enormous amounts of energy and water are being wasted through inefficient installation and operation of STWs, thus decreasing the feasibility of groundwater irrigation in marginal areas. Surveys carried out in Bangladesh, Pakistan and India show major inefficiencies in well installation and pump and engine operation.

In addition, local copying and manufacture of pumps and engines by many small manufacturers has resulted in lower quality products, in terms of quality of design, materials and manufacture. In Pakistan, for example, established manufacturers of thoroughly tested quality pumps, such as KSB, Meco Pumps, and Golden Pumps have largely pulled out of agriculture because they cannot compete on cost with the 'unorganised' sector of small manufacturers. Farmers are interested in cheap products and neither the manufacturers, nor the retailers, nor the farmers are fully aware of all of the different aspects of water pumping. They believe that so long as water is reaching the surface, then the pump and engine are doing their job. Efforts are being made to address this, through initiatives like the Bogra Metal Enterprises Development Project in Bangladesh, and the Water Resource Research

Box 8: Contribution to irrigation from private STWs in Bangladesh and Pakistan

Country	Total no. of private STWs	Year	% of groundwater irrigated area	% of total irrigated area	% of groundwater supplied for irrigation	% of total water supplied for irrigation
Bangladesh	582,335	1996	60%	55%	-	
Pakistan	358,000	1993	-	-	72%	27%

(after NMIDP, April 1997;van Steenbergen, 1997)

One of the problems of educating the small-scale manufacturers, is that they are 'unorganised', largely operating outside of the formal sector and wish to remain anonymous.

Institute's work with MECO Pumps (in pursuit of ISO 9000 accreditation) in Pakistan. However, in Pakistan in particular, one of the problems of educating the small-scale manufacturers, is that they are 'unorganised', largely operating outside of the formal sector and wish to remain anonymous.

Within regions there are great similarities in well configuration for STWs but configurations differ widely between regions.

One of the striking features of the choice and use of technology in Pakistan and Bangladesh is that within regions there are great similarities in well configuration for STWs but that configurations differ widely between regions. This has also been identified in India (Jan Bom and van Steenbergen, 1997) and has been attributed to depth to water table, prevailing land ownership, soil condition and local tradition, but also evidence of the technology vacuum in which private tubewell development has taken place (Box 9). People use what is available in a given region, whether it is the most technically appropriate or not. It is also evidence of the powerful influence that farmer-farmer training can have. This is the experience of organisations in Bangladesh and Pakistan working with farmers. Those working now in groundwater irrigation on a small-scale, such as the Water Resources Research Institute in Islamabad, the National Rural Support Programme in northern Punjab and Orangi around Karachi advocate intensive inputs with small groups of farmers. If there are real benefits then the farmers will not hesitate to take on new ideas.

Engines:

Many spares parts are interchangeable between different makers' products

This technology vacuum also appears to affect the technology markets themselves and may act as a considerable constraint to innovative design and manufacture. When considering **engines** in Pakistan, for example, 'peters' engines, copies of British/Chinese imported engines, manufactured cheaply in-country are made by many different companies. They are, however, almost identical. Indeed, so much so that most spare parts are interchangeable between makes. This makes the supply of spare parts a relatively effective process and can be seen as an advantage.

However, it also means that commercial companies are reluctant to go out on a limb and design a new product which is radically different. Many of these cheap

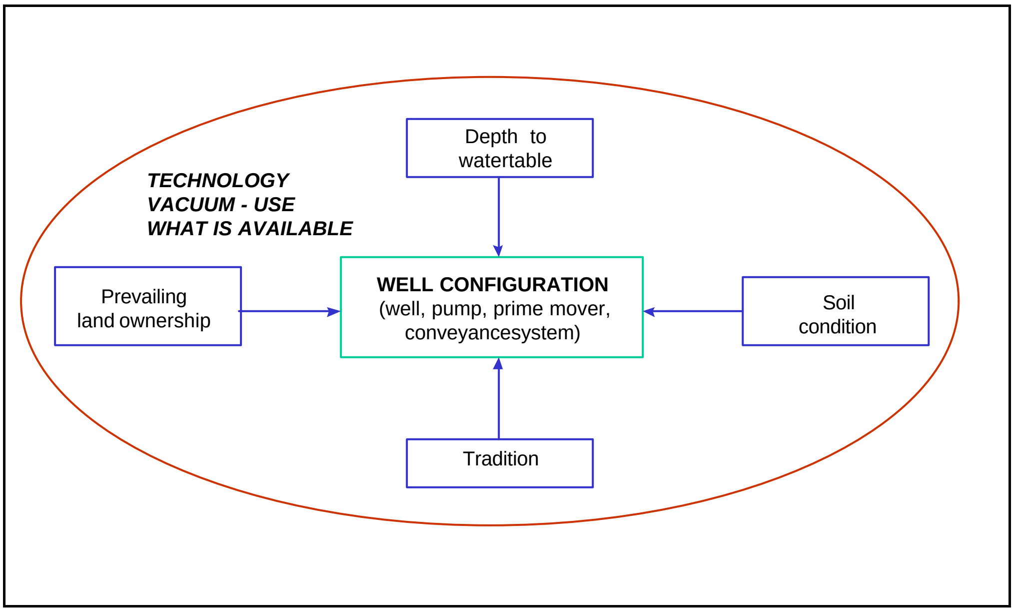
Pumps:

Cheap pumps may be so poorly casted or finished, that spare parts for the same make often do not fit.

products appear to have design failings in common and these will be addressed in the well operation section of the guidelines. However, **pumps** may be so poorly casted or finished (by hand) by the smaller manufacturers, that not only are spare parts between different makes not interchangeable, but spare parts that fit for the same make are often not available

The guidelines are broken down into well installation, pump manufacture and selection, prime mover manufacture and selection, and well operation.

