DEVELOPING GROUND WATER AND PUMPED IRRIGATION SYSTEMS

Nile Basin Initiative – NELSAP

Regional Agricultural Trade and Productivity Project (RATP)

Training Manual 6

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Developing Ground Water and Pumped Irrigation Systems

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Nile Basin Initiative (NBI)
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Bancy M. Mati

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Illustrations and diagrams drawn by: Munene M. Muverethi

Contacts:
NELSAP/Regional Agricultural Trade and Productivity Project
Quartier Kigobe Sud, Kigobe Main Road, Plot No: 7532/C
P.O Box: 4949
Bujumbura- BURUNDI

About this Training Manual

The Nile Basin Initiative (NBI) is a partnership of the riparian states (Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda**,** Eritrea is participating actively in the NBI as an observer) that seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security through its shared vision of "sustainable socioeconomic development through the equitable utilisation of, and benefit from, the common Nile Basin water resources". NBI's *Strategic Action Program* is made up of the *Shared Vision Program (SVP) and Subsidiary Action Programs (SAPs)*. The SAPs are mandated to initiate concrete investments and action on the ground in the *Eastern Nile (ENSAP) and Nile Equatorial Lakes sub-basins (NELSAP).*

NELSAP through its sub basin programs implements pre-investment programs in the areas of power, trade and development and natural resources management. As part of its pre-investment framework, the Regional Agricultural Trade and productivity Project (RATP), in concert with the NELSAP, intends to promote and disseminate best practices on water harvesting and small scale irrigation development as a contribution towards agricultural development in the NEL Countries. NELSAP has previously implemented completed a project called Efficient Water Use for Agriculture Project (EWUAP). One of the recommendations of EWUAP was the need to develop Training/Dissemination materials on "*adoption of low cost technologies for water storage, conveyance, distribution, treatment and use for agriculture that can be adapted by communities and households of the rural and peri-urban poor*". This Training Manual is the initiative of NELSAP, for that purpose.

This Training Manual summarizes the methods of developing ground water resources for irrigation and the use of pumps. It presents the planning, design, development, operations and maintenance of ground water and pumps, and the major factors considered. The Manual is meant to improve the skills of engineers, technicians, extension workers, managers and practitioners of irrigated agriculture, especially those working in smallholder irrigation in Africa. More specifically, the manual equips the reader with knowledge on how to (i) identify appropriate ground water resources and their development for irrigation, (ii) select a suitable pump and plan appropriate pumping mechanisms for irrigation, and (iii) plan and design pumped irrigation systems. This Manual is meant to inform, educate, enhance knowledge and practice targeting smallholder irrigation in the NEL region. The information contained here is not exhaustive and readers are encouraged to seek further information from references cited in this publication and elsewhere.

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Glossary of Key Terms

Term	Definition/Brief Description
Annular space	Small, ring-shaped space between pipe and ground, formed when a pipe is placed in the ground.
Aquifer	A permeable stratum or geological formation of a permeable material, which stores water and is capable of yielding appreciable quantities of ground water.
Artesian aquifer	A permeable water-bearing formation situated between two layers of much lower permeability. It is also known as a confined aquifer.
Borehole	A narrow well sunk through an impermeable stratum to draw water from a relatively deep confined aquifer. It is also known as tube well, driven well, artesian well or deep well.
Contaminant	An impurity which makes water unfit for human and livestock consumption, domestic use or for irrigation.
Drainage	The process of managing and/or removing excess surface water and controlling water logging from shallow water tables.
Flood irrigation	The application of irrigation water where the entire surface of the soil is covered by ponded water.
Flow rate	The rate of volume discharge through the pump (in litres per second)
Gravity flow	Flow of water from high level to low by natural forces.
Gravity-fed irrigation	Irrigation in which water is available or made available at a higher level so as to enable supply to the land by gravity flow.
Groundwater	Water that exists beneath the earth's surface in underground streams and aquifers.
Head	The energy supplied to liquid (per unit weight) by the pump. It is expressed as a column height of liquid (either vertical lift or suction), given in metres of head (m)
Impervious	Material or layer that does not allow liquid to pass through.
Infiltration	The process of water passing from the surface, through the soil, and into the ground.
Intake	The point where water enters a supply system.
Irrigation	Any process, other than by natural precipitation, which supplies water to crops or any other cultivated plants.
Marginal-quality water	This term includes urban wastewater, agricultural drainage water, and saline/sodic surface water and groundwater
Operating temperature	The range of temperatures at which the pump can operate or the temperature limit of the media handled by the pump.
Outlet diameter	The size of the discharge or outlet connection of the pump. It determines the size of connections made between the pump and the system.
Overhead irrigation	A method of irrigation water application in which the water is ejected into the air to fall as spray on to the crops or on the ground surface.
Perched aquifer	A special case in which water is found to occur within an unconfined aquifer, which is normally limited in size, as the aquifer lies on an impervious layer higher than the area's general water table.
pH	A measure of acidity or alkalinity of a liquid. A pH of 7.0 is neutral; a pH less than 7.0 is acidic; a pH greater than 7.0 is alkaline.

Term	Definition/Brief Description
Power rating	The power required to operate the pump, measured in Watts (W) or Kilowatt hours (KWH)
Pressure	The force per unit area generated by the pump used to describe the performance of most positive displacement and some dynamic pumps. It is usually given in bars
Recycled water	Water that has already been diverted and used at least once. Recycling takes place, for example, by reusing drainage water or urban waste water.
Salinity	Soils having high concentration of soluble salts. Salinity may be caused by the presence of salts in the soil or from irrigation water.
Salinization	The increased accumulation of excessive salts in land and water at sufficient levels to impact on human and natural assets (plants, animals, aquatic ecosystems, water supplies or agriculture).
Shallow well	A well that draws water from an unconfined aquifer or shallow ground water table. Also known as dug well.
Surface irrigation	Application of water by gravity flow to the surface of the field. Examples are: basin, border, furrow, corrugation, wild flooding, and spate irrigation.
Unconfined aquifer	A permeable formation in which groundwater is in contact with a free surface open to the atmosphere – water in is at atmospheric pressure.
Waste water	The water which is of no further immediate value to the purpose for which it was used or in the pursuit of which it was produced because of its quality, quantity or time of occurrence.
Waste water treatment	Process to render waste water fit to meet applicable environmental standards or other quality norms for recycling or reuse and irrigation.
Water control	The physical control of water by measures such as conservation practices on the land, channel improvements, and installation of structures for reducing water velocity and trapping sediments.
Water table	The top or upper limit of an aquifer or ground water.
Water treatment	A process in which impurities such as dirt and harmful materials are removed from water.
Water withdrawal	The gross amount of water extracted from any source, either permanently or temporarily, for a given use, including irrigation. It can be either diverted towards distribution networks or directly used.
Well	A hydraulic hole, usually vertical, excavated in the earth for the purpose bringing ground water to the surface. Wells may be classified as either open wells or tube wells.

1. INTRODUCTION

1.1 Ground water resources

Ground water is the water found underground, which occurs in the saturated zone of variable thickness and depth, below the earth's surface. Ground water exists within unconsolidated layers and water-bearing formations below the ground that make up underground reservoirs. These reservoirs may be near the earth's surface, such as high water tables, or in very deep sub-terranean aquifers. Ground water is normally utiliseutilised by excavating shallow wells and boreholes, which are subsequently used for irrigation (Figure 1.1). Various lifting devices and pumps are needed to bring the underground water to the surface. For certain areas, groundwater is the most viable source of freshwater for drinking and/or irrigation.

Figure 1.1 (a) Shallow ground water resources used for irrigation **(b) Vegetable crop irrigated with ground water** *(Photos by B. Mati)*

Compared with conventional surface water irrigation systems, groundwater irrigation may offer more reliable supplies, lesser vulnerability to droughts and easy accessibility for individual users. Over the last two decades, groundwater irrigation has become commonplace in many arid and semiarid zones. This is largely due to advances in drilling and pumping technologies, and development of hydrogeology. Moreover, groundwater is generally less prone to pollution and sedimentation than surface water. Intensive groundwater use can lead to increase in depth of the water table or depletion of the ground water resources. Abstraction costs increase with depth as more energy is required for pumping and drilling of deeper wells may be required. While irrigation cost also increases. Despite the economic importance of groundwater irrigated agriculture, farmer-scale development has not been coupled with an adequate management on the part of governmental water authorities.

1.2 Occurrence of ground water

Ground water has formed over millions of years. It emanates from rainfall that passes through the soil voids and cracks in rocks to percolate below the ground surface. These voids are generally inter-connected, permitting the movement of ground- water. But in some rocks, they may be isolated, thus preventing the movement of water between the interstices. Hence it is evident that the mode of occurrence of the ground water depends largely upon the type of sub-terranean formation and the geology of the area. The occurrence of ground-water depends mainly on two geological factors:

(i) the porosity of the formation, and
(ii) permeability of the rocks.

All earth materials, from soils to rocks have pores. Ground water occurs when the pores are completely saturated with water which can be easily extracted. When close to the ground surface, such a formation is called a water table. The saturated formations are classified into four categories: aquifer, aquitard, aquiclude and aquifuge as follows:

1.3 Aquifers

An aquifer is a permeable stratum or a geological formation of a permeable material, which stores water and is capable of yielding appreciable quantities of ground water. The terms 'appreciable quantity' is relative, depending upon the availability of ground water. In the regions, where ground water is available with great difficulty, even fine-grained materials containing less water quantities are considered to be aquifers. Most important formations are unconsolidated sands and gravel sandstones (Table 1.1).

Table 1.1: Typical porosities and permeabilities for various water-bearing materials

Lithology	Porosity (%)	Permeability (m/day)
Clay	42	10-8-10-2
Silt/Fine sand	43-46	10-1-5
Medium sand	39	5-20
Coarse sand	30	20-100
Gravel	28-34	100-1000
Sandstone	33-37	10-3-1
Carbonate (limestone, dolomite)	26-30	10-2-1
Fractured/Weathered rock	30-50	0-300
Volcanics, (e.g. basalt, rhyolite)	17-41	0-1000
Igneous rocks (e.g. granite, gabbro)	43-45	<10-5

Source: ICRC, 2010

The amount of water yielded by a well excavated through an aquifer depends on many factors, some of which, such as well diameter are inherent in the well itself. But all other things being equal, the permeability and the thickness of the aquifers are the most important. Aquifers vary in depth, lateral extent, and thickness; but in general, all aquifers fall into one of the two categories:Unconfined or non-artesian aquifers, and,

(i) Confined or Artesian aquifers.

1.3.1 Unconfined aquifers

Unconfined or non-artesian aquifers are permeable formations in which groundwater possesses a free surfaces open to the atmosphere. Top of the aquifer is the water table and above the water table is the vadose (soil or aerated) zone. It is the top most water bearing stratum, having no confined impermeable over burn (i.e. no aquiclude) lying over it. The ordinary shallow wells of 2 to 5m diameter, which are constructed to tap water from the top most water bearing strata.ie from the unconfined aquifers, are known as unconfined or non-artesian wells. The water level I these wells will be equal to the level of the water table. Such wells are, therefore, also known as shallow wells or gravity wells.

1.3.2 Confined aquifers

A confined (or artesian) aquifer is a permeable, water-bearing formation sandwiched between two layers of much lower permeability. Thus, the water is usually under pressure. Water levels in wells penetrating confined aquifer rise above the top of aquifer so the aquifer is also referred to as artesian aquifer. The imaginary surface to which water rises in wells tapping artesian aquifer is called the piezometric surface**.** Artesian aquifers are classified as leaky or non-leaky depending upon whether groundwater in the aquifer is confined by aquitards or aquicludes and when an aquifer is confined on its upper and under surface by impervious rock formation (i.e. aquiclude).

The question whether it will be a flowing wells or a non flowing artesian well depends upon the topography of the area and flowing artesian well depends upon the topography of the area and is not the inherent property of the artesian aquifer. In fact if the pressure surface, lies above the ground surface , the well will be a flowing artesian well; whereas, if the pressure surface, the well will be a flowing artesian well, whereas, if the pressure surface is below the ground surface, the well will be artesian but non-flowing, and will require a pump to bring water to the surface. Such non –flowing artesian wells are sometimes called as sub-artesian wells.

1.3.3 Perched aquifers

A perched aquifer is a special case in which some quantity of groundwater is held above an impervious stratum and is not connected with the main water table. Such a water table is called a perched water table. Not much water can be drawn from such an aquifer as the quantity of water available is limited to the volume contained above the impervious stratum.

1.3.4 Other formations related to ground water

a) Aquiclude

An aquiclude is a geological formation which is essentially impermeable to the flow of water. It may be considered as closed to water movement even though it may contain large amounts of water due to its high porosity. Clay is an example of an aquiclude. An aquiclude is usually found adjacent and aquifer.

b) Aquitard

An aquitard is a formation through which only seepage is possible and thus the water yield is insignificant compared to an aquifer. It is partly permeable. A sandy clay unit is an example of an aquitard. Through an aquitard, appreciable quantities of water may leak to an aquifer below it.

c) Aquifuge

An aquifuge is a geological formation which is neither porous nor permeable. There are no interconnected openings and hence it cannot transmit water. Massive compact rocks without any fractures are an aquifuge. However, they constrain the water bearing formations.

1.4 Use of groundwater for Irrigation

The availability of groundwater can become a reason for the use of an irrigation scheme. Groundwater-based irrigation is often located in areas where both aquifer and climatic conditions are favourable, and where groundwater recharge compensates groundwater extraction. Pumping costs and the relatively stable surface water availability may also explain the preferred use of surface water. The preference for groundwater or surface water use is also related to tenancy, with private schemes more often irrigated with groundwater and public or state farms more often irrigated with surface water. Another factor is crop type, with vegetables often irrigated with groundwater and staple cereal crops cultivated at the large scale more often irrigated with surface water. This is because irrigation is used in general to intensify agricultural production by reducing drought stress which results in higher crop yields. Such intensification is necessary in particular in highly populated areas because of the low per capita availability of agricultural land.

1.5 Advantages and disadvantages of ground water for irrigation

Irrigation with ground water has several benefits as well as limitations. A comparative analysis is provided in Table 1.1, based on development costs and adaptability to smallholder irrigation.

Table 1.1 Comparative benefits of developing various water sources for irrigation

Water Source	Comparative capital cost	Comparative running costs	Comments / Requirements
Rainwater catchment Medium size	Medium Storage ponds, dams needed.	Low	Makes use of excess rain/runoff Good water quality for irrigation No or few salinity problems Best option wherever possible
Spring protection	Low Medium, if piped to community	Low	Needs a reliable spring flow throughout the year Possibility for gravity system
Shallow wells	Low (local labour) Hand pump needed.	Low	Abstraction can be by bucket, manual or motorized pumps Energy needed for lifting water Salinity check
Boreholes/ Tube wells	High Well drilling equipment needed.	High Motorized pumping	Uses deep aquifer. Energy needed for pumping Needs maintenance of mechanical pumps Low quantities of water. Possibility of salinity issues.
River / lake abstraction	High Design and construction of intake.	High Treatment and pumping usually needed	Possibility of gravity irrigation Large quantities of water. Few salinity problems. Best option wherever possible

1.5.1 Advantages of ground water irrigation

Compared to surface water sources, ground water has the following advantages

(i) Depending on locality, ground water can be cheaper than surface water sources
(ii) Ground water is easier to develop for individual irrigators
(iii) Where irrigators are scattered and not easy to develop canals, ground water may be a better alternative.
(iv) Irrigators can have their own private wells and thus do not have to depend on centralized water delivery systems
(v) The supply of water from a well can be started as soon as required and can be stopped at any moment, thus taking advantage of momentary rainfall.

(vi) Most wells are generally lined, thus resulting in lesser percolation losses.
(vii) Pumping from ground water helps in lowering the ground water-table, and thus helps in reducing water logging, which may be an added advantage in certain areas.
(viii) The well water which is warmer in cold weather and colder in hot weather is more suitable to crops.
(ix) The well water may be cleaner than from surface reservoirs and thus, the irrigation scheme may be combined with rural/urban water supply system.
(x) There is usually no need for land acquisition or taking up space on the land, when using ground water sources.
(xi) Ground water is easier to recharge from natural rainfall, thus making it more sustainable.

1.5.2 Disadvantages of ground water

(i) Ground water always requires a pump or lift mechanism, hence energy to supply water from source to the field, unlike surface water systems which sometimes utilise gravity.
(ii) Surface water supplies enable the combination of irrigation with flood control and/or hydropower projects, thus giving added benefits and enabling the multipurpose use of water.
(iii) Developing boreholes can be more expensive than surface water supplies
(iv) Volumes of water extracted from wells and boreholes provide less as compared to surface methods.
(v) Depending on aquifer type, the water in some boreholes may be finite, and thus unsustainable.
(vi) Frequent breakdown of power and motor parts cause large-scale interruptions in the working of boreholes.
(vii) Ground water is prone to pollution from pesticides and salts such as nitrates. Salt accumulation is of particular concern in arid areas where irrigation is the main source of water.

2. GROUND WATER QUALITY AND MANAGEMENT

Ground water sometimes contains dissolved minerals which could be beneficial or harmful to irrigated agriculture. Groundwater can be easily polluted from various effluents, such as from commercial and industrial wastes. Other common problems with ground water quality for irrigation include salinity, sodicity and pH levels. Ground water usually has pH values ranging between 7.1 and 8.5, indicating slightly alkaline to alkaline nature of groundwater. Salinity, sodicity and toxicity generally need to be considered for evaluation of the suitability of the quality of groundwater for irrigation. Salts are highly harmful since they limit growth of plants physically, by restricting the taking up of water through modification of osmotic processes. Also salts may damage plant growth chemically by the effects of toxic substances upon metabolic processes.