Box 9: Influences on well configuration



(after Jan Bom and van Steenbergen, 1997)

3.1 Well Installation

Installation of the STWs is a relatively simple and inexpensive operation, using hand dug or manually operated percussion rigs, and it is not intended to go into this in detail here. There are, however, a few points which can lead to reduction of high well resistance and increase the viability of groundwater irrigation for marginal entrants to private sector water supply. The guidelines refer to:

- Selection of materials
- Well development
- Aquifer Development

3.2 Well Modification to Extend Limits of Suction Mode

The main form of well modification in Bangladesh and Pakistan is **deep setting** of wells. This section summarises the reasons for, and specifications of, deep set wells in Pakistan and Bangladesh.

Deep setting can be seen as:

(i) a legitimate requirement in areas where the static water levels are below suction limits throughout the year

(ii) a failure in effective water management for the early part of the irrigation season in areas where pits are used for only part of the irrigation season

Deep set wells are constructed so that suction mode technologies can access water from greater depths. With a suction limit of 21 feet for most pumps, if water is required from greater depths, without changing to expensive force mode technologies, then the traditional answer is to lower the pump below the ground surface, in a pit. Pit construction requires only labour and materials (such as bricks or reinforced concrete) which are generally cheap. Therefore, deep setting of wells is usually a cheaper option than a change to more expensive force mode technologies.

In Pakistan, very wide and deep set wells are used to access water from considerable depths. Many wells are over eight ft wide (brick lined) and over 30 ft deep. In Bangladesh, NMIDP defined deep set wells in two ways: (i) deep set wells, which are generally unlined and excavated to a depth of seven to ten feet, and (ii) very deep set wells which are usually lined and excavated to greater than seven to ten feet deep. The reasons for the much deeper wells in Pakistan are that (i) groundwater levels are much deeper, and (ii) groundwater recharge is much less and less hydrostatic pressures are placed on the well following recharge. In many cases in Bangladesh deep setting is only a temporary measure to access water at the end of the irrigation season when static water levels have fallen.

The National Minor Irrigation Project in Bangladesh has produced thorough guidelines on the design, construction and costs involved in deep setting (see NMIDP, 1997h in 'Guidelines Publications' of references).

The technology for deep set wells is cheap and the design standards are not stringent, so the technical aspects are not covered in these guidelines.

3.3 Other Methods for Extending Suction Mode Pumping Limits

Deep setting of wells is a tried and tested method for increasing the depth from which groundwater can be extracted using the cheaper suction mode technologies. However, deep setting of wells requires wider pits (hence loss of agriculturally productive land) and, for poorer farmers, can be relatively expensive, particularly where deep setting is only required for a part of the irrigation season. Whilst this is a cheaper option than changing to force mode extraction, there are other methods which can be employed to either increase the discharge or the head for suction mode pumps. Two main methods could be seen as practical for Bangladesh and Pakistan. The guidelines refer to methods of:

- Increasing operating head through (i) using two suction mode pumps in series, or (ii) borehole jet pump installation

- Increasing discharge, through (i) using two suction mode pumps in parallel, or (ii) using more than one well per pumpset

3.4 Pump manufacture and selection

Observations from site visits and literature reviews indicate that there are several shortcomings in the standards of pump manufacture and selection. All pumps perform to a particular standard and should, in theory, have their own pump performance curve. Pump performance is a function of discharge and head (lift). For different heads against which the pump is operating, different discharges may be achieved. The greater the head against which the pump is operating the less the discharge available for any given power input. To maintain discharge as head increases greater power (and cost) is required. The main importance of the pump performance curve is where static water levels change significantly during the irrigation season, or where pumping takes place against higher heads. The difference in performance (and hence profitability) between a pump with a steep head/discharge curve and one with a shallow head/discharge curve is considerable.

The difference in performance (and hence profitability) between a pump with a steep head/discharge curve and one with a shallow head/discharge curve is considerable.

The choice of pump should be linked to the appropriate selection of prime mover. Differently powered pumps will have different head/discharge relationships.

In Bangladesh, a National Water Management Plan team have taken data collected by NMIDP and looked at the cost of pumping in terms of fuel consumption for different water duties (NWMP, 1999). Water duty is measured in water horse power (WHP) and is a function of discharge and head. The results (Box 10) indicate the wide range of costs of delivering given volumes of water from given heads. Whether a farmer gets a pumpset with low or high operating costs, is presently often more to luck than anything else, without information on the standards and efficiencies of the pump and prime mover.

Pump test facilities:

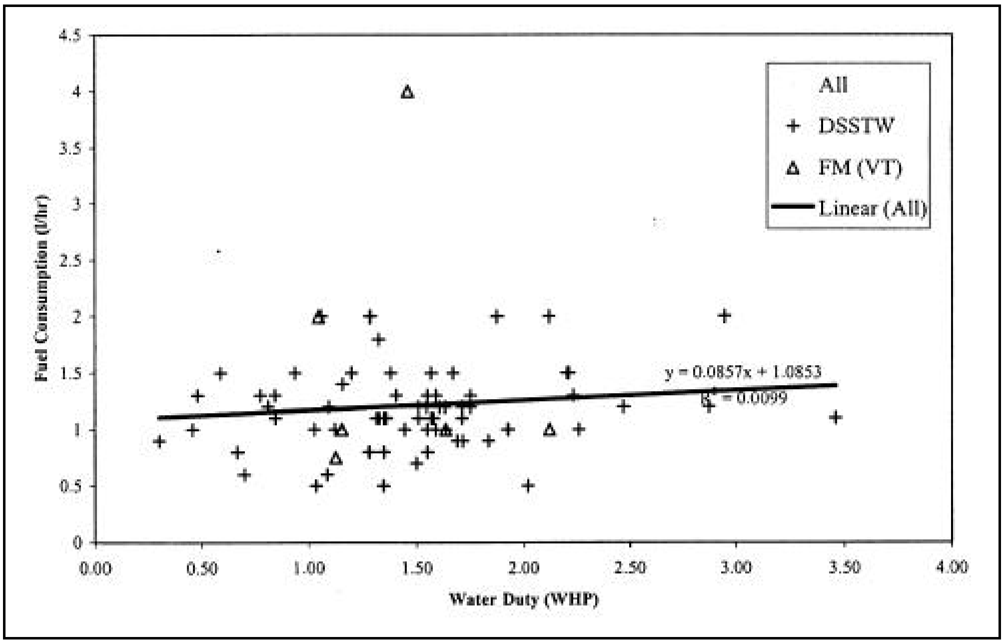
Bangladesh - first commercial pump testing centre set up in Bogra, (joint venture by RDA and BMEEG. Also at BUET, Dhaka