2.1 Ground water pollution

In many countries, groundwater and the aquifers that host it are inherently vulnerable to a wide range of human impacts. The development of mechanised pumping has induced widespread draw-down externalities, including the depletion of important shallow aquifers. The disposal of human and industrial waste and the percolation of pesticides and herbicides have degraded many aquifers beyond economic remediation. Groundwater exploitation has resulted in various consequences ranging from the drawdown of water levels beyond the limits of the wells. There are also effects on environmental health resulting from the intrusion of poor-quality water. The impacts of over abstraction and water-level declines have been reported widely. Over-abstraction can lead to a wide range of social, economic and environmental consequences including: critical changes in patterns of groundwater flow to and from adjacent aquifer systems; declines in stream base flows, wetlands, etc. with consequent damage to ecosystems and downstream users; increased pumping costs and energy usage; land subsidence and damage to surface infrastructure; access to water for drinking, irrigation and other uses, particularly for the poor and increases in the vulnerability of agriculture (and by implication food security) and other uses to climate change or natural climatic fluctuations as the economically accessible buffer stock of groundwater declines.

Pollution is one of the most serious challenges to the sustainable management of groundwater resources. The significance of pollution for groundwater resources is increased by the long time scale at which processes affecting groundwater function. Replenishment times for groundwater systems are very much longer. This is because water usually takes many years to move through the soil and unsaturated zone of the aquifer. Not all aquifers are equally vulnerable to pollution. Those where fractures or cavities permit rapid flow tend to be more vulnerable than those where water flows slowly through porous media and more opportunities exist for attenuation of pollutants. However, once polluted, slow movement of groundwater through a porous aquifer generally makes cleanup difficult, expensive, and in some cases impossible. Beyond the inherent vulnerability of aquifers to contamination, much depends on the nature of pollutant sources. Contaminant behaviour varies greatly with respect to the specific transport properties in each aquifer system. In addition, the range of contaminant types is increasing as new products appear in effluent disposal and land application. Three main sources of groundwater pollution are: agricultural, urban and industrial.

2.1.1 Salinity hazard

The suitability of groundwater for irrigation depends on the mineral constituents of the water on both the plant and the soil. Salinity content is measured using parameters such as Electrical Conductivity (EC), percent sodium, magnesium hazard and Sodium Absorption Ratio (SAR). Excess salt increases the osmotic pressure of the soil solution that can result in a physiological drought on the plant. Even though the field appears to have plenty of moisture, the plants wilt because insufficient water is absorbed by the roots to replace that lost from transpiration. The total soluble salt content of irrigation water generally is measured either by determining its electrical conductivity (EC), reported as micromhos per centimetre, or by determining the actual salt content in parts per million (ppm).

Table 2.1 Salinity and alkali hazard classes after

Quality of water	Electrical conductivity (µmhos cm $^{-1}$)	Sodium adsorption ratio (equivalent per mole)
Excellent	<250	<10
Good	250-750	10-18
Doubtful	750-2250	18-26
Unsuitable	>2250	>26

Source: Richards (1954)

2.1.2 Alkali hazard

The main problem with a high sodium concentration is its effect on the physical properties of soil. In addition, sodium contributes directly to the total salinity. A high sodium content (SAR) leads to development of an alkaline soil. Irrigation with Na-enriched water results in ion exchange reactions: uptake of Na^+ and release of Ca^{2+} and Mg^{2+}. This causes soil aggregates to disperse, reducing its permeability. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed as the sodium adsorption ratio (SAR).The following formula is used to calculate SAR:

$$\%Na = \frac{Na + K}{Ca + Mg + Na + K} X100$$

Ions in the equation are expressed in milli-equivalent per litre. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soils. Continued use of water with a high SAR value leads to a breakdown in the physical structure of the soil caused by excessive amounts of colloidal absorbed sodium. This breakdown results in the dispersion of soil clay that causes the soil to become hard and compact when dry and increasingly impervious to water penetration due to dispersion and swelling when wet. Fine-textured soils, those high in clay, are especially subject to this action.

2.1.3 High sodium content

The sodium in irrigation waters is also expressed as percent sodium or soluble-sodium percentage (%Na) and can be determined using the following equation:

$$sodium\ adsorption\ ratio\ (SAR) = \frac{Na}{\sqrt{Ca + Mg}/2}$$

Where all ionic concentrations are expressed in milli-equivalents per litre.

2.1.4 Magnesium hazard

Although calcium and magnesium ions are essential for plant growth but they may associated with soil aggregation and friability. Water contains calcium and magnesium concentration higher than 10 meq l^{-1} (200 mg l^{-1}) cannot be used in agriculture.

2.2 Estimation of groundwater use

There are various methods used to estimate the quantities of water extracted from ground water. Unlike surface water which is easy to measure, ground water flow is usually invisible. Groundwater use estimates in large irrigated schemes are often based on the number of observation wells, their discharge capacity, and their operational hours. The operational hours are calculated from electricity/fuel usage or through surveys in the irrigation scheme. Such estimates only provide a range of groundwater extraction values and do not account for groundwater recycling. Commonly used methods of estimating ground water flows include:

2.2.1 Water balance methods

Water balance methods involve hydro-geological modelling just like with surface water balance. The ground water flows are estimated by taking consideration of all inflows, storages and outflows. There are three basic categories of water balance models: soil water balance, river channel water balance and groundwater (saturated zone) balance. These methods are applicable for both point and basin scale estimates. They are not very accurate and thus are used where data scarce is unavailable especially in semi-arid areas. The major advantage of water balance methods includes the fact that they use readily available data, can be applied rapidly, and account for all water entering and leaving the system. However, a major disadvantage of these methods is that recharge is the residual term, so their accuracy depends upon the accuracy of all the other water balance terms. In arid and semi-arid zones, groundwater recharge is heterogeneous in both time and space, and thus quite difficult to estimate accurately.

2.2.2 Direct measurements

Ground water flow can be estimated using direct measurements. This can involve use of lysimeters. A lysimeter is a containerised method in which undisturbed soil profiles are put and measured quantities of water added and the outflow collected and measured. Lysimeters are potentially the most accurate method for estimating recharge, but are difficult, time consuming and expensive to set-up. Their results represent point scale information, and their application is limited to experimental studies. They are more suitable for humid climates than for arid to semi-arid climates. Because the recharge process is quick in humid regions, data collected over a short time period are sufficient to get complete insight into the recharge process.

2.2.3 Tracer techniques

Tracer techniques involve use of inert isotopes, dyes or allowable salts at some point and following their decay/reduction in concentration as they move through a stratum. Tracers are amongst the most widely used methods for recharge estimation in arid and semi-arid regions. They too, only provide point or field scale information. A significant disadvantage of tracer techniques is that they do not directly measure flows quantities and therefore, may be inaccurate. Also, the residual effects of the isotopes or salts used may pose environmental hazards and strict regulation is needed for their use.

2.2.4 Darcian approach

The Darcian approach analyses the water fluxes in the unsaturated zone. It uses numerical models to assess transient flows and storage change in the aquifer. To extend these models to a region, the area is generally classified into homogenous sub-regions, and these models are used for flow estimations for each sub-region. This method is valid only for field scale studies although it is often used for climate studies. The main advantage of the Darcian method is that it assesses the physical processes of water flow in the unsaturated zones.

2.2.5 Empirical methods

Empirical methods utilise equations derived from factors associated with ground water flow. Ground water recharge is correlated with other variables, such as precipitation, canal flows, soil type and land use. Some of these relationships are site specific and are only used for forecasts, while others can have wider applications. Empirical methods cannot estimate recharge rates under non-conventional conditions; hence, physical approaches for recharge estimation are generally preferred. Thus, they are used to estimate ground water flows in data scarce environments

2.2.6 Remote sensing methods

Remotely sensed data, usually obtained from high resolution satellite imagery and ground based methods such as GPS surveys can also be used to estimate water quantities obtained from ground water. Recent advances in remote sensing techniques make it possible to estimate various hydrological parameters with increasing accuracy, especially in the fields of irrigated area and actual evapotranspiration mapping. Remotely sensed data when combined with hydrological models can provide a relatively accurate indication of ground water use, hence flows estimation.

2.3 Ground water recharge

2.3.1 Ground water replenishment

The original source of all water, including ground water, is precipitation. However, most ground water took millions of years to accumulate while abstraction takes a much short time to deplete these water resources. The sustainable use of ground water must contain plans for its replenishment. Depending on type of aquifer, this can be achieved naturally or through artificial methods. In unconfined aquifers, the rate of ground water recharge varies with the pattern of precipitation, surface runoff and stream flow. It also varies with the intrinsic permeability of the soil and other earth materials through which the water must percolate to reach the zone of saturation. In some places, ground water reservoirs are replenished quickly by the rain falling directly on the land surfaces face above them. In other places, surface water in streams, rivers, canals and lakes feeds the ground water reservoir when water levels in these bodies of surface water are higher than the water the table and the intervening layer is permeable. Replenishment of water when utilising a confined aquifer can be more complicated. The methods of artificial recharge include the following:

2.3.2 Artificial ground water recharge

Just as artificial surface reservoirs are constructed by building dams in order to store the surplus surface waters; in the same manner, artificial underground reservoirs are nowadays developed by *artificial recharge,* for storing water underground. Artificial recharge of ground water can be achieved by diverting runoff into shallow wells or soak-pits (Figure 2.1). The practice is encouraged in modern irrigated agriculture so as to augment the natural underground yield and for management of water supply systems. Artificial ground water recharge is usually necessary because in many cases, the rate of water abstraction exceeds the rate of replenishment by natural flows. For water bearing formations readily recharged from the surface, average abstraction duration can be designed to be equal to average recharge rate but should not exceed it. For deep artesian aquifers where a substantial amount of recharge occurs at a region away from the area where it is used, the abstraction age may exceed recharge in the area. But ground water utilisation in such cases must be on the basis of quantitative estimates of how much of the total ground water is used. In coastal regions, however, the average pumping must be considerably less than the average so as to avoid intrusion of sea water into the ground water reserves.

Figure 2.1 (a) Artificial recharge of ground water from road runoff - see inlet pipe *(Photo by B. Mati)*

2.3.3 Soil and water conservation measures

Proper soil and water conservation measures in the catchment can improve infiltration and is an effective way to recharge ground water reserves, particularly of unconfined aquifers. The amount of rainfall infiltrated into the soil varies greatly with the condition of soil surface and it depends on the slope of the land and field structures like terraces, contours bunds and other structures which tend to hold the runoff water over long period on the surface (Figure 2.2). Ground water recharge works better if the soil and water conservation measures are spread throughout the catchment as part of a more holistic integrated watershed management.

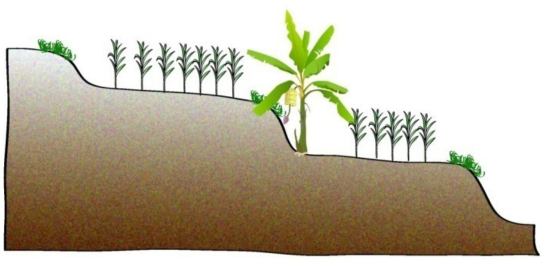


Figure 2.2 (a) Illustration of soil and water conservation for ground water recharge (b) Terraced agricultural land recharges ground water (*photo by B. Mati)*

2.3.4 Diversion of surface flows

Surface flows, whether direct surface runoff or excess stream flows can be diverted into storage reservoirs, unlined open ditches (e.g. cutoff ditched), various types of pits, or shallow wells excavated for the purpose of recharging ground water. The most common artificial methods of ground water recharge are essentially the same as those of surface irrigation, with the difference that in recharge operation the water is allowed on the field for a much longer period. Suitable diversion structures, constructed across a stream channel, cause the water level to rise on the upstream side, which can be diverted to the land surface. This type of application which is generally called water spreading can be broadly classified into:

(i) basin method, and

(ii) furrow or ditch method. Of these, the basin method permits a maximum wetted surface area and is mostly recommended.

a) Basin method

In the basin method, water is diverted to the uppermost of a series of basins or percolation tanks separated from one another by low height levees. The levees generally run on contours. They are constructed with material like stone or boulder will withstand the overtopping of water. In places where such materials are not available, suitable structures are constructed on the levees to allow water to drop from the higher basin to the lower. Basin method is particularly suitable where ground surface is irregular and infested with a number of shallow gullies and ridges.

b) Furrow method

In the furrow method of recharge, water is diverted from a main canal running along a contour into a series of parallel furrows. These furrows differ from irrigation furrows in that they are flat bottomed and shallow to allow maximum possible surface area to come in contact with water. The selection of a particular method of water spreading depends upon factors like topography, slope, and type of soil and cost of labour involved. The selection of sites for water spreading must be made with knowledge of the geologic nature of the ground water potential, so as to obtain efficient utilisation of the storage capacity and of the transmissibility of the aquifers. This is necessary to ensure that the applied water reaches the zone intended to be replenished. The selection should also be made with respect to the texture and structure of the surface soil in order to obtain the most rapid rates of water movement into and through the soil.

2.3.5 Water spreading methods

These are methods that comprise spreading the water over the surfaces of permeable open land (Figure 2.3) and ditches, from where it directly infiltrates to rather shallow aquifers. In this method, water is temporarily stored in shallow ditches or is spread over an open area by constructing low earth dykes (called bunds). The stored water, slowly and steadily, percolates downward so as to join the nearby aquifers. The recharging rate depends upon the permeability of the spread area and on the depth of water stored, and is generally less; say of the order of 1.5 m/day, though rates as high as 22.5 m/day have been possible. Certain chemicals, when added to the soil, may help in increasing the recharging rate and are under research.

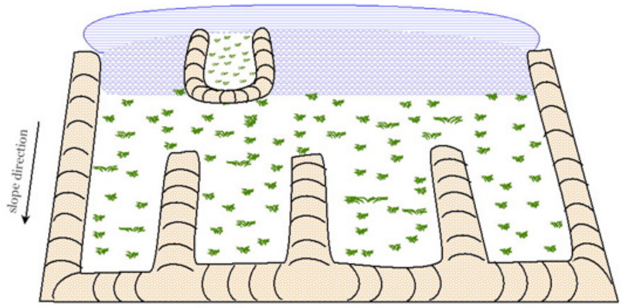


Figure 2.3 (a) Water spreading techniques for rainwater harvesting also recharges ground water	**(b) Shallow basin to collect excess runoff for ground water recharge** *(Photo by B. Mati)*

2.3.6 Recharge wells

In areas where the water bearing stratum is overlain by an impermeable layer, surface methods of recharge may not be suitable. Water may penetrate the top soil and as soon as it strikes the impermeable layer it may flow away as inter-flow and may not join the water table. Depending upon the depth of the impermeable layer, ground water recharge can be done by large pits or wells, the former being used where the impermeable layer is encountered at large depths. Sometimes water is recharged into the soil through tube wells. Recharge by wells are also practiced where the land surface is unavailable for surface methods of recharge because of cultivation requirements or is unsuitable for water spreading as in urban areas. The volume of water recharged by the well or pit method is, however, low and the method is not practiced where surface methods are feasible. This consists in injecting the water into bore holes, called recharge wells. In this method of recharge, the water is, therefore, fed into recharge wells by gravity or may be pumped under pressure to increase the recharge rate, if surface conditions permit. The recharge wells, used for this purpose, are just like ordinary production wells. In fact, the ordinary production wells are many a times directly used for recharge during the off season, when the water is not required for some use.

The recharge-well method is certainly preferred when the water spreading method cannot yield appreciable recharge, because of low permeable areas. High recharge rates can be obtained with these aquifers at any level, and thus, may be used for replenishing deeper aquifers, and also where it is most needed. The water to be used in the recharge wells should, however, be purer than that is required in the first method. This water should be free of suspended matter, so as to avoid clogging of the wells screens. Since the recharge wells inject the water directly into the aquifer, the water used for recharging must also be free from bacteria. Hence, if treated sewage is used for recharge, it should generally be relatively pure.

2.3.7 Percolation ponds

Percolation ponds (or percolation tanks), are small reservoirs constructed for the purpose of harnessing small flows to recharge ground water aquifers (Figure 2.4). They are suited to areas where shallow wells exist and the good water yielding properties of the sub-strata, which are possible to recharge with rainfall. Hydrological surveys are needed before construction of such ponds. Sometimes, percolation ponds are excavate simply to conserve rainfall in a watershed, so to "capture every drop", and to improve water percolation into the soil profile. They are also used as a core component of integrated watershed management activities.

Figure 2.4 Artificial recharge of ground water using percolation pond *(Photo by B. Mati)*

2.3.8 Induced infiltration method

The induced Infiltration method is sometimes used for recharge is that of induced infiltration, which is accomplished by increasing the water-table gradient from a source of recharge. In this method, wells are constructed near the river banks. The percolating water is collected in the well through radial collectors, and is then discharged as recharge into a lower level aquifer for storage.