Pakistan pump testing facilities at KSB (Islamabad), Meco Pumps (Lahore) and Golden Pumps (Gujranwala).

3.5 Engine manufacture and selection

The issues relating to engine manufacture and selection are similar to those for the pump. The engine selected should match the energy requirements for water extraction and the capacity and performance of the pump. Ideally, performance

Box 10: Examples of fuel consumption for different water horse power



(NWMP, 1999)

curves should be available for a variety of combinations of pump and engine capacity. Throughout the sub-continent, engines with higher than necessary power inputs are frequently being used.

The prime mover should match the energy requirements for water extraction and the capacity and performance of the pump.

There are a improvements which can be made to the design and manufacture of the engines currently available in Bangladesh and Pakistan to improve fuel efficiency in particular. Foremost among the improvements is to reduce the speed of the engines and to improve the water pumps in the engines. The high speed models use more fuel than performance warrants. The water pumps are often absent from the engines, or if present, not in good working condition.

3.6 Selecting appropriate prime mover power requirements

There are two procedures, suggested in the Guidelines, for selecting the most appropriate prime mover. One relates to aquifer conditions and one relates to irrigation water requirements. **Both procedures require information on pump and/or prime mover efficiency.** No accurate selection can be made without this information and creation of this information is strongly recommended.

3.7 Matching pumps to prime movers

The process of matching pumps to prime movers is not an exact science

Reviews of groundwater irrigation in Bangladesh (IIMI et al, 1995) and Pakistan (van Steenbergen, 1997) suggest that the process of matching pumps to prime movers is not an exact science. There are many cases in the IIMI survey of

Additional HP does not necessarily lead to greater discharge, although it does lead to greater fuel consumption and cost.

considerable over capacity in prime mover power. Many farmers interviewed reported that their solution to increasing discharge was to increase the horse power of their engine. This may produce greater discharge but at considerable risk of damage to the well. Matching prime movers to pumps is not a simple process and one for which there is little in the way of prescriptive information. The NMIDP in Bangladesh started to do some evaluation in this field and this is being continued by the National Water Management Plan. Box 11 illustrates that additional horse power does not necessarily lead to greater discharge, although it does lead to greater fuel consumption and cost.

3.8 Pump operation

EM stands for effective micro-organisms. The Japanese company is EMRO. Details are available from WRRI (see WRRI, 1998a in 'References'.

Common themes relating to pump operation are found in Bangladesh, Pakistan and India. Results from experimental work carried out in India (Jan Bom and van Steenbergen, 1997) have shown an improved fuel efficiency in diesel operated pump sets by 50%. These steps are shown in the Guidelines and include:

- Increasing the temperature of the water coolant
- Reducing suction friction losses

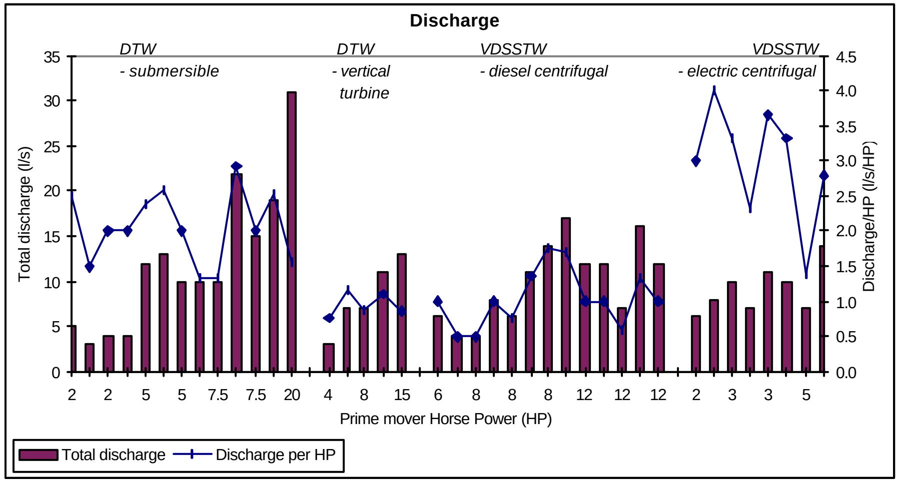
3.9 Other technical suggestions for increasing fuel efficiency