2.4 Irrigation management practices for groundwater protection

2.4.1 Irrigation scheduling

It is important that when irrigating with ground water, regular assessments of soil moisture and water application rates are conducted. If possible, a functional flow meter and accurate pressure gauge, either at the pump or on the pipeline near the point of discharge, is essential for accurate measurement of irrigation water. It is critical that the determination of the water budget is done systematically and accurately so that the water needs of the crop are met without over-application. Weather patterns should be assessed before each water application and irrigation should not exceed the soil field capacity. For a number of crops, deficit irrigation techniques that leave room in the rooting zone for additional moisture from rainfall have been demonstrated to protect groundwater without yield reductions. Irrigation water should be managed so that stored soil water is at a minimum whenever there is no crop in the field. Irrigation has the potential to meet these variable demands more readily than dryland agriculture, thus maintaining a stable environment for plant growth. Large amounts of unused residual chemicals are not likely to be left in the soil if management results in vigorous plant growth throughout the year. The potential for chemical leaching and ground-water contamination is drastically reduced if proper water scheduling is adhered to.

2.4.2 Conjunctive use of surface and ground water

Conjunctive use involves the coordinated and planned utilisation of both surface and groundwater resources to meet water requirements in a manner where water is conserved. In a conjunctive scheme, during periods of above normal rainfall, surface water is utilised to the maximum extent possible and, where feasible, artificially recharged (pumped into aquifers through wells known as injection wells) into the aquifer to augment groundwater storage and raise groundwater levels (care should be taken to not the raise the levels to the crop root zone). Conversely, during drought periods the limited surface water resources will be supplemented by pumping groundwater, thereby lowering the water levels. However, the cost of setting up such a scheme could be prohibitive for most African countries.

2.4.3 Operation and maintenance

Although the use of ground water is encouraged for irrigation, proper management and maintenance is necessary to avoid degradation of groundwater systems due to over-abstraction and quality changes (pollution, salinity). In general, it is necessary to make use of professional methods and personnel during the design and implementation of ground water based irrigation, to ensure correct and sustainable use of groundwater resources. In particular, there should be coherent planning frameworks to guide all scales of groundwater development and the consequent policy and institutional support to ensure adherence to standards and regulations. As groundwater is part of the larger ecosystem, its abstraction for irrigation should take cognizance of water for other uses and environmental externalities.

3. SHALLOW WELLS

3.1 What is a well?

Water well is a hole usually vertical, excavated in the earth for bringing ground water to the surface. The source of water in a well is an aquifer. There are two broad classes of wells, based on the type of aquifer, they include:

a) Shallow or unconfined wells, also known as water table wells, are those that penetrate into aquifers in which the water is not confined by an overlying impermeable layer. The level at which the soil is saturated is the water table. Pumping the well lowers the water table near it. These wells are particularly sensitive to seasonal changes and may dwindle during dry periods.

b) Deep or confined wells, also known as artesian wells are sunk through an impermeable stratum into an aquifer that is sandwiched between two impermeable strata (aquitards or aquicludes). The majority of deep aquifers are classified as artesian because the hydraulic head in a confined well is higher than the level of the top of the aquifer. If the hydraulic head in a confined well is higher than the land surface it is a "flowing" artesian well.

Two additional broad classes of well types may be distinguished, based on the use of the well:

a) Production or pumping wells – these are, are large diameter (greater than 15 cm in diameter) cased (metal, plastic, or concrete) water wells, constructed for extracting water from the aquifer by a pump

b) Monitoring wells or piezometers - are often smaller diameter wells used to monitor the hydraulic head or sample the groundwater for chemical constituents.

Obviously, a well constructed for pumping groundwater can be used passively as a monitoring well and a small diameter well can be pumped, but this distinction by use is common.

3.2 Types of shallow wells

Shallow wells provide a cheap and low-tech solution to accessing groundwater in rural locations in developing countries, and may be built with a high degree of community participation, or by local entrepreneurs who specialize in hand-dug wells and can be excavated to 60 metres depth. These wells are inexpensive and low tech (compared to drilling) as they use mostly hand labour for construction. Shallow wells have low operational and maintenance costs, in part because water can be extracted by hand bailing, without a pump. The wells can be easily deepened, which may be necessary if the ground water level drops, by telescoping the lining further down into the aquifer. The yield of an existing shallow well can be improved by deepening or introducing vertical tunnels or perforated pipes. There are variations to the conventional shallow well, and ground water may be obtained using various structures (Figure 3.1).

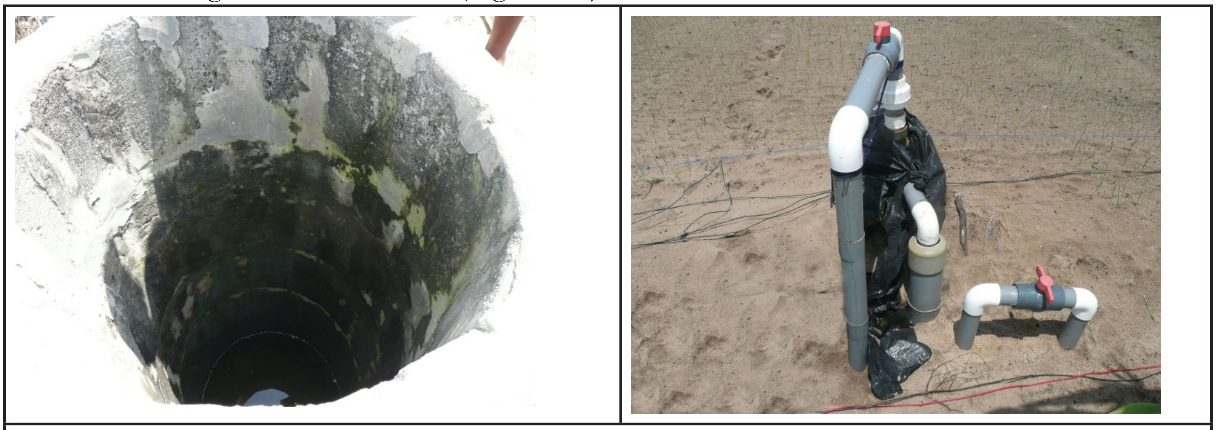


Figure 3.1 (a) Open shallow well lined with concrete *(Photos by B. Mati)*
(b) Tubewell for shallow ground water extraction

3.2.1 Hand dug wells

The traditional method of obtaining groundwater in rural areas of Africa and still the most common is by means of hand-dug shallow wells. However, because they are dug by hand, their use is restricted to suitable types of ground, such as clays, sands, gravels and mixed soils where only small boulders are encountered. Some communities use the skill and knowledge of local well-diggers, but often the excavation is carried out, under supervision, by the villagers themselves. The volume of the water in the well below the standing water table acts as a reservoir, which can meet demands on it during the day and should replenish itself during periods when there is no abstraction.

3.2.2 Qanat

A qanat (plural qanawat) is Arabic term for an underground system of water collection and conveyance popular in North Africa and the Middle East. The system is made up of a series of wells and linked underground water channels that collects flowing water from a source usually a distance away, stores it, and then brings the water to the surface using gravity. The channel is either partially or totally covered and gravity causes water to flow to its outlet on the ground surface at a lower elevation. Manholes are created along the qanat length to allow construction and maintenance. They are best constructed in an area having a high water table.

3.2.3 Infiltration wells

Infiltration wells are the shallow wells constructed along the banks of the rivers in river water seeping through the river bottom. The water before it is collected in these wells has to pass through sand beds, which act as natural filter for purifying this water. Therefore, this water is relatively clean and can be used for drinking and irrigation.

3.2.4 Infiltration galleries

Infiltration galleries are just like horizontal wells constructed at shallow depths (3 to 5m) along the banks of the river. Some holes, like that of weep holes of a retaining wall, are provided in these galleries which are protected from behind by means of rubble packing to avoid their clogging. The water seeping from the river bed and banks enters these galleries through the holes provided for those purpose.

3.2.5 Under-flow channels and conduits

The flow of water in an unconfined aquifer is comparable to the flow of water in a channel; and flow of water in a confined aquifer is comparable the flow of water in a closed conduit. During the dry season, many streams may be dry with no surface flow but they may carry applicable of water as under-flow. Depending upon whether the flow is under non-artesian conditions or artesian conditions, it may be classified as underflow conduits, respectively.

3.3 Salient features of shallow wells

3.3.1 Well width and depth

Shallow wells are located within the pervious water-bearing stratum and draw their supplies from the surrounding material. They generally have an open water surface, albeit the well can be covered or capped. The depth of most shallow wells ranges, from 5 metres deep, to deep wells over 20 metres deep. Wells with depths of over 30 metres are sometimes constructed to exploit a known aquifer. It is impractical to excavate a well which is less than a metre in diameter; an excavation of about 1.5 metres in diameter provides adequate working space for the diggers and will allow a final internal diameter of about 1.2 metres after the well has been lined.

3.3.2 Flow discharges

Shallow wells are suitable for low discharges of the order of 18 cubic metres per hour (i.e. about 0.005 cumecs). The walls of an open well are may be built of precast concrete rings or in brick or stone masonry, or simply unlined. The yield of an open well can be low, because such wells are excavated to a limited depth. Moreover, in such a well, the water can be withdrawn only at the critical velocity for the soil. Higher velocities cannot be permitted as that may lead to disturbance of soil grains and consequent subsidence of well lining in the hollow so formed. The limit placed on velocity, therefore, also limits the maximum possible safe discharge of a shallow well.

3.3.3 Hydraulics of shallow wells

Irrigation wells operate according to certain fundamental hydraulic principles. Water flows into the well from the surrounding aquifer because the pumping of the well creates a difference in pressure. Before pumping, the water in the well stands at a height equal to the static water level or static water pressure in the saturated sand around the well. When pumping starts, the water in the well is pulled down and the water starts to flow into the well from the bearing formation because the water level or pressure inside the well during pumping is lower than it is in the aquifer outside the well. This pressure different is the 'drive' that causes the water to move through the pores of the sand towards the well. The closer the water gets to the well, the faster it has to move because the area through which it has to travel is continuously decreasing.

3.4 Advantages and disadvantages of shallow wells

3.4.1 Advantages

Shallow pumping wells can often supply drinking water at a very low cost. A dug well can be made much safer and more productive by driving a well point with a screen into the water-bearing formation, thus converting it into a driven well. Hand-dug wells have diameters large enough to accommodate one or more men with shovels digging down to below the water table. They can be lined with laid stones or brick; extending this lining upwards above the ground surface into a wall around the well serves to reduce both contamination and injuries by falling into the well.

3.4.2 Limitations of shallow wells

The limitations of shallow wells are numerous. It is difficult to excavate shallow wells in areas where hard rock is present. Digging of hand dug wells are also time-consuming to construct even in favourable areas. The construction generally requires the use of a trained well construction team, and the capital investment for equipment such as concrete ring moulds, heavy lifting equipment, well shaft formwork, motorized de-watering pumps, and fuel can be large for people in developing countries. Construction of hand dug wells can be dangerous due to collapse of the walls, falling objects and asphyxiation, including from dewatering pump exhaust fumes. Shallow wells are more difficult to protect from contamination, and their yields are also very low because they do not penetrate into larger productive aquifers. Because they exploit shallow aquifers, the well may be susceptible to yield fluctuations and possible contamination from surface water, including sewage. Since impurities from the surface easily reach shallow sources, a greater risk of contamination occurs for these wells when they are compared to boreholes.

The velocity of percolating water into the well depends upon the depression head. If more amount of water is withdrawn from the well and thereby increasing the depression head, higher flow velocities will prevail in the vicinity of well. Thus, at a certain rate of withdrawal, it is possible that the flow velocity may exceed the critical velocity for the soil, thereby causing the soil particles to lift up. As more and more soil particles are lifted, a hollow is created in the bottom of the well, resulting in increased effective area, so that, ultimately, the velocity falls below the critical value, and then no further sand goes out of the well. The formation of such hollows beneath the wells is undesirable in shallow wells, because there is danger of subsidence of the well lining. The maximum rate of withdrawal from such well is therefore, limited.

3.5 Construction of shallow Wells

From a construction point of view, the wells may be classified into the following three types:

(i) Wells with an impervious lining, such as masonry lining

(ii) Wells with a pervious lining, such as dry brick or stone lining, and fed through the pores in the lining.

(iii) No lining at all, i.e. earthen well.

3.5.1 Methods of digging wells

a) Wells with impervious lining

These wells provide the most stable and useful type of wells for irrigation. For constructing such a well, a pit is first of all excavated, generally by hand tools up to the soft moist soil. Masonry lining is then built up on a kerb up to a few metres above the ground level. A 'kerb' is a circular ring of reinforced concrete, timber or steel having a cutting edge at the bottom and a flat top, wide enough to support the thickness of well lining called 'steinning'. The kerb is then descended into the pit by loading the masonry by sand bags, etc. As the excavation proceeds below the kerb, the masonry sinks down. As the masonry sinks down, it is further built up at top. To ensure vertical sinking, plumbobs are suspended around the well steinning, and if the well starts tilting, it may be corrected by adjusting the loads or by removing the soil from below the kerb which may be causing the tilt. The well lining is generally reinforced with vertical steel bars.

After the well has gone up the water table, further excavation and sinking may be done either by continuously removing the water through pumps, or the excavation may be carried out from top using a type of self closing bucket which is tied to a rope and worked up and down over a pulley. A smaller diameter hole is then is then made through the water bearing stratum in the centre of the well. Sometimes, shallow wells may be sunk as described above up to a required depth, and partly filled with gravel or broken ballast. This functions as a filter through which water percolates and enters the well, but the sand particles will be prevented from rising up.

b) Wells with pervious lining

In this type of wells, dry brick or stone lining is used on the sides of the well. Concrete mortar or binding material is used. The water thus enters from the sides, through the pores in the lining. The flow is, therefore, radial. Such wells are generally plugged at the bottom by means of concrete. If the bottom is not plugged, the flow pattern will be a combination of radial flow and spherical flow. Such wells are generally suitable in strata as of gravel or coarse sand. The pervious lining may have to be surrounded by gravel, when such a well is constructed in finer soils, so as to prevent the entry of sand into the well along with the seeping water

c) Digging wells in stable formation

In stable ground, wells are often excavated down to water level without a lining, and are lined with in situ concrete, or with pre-cast concrete rings, from this level upwards. Wells safely dug during the dry season may become unstable when the water level rises in the wet season and therefore must be lined before this occurs to prevent a collapse. Although in firm stable ground unlined wells may be safely excavated and may give long service in operation, it is prudent, and in most cases essential, to provide a permanent supporting lining which will support the sides of the excavation and prevent them from collapsing; suitable lining materials are concrete, reinforced concrete, ferro-cement, masonry, brickwork. These wells can therefore be constructed only where the water table is very near to the ground. Shallow wells can be excavated manually drilled (Figure 3.2).

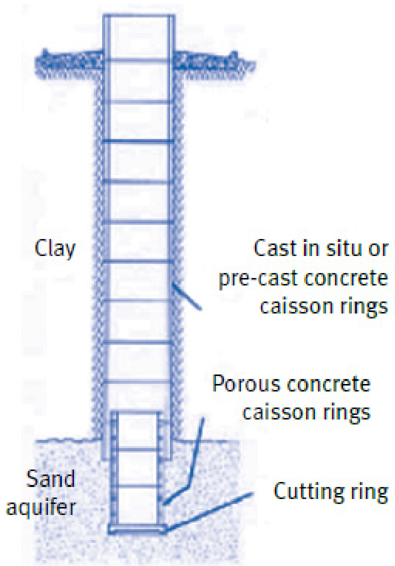


Figure 3.2 (a) Main features of a shallow well
(Source: WaterAid, 2009)

3.5.2 Supporting the sides during excavation

There are several methods of the excavation while digging proceeds: They include the following:

a) One method, which is also the safest for excavate within pre-cast concrete rings which later become the permanent lining to the sides of the well. The first ring has a cutting edge, and additional rings are placed on it as excavation proceeds. As material is excavated within the ring, it sinks progressively under its own weight and that of the rings on top of it. This method should always be used in unstable ground. When construction has finished, the joints between the rings above the water table should be sealed with cement mortar.

b) In suitable ground, excavation may proceed for a short distance without support to the sides; these are then supported by means of concrete poured in situ from the top, between the sides of the excavation and temporary formwork, which becomes the permanent lining to the well. This process is repeated until the water table is reached.

c) In suitably stable ground, excavation may proceed within the protection of vertical close-fitting timber boards, supported by horizontal steel rings. The timbers are hammered down as excavation proceeds and additional timbers are added progressively at ground level. The steel rings must be hinged, or in two parts bolted together, so that lower ones can be added as the excavation progresses. The vertical spacing between the rings will depend on the instability of the ground.

3.5.3 Excavation below the water level

Regardless of which method has been used to excavate the well to the water table, excavation below this level should never be attempted until the sides of the excavation have received the support of their permanent lining, from water table to ground level. Excavation below the water table should be carried out within pre-cast concrete caisson rings of a smaller diameter than the rest of the well. The initial caisson ring is provided with a cutting edge and additional rings are placed on top of it; as the material within is excavated, the rings sink progressively under their own weight. To facilitate the entry of water, these lower rings are often constructed with porous, or no-fines, concrete and their joints are left disjointed.

3.5.4 Methods of lining a well

Although pre-cast concrete rings may be used, they become the permanent lining of the well after being sunk progressively as excavation proceeds within them; many other materials have been used successfully. They include:

(i) Sinking caissons (concrete rings).
(ii) Reinforced concrete or ferro-cement cast in situ above water line, concrete rings sunk below the water line.
(iii) Masonry lining of burnt bricks above water line, caisson made of blocks with cutting ring below water line.
(iv) Galvanised iron rings bolted together as temporary measure for emergencies.