3.9.1 EM_z ceramics and diesel consumption

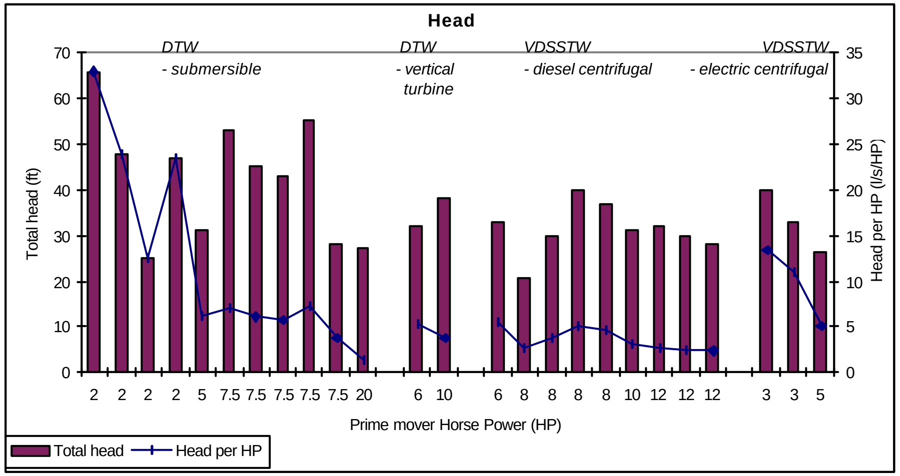
This new technology, developed in Japan, is currently being tested by WRRI in Pakistan (WRRI, 98a) to substantiate claims made in Japan of at least 30% savings in diesel consumption. The technology uses micro-organisms, capable of emitting magnetic resonance, stored in clay, and heated to 700^0C to create ceramic balls (about 5mm in diameter). EM_z ceramics, as they are known, have been shown to improve fuel combustion by 7% initially to over 30% in 20 days for water cooled 8 HP diesel engines, and to over 40% in 30 days for 3 HP air cooled engines. The EM_z ceramics are approximately Rs. 20/- each and last indefinitely. Two ceramics are needed for engines up to 16 HP, six ceramics for engines of 16-30 HP and ten ceramics are needed for engines in excess of 30 HP. In addition, 50-100 ml of EM_z fluid can be added to the engine oil which also improves engine performance, but also extends the life of the engine.

Box 11: Performance of different types of well and pump in Bangladesh

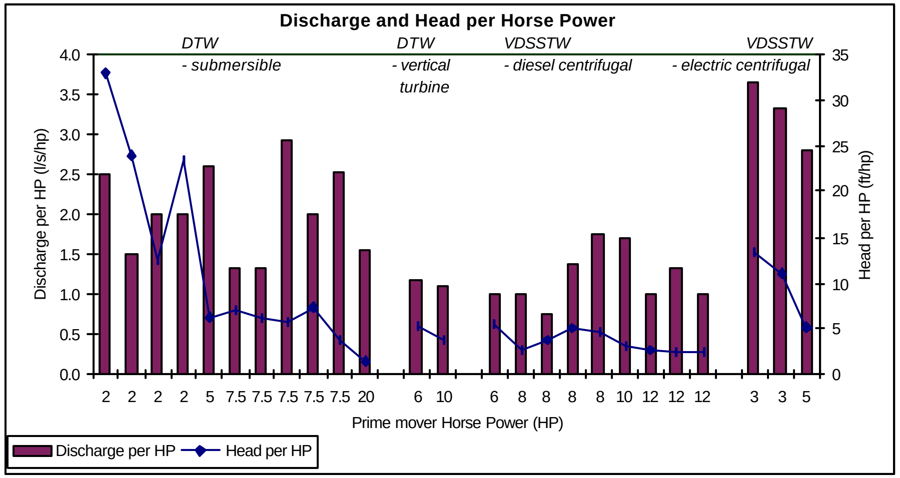
A: Total and per horse power discharge for NMIDP survey wells



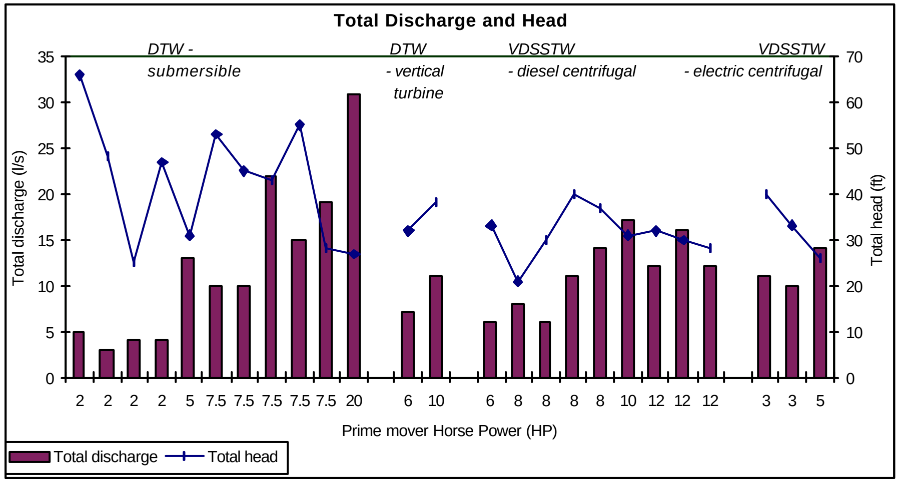
B: Total and per horse power head for NMIDP survey wells



C: Discharge and head per horse power for NMIDP survey wells



D: Total discharge and head for NMIDP survey wells



(from NMIDP, June 1996)

3.9.2 Energy efficient Jack pump

Contact details for further information are in the references under WRRI, 1998b

The Jack pump, used originally in the oil industry (the 'nodding donkey' - see Box 12), and working on positive displacement reciprocating principles, is the most energy efficient of all pumps. It is most appropriate in those areas where pumping from great depths is required and may be appropriate for either the public or private sector (where high value crops are being grown). The pump is extremely robust and requires almost no maintenance. The main characteristics of the Jack pump are:

- high energy and water efficiency - 87%
- suitable for shallow and very deep pumping
- low energy requirement
- suitable for alternative energy sources (solar, wind, diesel, electric)low operation and maintenance requirement
- long life
- no corrosion problem (WRRI, 1998b)

Box 12: Diesel powered Jack pump

For a one cusec tubewell, the diesel powered Jack pump was estimated to be 15% of the capital cost of a WAPDA installed electric well (including cost of transmission line - 30% without this cost) and also 15% of the annual running costs. Discharge can be increased by increasing the well casing diameter or by increasing the stroke length of the pump (the stroke length for the well used in the cost comparisons above was 30 inches).