3.5.5 Gravel packing

After construction of the well shaft has been completed, the bottom is plugged with gravel. This helps to prevent silty material from clay soils, or fines from sandy materials, being drawn into the well. Any annular space between the pre-cast caisson well rings and the side of the excavation should also be filled with gravel; such filling behind the rings which are below the water helps to increase water storage and to prevent the passage of fine silts and sands into the well. The space behind the top three metres, or so, of the well rings should be backfilled to ground level with puddled clay, or concrete, and the well rings should project about one metre above a concrete apron. These aprons provides a sanitary seal to prevent polluted surface water seeping into the well and should slope away from it and drain into a channel which discharges into a soakaway (Figure 3.3).

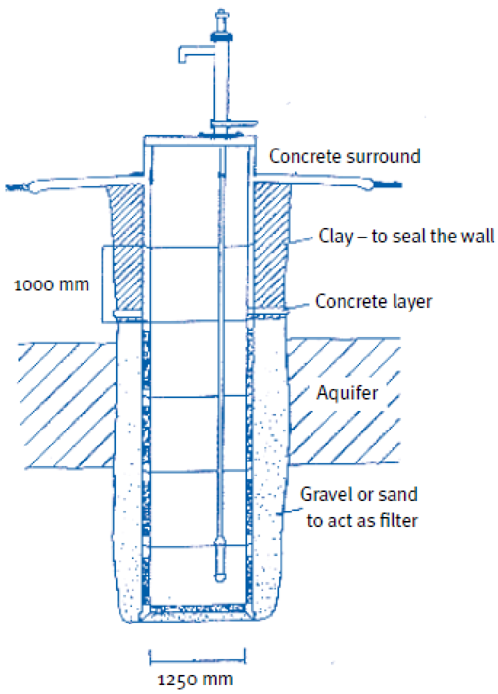


Figure 3.3 Gravel packing shallow well *(Source: WaterAid, 2009)*

3.6 Water Abstraction

It is desirable for the well to have a concrete cover slab to reduce the possibility of contamination. Water is abstracted by means of either a bucket and windlass (Figure 3.4) above an access hole, or a hand pump, depending upon the yield of water available and the ability of the benefiting community to pay for ongoing maintenance for the hand pump and spare parts. A hand-dug well fitted with a hand pump can serve the needs of about 300 people. The following diagram shows a typical layout for the well head of a well with a hand operated windlass:

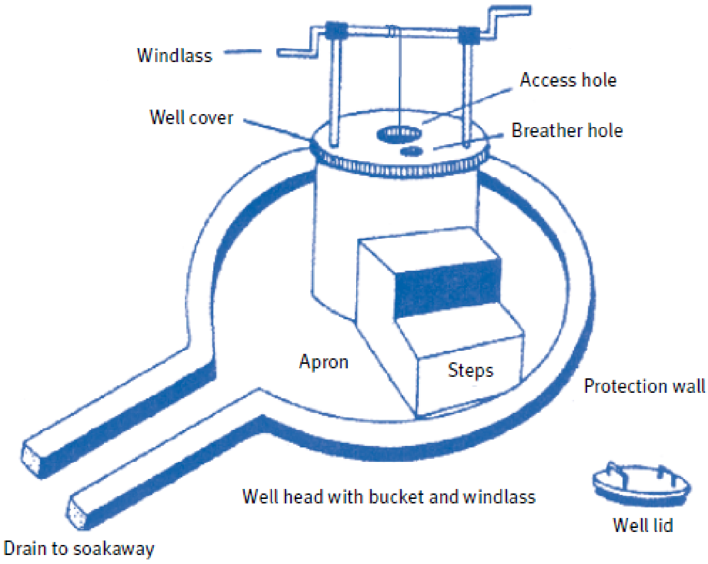


Figure 3.4 Sketch showing a completed shallow well with windlass *(Source: WaterAid, 2009)*

3.7 Protecting the well from pollution

Wells can vary greatly in depth, water volume and water quality. Since shallow wells penetrate into aquifers that are near the ground surface, they can become contaminated by dirt, sewers, chemicals, or fertilizer effluents. Furthermore, surface runoff can carry pollutants down into shallow aquifers and well water. Thus, well water typically contains more minerals in solution than surface water and may require treatment to soften the water by removing unwanted minerals such as arsenic, iron and manganese. Thus, wells must be designed to prevent pollution from entering and contaminating ground water. A well should be protected against pollution by observing the following:

- Lining the walls and sealing the well head,
- The well should not be located within a radius of 30 m of pollution sources, e.g. latrines
- Surface runoff should be diverted away from the well
- The well should have an overlapping, tight-fitting cover or sanitary seal at the top of the casing or pipe sleeve.
- The annular space around the well casing should be properly sealed with cement or clay.
- Should have a pump house to protect the well-head, storage tank, and other equipment.
- Fitting a self-priming hand pump, constructing an apron,
- Ensuring the area around the well is kept clean and free from stagnant water, animals and other sources of contamination (latrines, garbage pits), and

Carrying out environmental/hygiene education for the water users.

4. BOREHOLES

4.1 What is a borehole?

A borehole (variously known as tube well, driven well, artesian well or deep well) is a well sunk through an impermeable stratum to draw water from a relatively deep, confined aquifer. Boreholes are generally much deeper and narrower wells, measuring from less than 100 mm diameter to about 150 mm and can range from 3 to 18 m deep, but in some areas can go deeper than 900 m deep. Boreholes extract water at a given rate such that the artesian aquifers exhibit only small changes in storage volume. The hydrostatic pressure within an aquifer partially supports the overburden, while the remainder is supported by the solid structure of the aquifer. During pumping, the aquifer gets compressed and forces some water from it. In addition, lowering of the pressure causes a small expansion and subsequent release of water.

4.1.1 Salient features of boreholes

A borehole is literally a vertical pipe below ground surface, which passes through different geological formations of water-bearing and non-water–bearing strata. Normally, blind pipes are located at the non water bearing strata and perforated pipes or well screens are placed against the aquifer. Water enters the well through the bottom of the hole/pipe through filter points. In regions where the aquifer formations are made up of coarse sand gravel, the boreholes are shallow and consist of a well screen and a short length of casing pipe. Such wells are called filter points. Some salient features of a simple borehole include:

- The casing – often made of PVC to retain the hole in position.
- Submersible pump, which can be lifted out for maintenance or repair.
- Sanitary seal – which prevents seepage down the borehole
- Slotted casing – at the bottom of the borehole through which pumped water enters
- Capping - to support the external surfaces of the borehole against collapse, either temporarily or permanently.

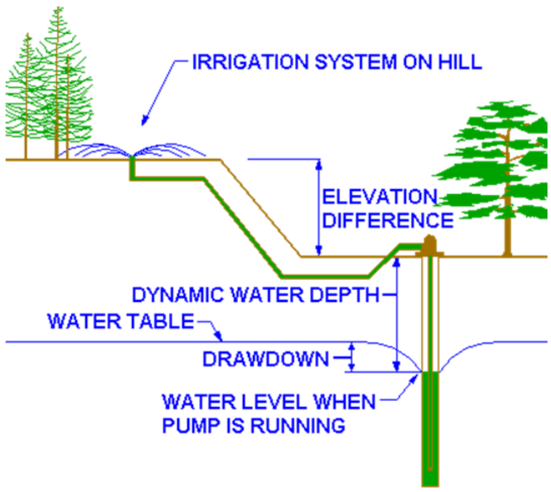


Figure 4.1 (a): Illustration of the features of a borehole for pumped irrigation

(b) Electricity powered ground water pumping from borehole *(Photo by B. Mati)*

4.2 Terminology relating to water abstraction in wells

4.2.1 Static water level

Static water level is the level at which the water stands in a well before pumping. It is generally the level of the water table, but in artesian wells, the static level may in some cases e above the table. The pressure of water at the static level may be above the table. The pressure of water at the static water level is atmospheric. Static water level is generally expressed as the distance from the ground surface to the water level in the well.

4.2.2 Piezometric surface

The piezometric surface is the height at which water will stand in an open pipe or piezometer, which extends into the aquifer. The height "H", the water will rise in the pipe above its bottom is equal to the pressure "P" at the bottom point of the pipe divided by the unit weight "W" of water, i.e.

$$\mathbf{H = P/W}$$

4.2.3 Pumping water level

This is the level at which water stands in a well when pumping at any given rate. This level is variable and changes with the quantity of water being pumped.

4.2.4 Drawdown

Drawn down at any instant is the difference between the static water level and the pumping water level at that instant. Drawdown affects the yield of a well. The maximum practical drawdown in a well is limited to the pumping water level reaching the top of the well screen.

4.2.5 Area of influence

As water is pumped out of well, it gets the supply from the surrounding formations. There is thus an imaginary inverted cone formed around the well having the static water as base and pumping level as apex. The zone affected by the pumping of the well is known as the area of influence. The boundary of the area of is called the circle of influence. The radius of the circle of influence is called the radius of influence. As more water is pumped out of the well, it takes more water from storage and as a result, the radius of influence increases till a position is reached when the rate of discharge from the well becomes equal to the rate of recuperation from the storage of the well. At this point, the cone of depression is stabilized. This equilibrium condition changes when the discharge rate is increased or decreased.