4. FORCE MODE TECHNOLOGIES

Main issues for force mode technology are affordability and manageability. Technical feasibility guidelines therefore brief.

Force mode technologies are used in both the public and private sectors in Bangladesh and Pakistan and still contribute a significant proportion of the countries' irrigation water (Box 13). These are the technologies which are at the centre of the transfer process. In both countries, most of the force mode pumps are likely to have been transferred in the next few years. There is no doubt that many of these pumps are technically feasible in most areas of Bangladesh and Pakistan. The prime concern with these technologies is their affordability and manageability.

Box 13: Contribution to irrigation from force mode wells in Bangladesh and Pakistan

Country	Total no. of private DTWs	Year	% of groundwater irrigated area	% of total irrigated area	% of groundwater supplied	% of total water supplied
Bangladesh	32,184	1996	16%	15%	-	
Pakistan	25,000 approx.	1993	-	-	28%	11%

(after NMIDP, April 1997;van Steenbergen, 1997)

4.1 Well installation

Many references and guidelines for DTW installation have been produced, most notably Driscoll (1986) and Clarke (1988), and, for Pakistan, IWASRI (1997). See 'Guidelines Publications' in references.

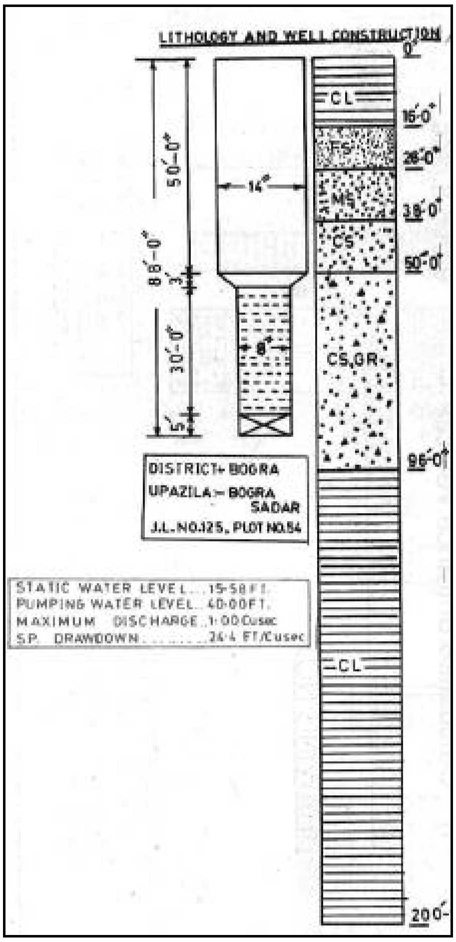
Force mode technologies include submersible pumps (low or high discharge) and turbine pumps in DTWs. Very few new DTWs are being installed for irrigation in either Bangladesh or Pakistan since the end of the DTW and SCARP groundwater projects respectively. Drilling companies interviewed in Chittagong, for example, said that only one or two a year were commissioned and that these were for the Barind Multi-purpose Development Authority, a government project in an area where no alternative means of groundwater extraction are possible. Therefore, these guidelines will not cover well installation, except to illustrate some of the main well types and contexts and reasons for their use in Bangladesh and Pakistan (see Boxes 14 and 15).

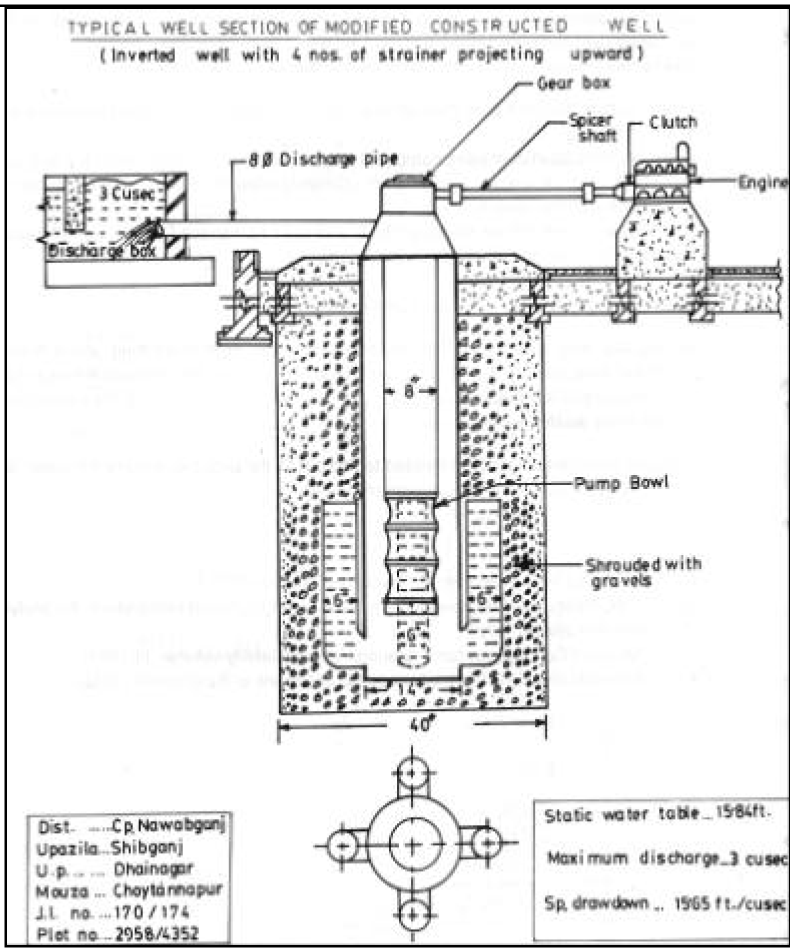
4.2 Well rehabilitation

STWs are cheap to install and, if well performance deteriorates, the solution is usually to drill a new one. For DTWs, well construction is expensive and if the performance of the well deteriorates, then well rehabilitation recommended. Rehabilitation is the process of restoring the well to its original performance.

Box 14: Main types of DTW in Bangladesh

The main types of well are single well shaft driven turbine and submersible wells, though designs have been modified by BMDA to increase discharge in poorer yielding aquifers.





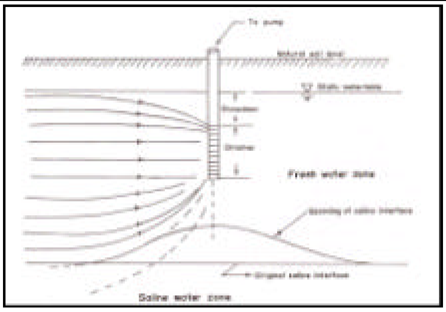
LEFT: Normal design of DTWs in Bangladesh

RIGHT: Modified design of wells in Barind area of Bangladesh. Greater screen area for same depth provides greater discharge.

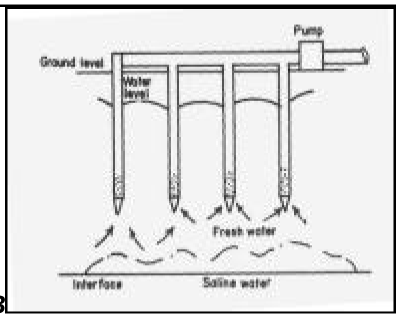
Box 15: Main types of DTW in Pakistan

Main types of DTW in Pakistan are the single well shaft driven turbine SCARP wells (left) and the single well submersible pumps(in Balochistan under construction (middle) and operation (right))

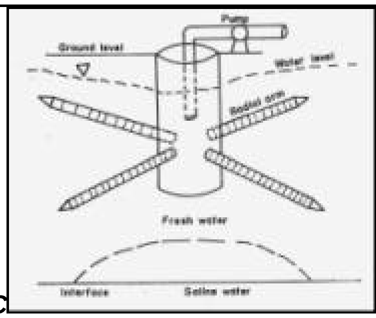
Many areas of Pakistan have areas of fresh groundwater over saline groundwater. The wells shown below are the most common solution to freshwater 'skimming': A – single strainer well, B – Multi-strainer well, C – Radial collector well, D – Re-injection well, and E – 'Scavenger' well (see IWASRI, June 1998, for thorough evaluation of the performance of these wells).



A



B



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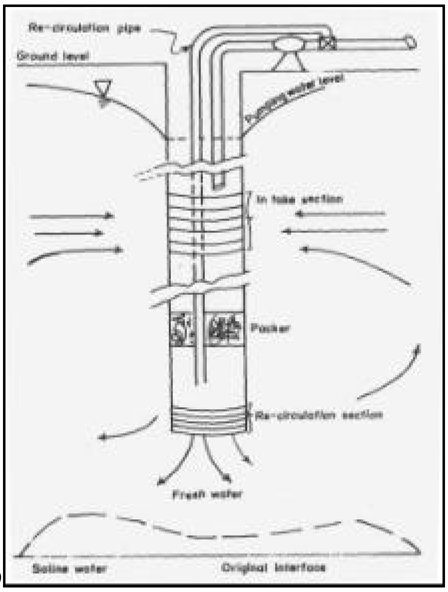
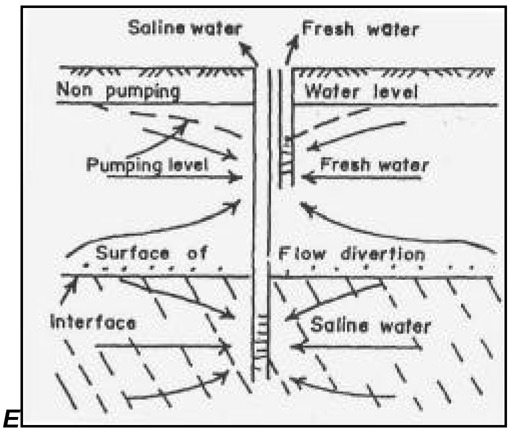


D



E

4.2.1 Identifying a problem

Concise guidelines: 'Monitoring, maintenance and rehabilitation of water supply boreholes', by CIRIA, UK (see CIRIA, 1995, in 'Guidelines Publications' in the references).

The need for rehabilitation will depend on the awareness of a deterioration in performance. The method of rehabilitation will depend on what is causing the performance of a well to deteriorate.
Deterioration in performance can be due to two main factors - aquifer losses and borehole losses. Borehole losses are attributable to a problem in the well and are the ones that may result in the need for rehabilitation of the well. Aquifer losses would need regulation for aquifer management solutions.

In Pakistan, IWASRI have produced a 'Review of Investigations into the causes of tubewell deterioration and rehabilitation trials' (see IWASRI, 1997, in 'Guidelines Publications' of the references).

4.2.2 Remedying the problem

Many processes can be treated through the use of high pressure jetting, brushing, or airlift pumping and surging to loosen and lift material from the well. If well performance has declined, it is not clear what is the cause and this equipment is available it is worth trying these methods to try and enhance performance.

More sophisticated rehabilitation methods shown in CIRIA,, 1995.

4.3 Pump manufacture and selection

Normally agencies invite tenders to procure the pumping unit with a pre-determined schedule. The quoted price is the main or sometimes only criteria for selection of the pump. This should not be the only criteria. Good practice in pump selection is provided by BMDA, who incorporated a clause for reducing its operating cost in respect of electricity consumption. For evaluation of the bid, price and also the electricity consumption for the operating period is considered.
Criteria are:
- capital cost;
- minimum of 60% efficiency; and
- least energy consumption per hour.

As a result, submersible pump manufacturers have become more attentive to their products and have been encouraged to improve their expertise.

4.4 Prime mover manufacture and selection

The biggest shortcoming is not matching HP to the design discharge of the well. The same principles apply to the selection process for suction mode power requirements detailed in section 3.6 above and in the Guidelines.

5. CONVEYANCE SYSTEMS

From the survey of farmers in Bangladesh and Pakistan, the single biggest improvement that farmers said could be made to their groundwater irrigation system was to their conveyance system. This is partly due to the fact that it is the most visible reason to them for not getting as much water as they would like, but also because there are considerable inefficiencies within the conveyance systems. There are four main types of conveyance system available: unlined and lined earthen channels, and buried and surface pipe systems. Within these main types, materials and designs may differ considerably as shown below.

Guidelines on conveyance systems produced by Gisselquist (1989), van Bentum and Smout (1994) and RDA (1999). See 'Guidelines Publication' in references.

5.1 Considerations in choice of conveyance system

When considering the choice of conveyance systems, there are four main issues to consider:

- the physical environment in which the conveyance system is located;
- the size of the command area;
- the 'transit efficiency' of the conveyance system (i.e. the percentage of which entered the system leaving the system); and
- the cost of the system.

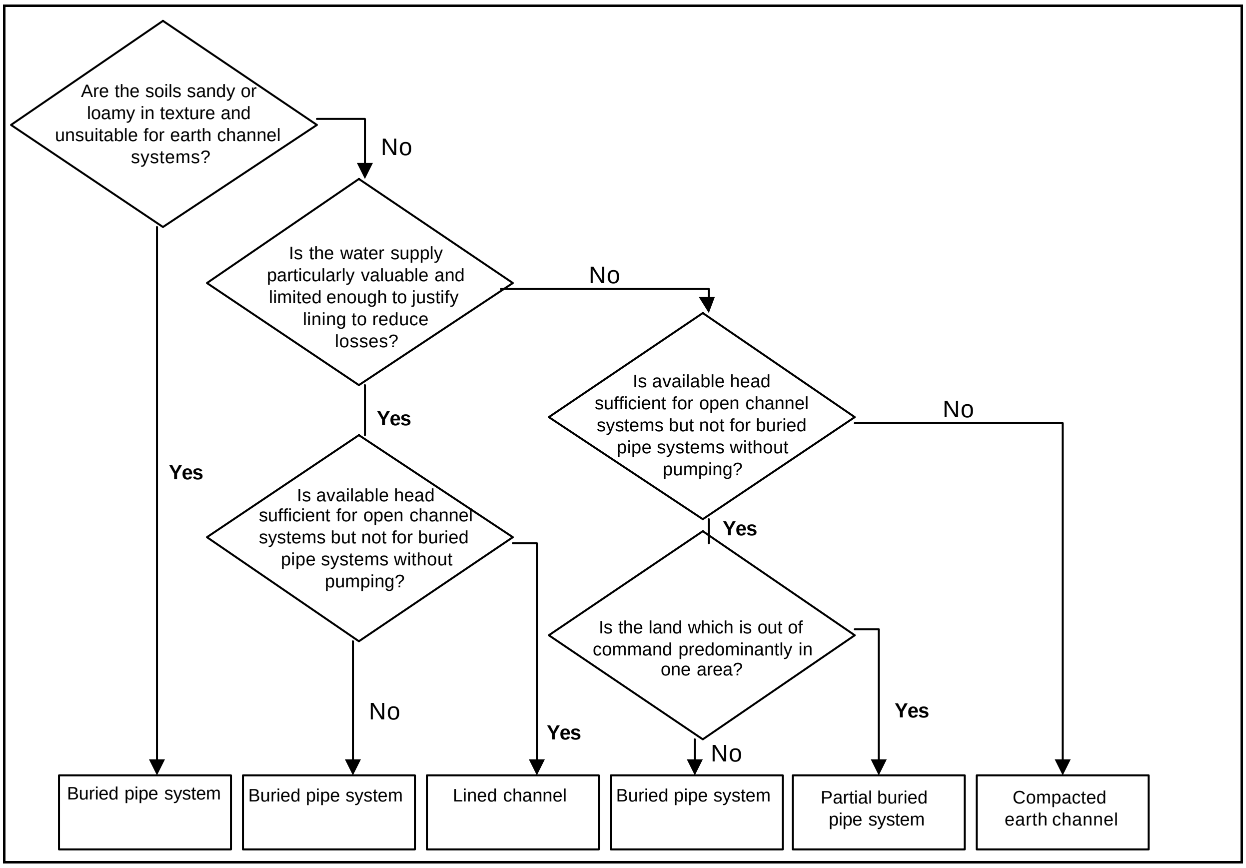
There is a trade off between performance and cost and the choice will often depend upon the management system.

If physical conditions in the area in which the system is located were the only criteria, then van Bentum and Smout (1994) neatly describe the decision-making process and most appropriate system in a flow chart which is shown in Box 16. These prescribe preferred options for different soil types, topography and command areas. The size of the command area is a key feature not only in defining the potential need for different types of conveyance system, but also in terms of generating sufficient finances to pay for the system.

Each of the main types of conveyance system has its own standard of performance, in terms of transit efficiency and an associated cost, and these are shown for different types of system and for different materials in Box 17. There is a trade off between performance and cost and the decision will often depend upon the management system in place.

Many farmers use unlined earthen channels because they perceive all alternatives to be more expensive. Systems are coming onto the market that are cheaper and have higher transit efficiencies. Given that conveyance systems are seen as a

Box 16: Flow chart for selecting conveyance system, based upon physical context



(after van Bentum and Smout, 1994)

Box 17: Performance and costs of different conveyance systems

Type of system	Materials	Transit efficiency %	Capital costs (Tk/ running m)	Annual maintenance costs (Tk/ running m)
Compacted earth channel		50	20	20
Lined channel	Pre-cast CC slab (trapezoidal)	70	120	5
Lined channel	Pre-cast asbestos sheet (trapezoidal)	70	300	12
Lined channel	Pre-cast ferro cement (trapezoidal)	70	170	9
Lined channel	Pre-cast ferro cement (semi-circular)	70	160	8
Lined channel	Cast in-situ CC (rectangular)	70	122	6
Buried pipe system	Asbestos	90	350	-
Buried pipe system	PVC	90	300	-
Buried pipe system	CC	80	250	-
Surface pipe system	Rubber	90	35	-
Surface pipe system	High density polyethelene	90	15	-

major problem for farmers, education on alternatives is a priority. This could potentially be done by credit agencies who could advise/ensure that an appropriate system is developed as part of the loan agreement. Dealers can also play an important role in providing advice.

In rural Balochistan, where many submersible pumps are now being installed to pump water from great depths, they suffer from persistent low voltage and can only achieve low discharges. Where this is the case, many farmers have installed lined ponds within the conveyance system so that they can pump overnight and allow the pond to fill and use the greater volume of water for irrigation the following day. The pond is usually located close to the village/house, which is also usually the highest part of the conveyance system, and is also used for washing and bathing.

6. TECHNICAL CHOICES AT THE POINT OF TRANSFER

6.1 Well and pumping technology

If technology is to be transferred from one sector to another, or from one form of management to another, then it is important to consider the following questions:

- ***What is the condition of the well and the pumping technology?*** Technology that has been installed in one sector and being transferred to another is likely to have been operating for several years. This may lead to increased risk of breakdown and decrease in performance. Attempts should be made to ensure that the technology is in good working order, or that support services are in place to supply technical assistance.
- ***How affordable is the technology for the transferees?*** Much of the DTW technology that is in the hands of the public sector is expensive to run and to maintain. If the public sector have been making a loss and are transferring technology to reduce their losses, then the chances of the recipients making it profitable are also slim. The PPSGDP in Pakistan have got over this by giving the farmers options which they will select according to their resource base:

  - keep the DTW technology;
  - keep the well, receive a new suction mode pumpset;
  - receive a new well and pumpset.

- ***What is the technical knowledge of the transferees?*** Many projects train transferees in pump operation and maintenance but do not even consider the wider technical knowledge required in the long term for sustainable operation. This knowledge includes monitoring techniques (for all components of the system) and access to/procedures for well maintenance and rehabilitation. This is particularly important in areas with 'aggressive' groundwater which can damage well components.

6.2 Energy sources

When transferring technology a certain amount of strategic research should be carried out to ensure that the transferees receive optimum usage of the well at minimum cost. Diesel engines for DTWs are expensive to run and maintain and many diesel powered pumps from DTWs have gone out of action because of this expense. Electricity is generally cheaper but is unreliable in both Bangladesh and Pakistan, causing damage to motors and reducing irrigation time. Electrification may be a solution at the point of transfer but it must be ensured that present or near future electrification plans will meet the demands for energy. In both cases, it must be ensured that repair and maintenance facilities, in whichever sector, are available to farmers, along with spare parts.

Solar energy is still too expensive an option for the amount of energy required for groundwater irrigation at this stage.

7. PUBLIC/PRIVATE SECTOR SUPPORT

7.1 Government

7.1.1 Support services

Governments must ensure that support services are in place before technology is handed over to the farmers. In the past support services have often gone along with the Government's ownership of the technology. Government's should either provide their own support services, for which charges may be made, or actively encourage private sector support services through training and financing (loans).

Where private sector support services are present then Government's should ensure that they are providing the correct services and provide training where needed.

7.1.2 Monitoring, dissemination and regulation

There are activities which the Government has a responsibility to perform. Among these are monitoring of groundwater (levels and quality), dissemination of groundwater information and regulation where required. There is currently no agency in either Bangladesh or Pakistan charged exclusively with this task, at a time when the need for these activities is greater than ever.

7.1.3 Government and the private sector

Governments should look to work with manufacturers of higher quality products in the promotion of the technology and the concepts attached to savings in total costs afforded by greatly reduced operating costs.

7.2 Manufacturers

In both countries there is a wide variety of quality in technology manufacture, installation and operation. The higher quality manufacturers have been withdrawing from the agricultural sector because they cannot compete on cost. They should be encouraged and supported to demonstrate to farmers that the use of their equipment will result in overall cost savings. Regulation of this sector is almost impossible and changes are only likely to occur if they are demand led.

7.3 Traders

Traders are usually just that and no more. Many traders in groundwater irrigation equipment offer this as one of many products in their store. They usually have no knowledge of what the farmers need and little advice, pre- or post-sale. Traders are an important contact point between farmers and other agencies. NGOs, manufacturers, and Governments should use as information disseminators.

7.4 NGOs

Much is said of NGOs in the 'Affordability' and 'Manageability' sections of the Reference Manual and Guidelines (where they are most important). However, NGOs can play a role in ensuring that farmers that they are either supporting or financing receive the best technology and the best advice possible. For example, if NGOs were technically prepared, then they could possibly provided credit only for particular equipment, or they could advise beneficiary farmers on methods of equipment installation and operation.