4.2.6 Well yield

The yield of a well is the volume of water discharged per unit of time from it. It is commonly expressed in litres per second or litres per minute. The maximum yield of a borehole is that yield which the borehole can sustain indefinitely before drawdown exceeds recharge from the aquifer.

4.2.7 Specific capacity

Specific capacity of a well is its yield per unit of drawdown. It is usually expressed as litres per minute per minute per metre of drawdown. Dividing the yield by drawdown, each measured at the same time, gives the specific capacity. It should be determined for fall of the first metre, as it is not the same for all draw-downs.

4.2.8 Borehole efficiency

Borehole efficiency is technically defined as the actual specific capacity (yield per unit of draw-down: say, litres per second per metre) divided by the theoretical specific capacity, both of which can be derived from a pumping test. Specific capacity declines as discharge increases.

4.2.9 Coefficient of storage

Coefficient of storage (A) for an artesian aquifer is the volume of the aquifer per unit change in the component of head normal to that surface. It is equivalent to the volume of water released from the aquifer of unit cross-sectional area and of the full height of the aquifer when the piezometric surface declines by unity. The water yielding capacity of an artesian aquifer can be expressed by its storage coefficient.

4.3 Advantages and disadvantages of boreholes

4.3.1 Advantages of boreholes

If they are properly designed and maintained, boreholes have several advantages such as:

- Boreholes 100 or 150 mm diameter are usually quicker and cheaper to sink, need no de-watering during sinking, require less lining material, are safer in construction and use, and involve less maintenance.
- They are less vulnerable to drought or drops in water level when drilled into deep water-bearing formations
- Can be designed to exploit more than one aquifer (when individual aquifers are vertically separated and not hydraulically connected)
- Compared to shallow wells, boreholes are less vulnerable to collapse
- Are less vulnerable to contamination
- Are, if properly sited, capable of producing large yields; so, mechanically or electrically powered pumps can be used
- Are amenable to quantitative monitoring and testing, which enables accurate assessment of aquifer parameters (as in aquifer modelling), water supply efficiency, and optimal design of pump and storage/distribution systems
- Can be used to monitor groundwater levels for other purposes, e.g. environmental studies or waste disposal
- The water from boreholes when used for irrigation has many benefits. It can be designed for group schemes or for individuals. Boreholes enable a farmer to maintain independent irrigation systems thus reducing conflicts over way leave and other land and property conflicts. Due to these boreholes one need not depend on rains for their irrigation purpose and get ample amount of water for all the construction purposes. Moreover, the energy required to extract water from them is less as compared to that in water purification plants. The problems arising due to pumping system, pipe leakage and others can also be averted by drilling the water boreholes.

4.3.2 Limitations boreholes

- High initial material costs and input of specialized expertise, i.e. construction, operation, and maintenance may require skills and expensive heavy equipment
- Vulnerable to irreversible natural deterioration if inadequately monitored and maintained
- Vulnerable to sabotage, can be irreparably destroyed with little effort if inadequately protected
- Require a source of energy if water extraction pumps are used (unlike gravity feed systems)

- Do not allow direct access, for maintenance or repairs, to constructed parts that are underground
- Depth for depth on any given site, hand-dug wells may yield more water than boreholes.

4.4 Developing boreholes

The development of a borehole requires that proper surveys have been done, and all data required are available. It starts with site identification.

4.4.1 Site identification

The choice of borehole site is an important part of the process of providing a safe and reliable supply of groundwater. The best sites are those in which catchment (natural water input) may be maximised. Such locations are not necessarily those that receive the highest rainfall (which may occur in upland watersheds). 'Bottomlands' – such as river valleys and lake basins – tend to be areas of maximum catchment as both surface water and groundwater migrate towards them under gravity. Fracture zones, although not always directly related to bottomland, can also be good reservoirs for groundwater, and may be located by ground observation or satellite images/aerial photographs, and by geophysical methods.

Another aspect of borehole siting that demands careful consideration in populated areas is the potential for contamination by cattle and pit latrines or other waste disposal facilities. Because near-surface groundwater migrates down-slope, a shallow dug well or a borehole tapping shallow groundwater should be sited as far away as possible (while bearing in mind the human need for proximity to a source of water) and upslope of potential sources of pollution (latrines or sewage pipes, for instance). Deeper aquifers confined by impermeable layers are at less risk of contamination from surface pollutants. One final consideration is the nature of the shallow aquifer. If the host formation is made of fine or medium-grain-sized sand, it will act as a natural filter for particulate pollutants, whereas fissured limestone, with a high rate of water transmission (transmissivity) will carry away pollutants faster and to greater distances from the source. It is estimated as a rule of thumb that most microorganisms do not survive more than 10 days of transportation by underground water.

4.4.2 Sinking boreholes

A water borehole is not just a hole in the ground. It is an engineering infrastructure which should be properly designed, professionally constructed and carefully drilled. Boreholes for extracting water consist essentially of a vertically drilled hole. Boreholes can get water from a much deeper level than can dug wells - often up to several hundred metres. They require lining to prevent collapse of the walls, which includes a means of allowing clean water to enter the borehole space (screen), surface protection, and a means of extracting water. Drilling by machine is an expensive process, and boreholes require expertise for both their design and their construction.

There are, however, compensations: this method of extracting water has a number of significant advantages. Thus, boreholes can be excavated by simple hand drilling methods (augering, sludging, jetting, driving, hand percussion) or machine drilling (rotary, percussion, down the hole hammer). Essentially, a drilling machine consists of a mast from which the drilling string components (tools plus drill pipes or cable) are suspended and, in most cases, driven. Modern systems are powered rotary-driven, but it is probably worth a short digression to describe some methods of manual drilling for water. The major methods of drilling boreholes are as follows:

4.4.3 Hand-auger drilling

Auger drills, which are rotated by hand, cut into the soil with blades and pass the cut material up a continuous screw or into a 'bucket' (bucket auger). Excavated material must be removed and the augering continued until the required depth has been reached. Auger drilling by hand is slow and limited to a depth of about 10 metres (maximum 20 metres) in unconsolidated deposits (not coarser than sand, but it is a cheap and simple process (Figure 4.2). However, it can be slow and is difficult to implement on stony or hard found.

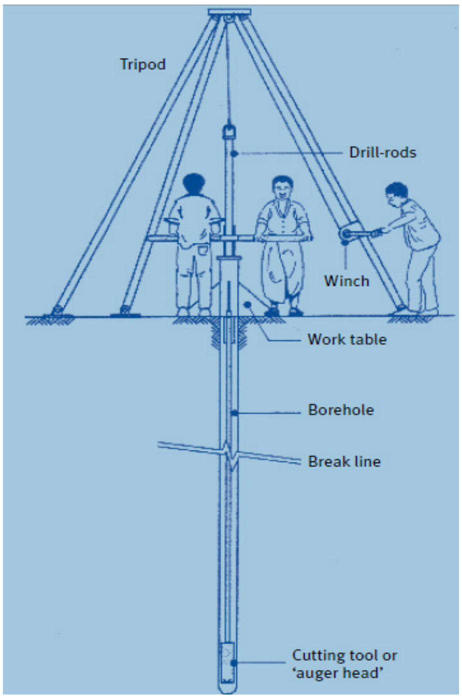


Figure 4.2 (a) Illustration of manual well drilling	(b) Manual drilling of a tube well *(Photo by B. Mati)*

4.4.4 Jetting

Jetting is a drilling method in which water is pumped down a string of rods from which it emerges as a jet that cuts into the formation. Drilling may be aided by rotating the jet or by moving it up and down in the hole. Cuttings are washed out of the borehole by the circulating water. Again, jetting is useful only in unconsolidated formations and only down to relatively shallow depths, and would have to be halted if a boulder is encountered

4.4.5 Auguring

Auguring cuts earth away by the rotation of a cylindrical tool with one or more cutting edges. The excavated earth feeds upwards inside the tool body, which needs lifting to the surface for emptying at intervals. This requires the whole auguring (drilling) train to be uncoupled and lifted; the weight involved can be considerable, and puts a limit to the depth of hand-operated auguring. The next diagram shows hand-augering using a Vonder rig:

4.4.6 Sludging

Sludging is a cheap but effective method of sinking small-diameter boreholes to a great depth in the water-logged silts and fine sands which underlie some flat river plains and deltas. Boreholes 25mm and upwards in diameter are sunk to depths of 60m or more. This method, which may be described as reverse jetting, involves a pipe (bamboo has been successfully employed) being lowered into the hole and moved up and down, perhaps by a lever arm. A boring pipe, usually a galvanised mild steel tube fitted with a case-hardened open socket at its base, moves vertically under the action of a bamboo lever pivoted on an H-frame. Soil, fluidised by repeated strokes of the case-hardened socket, is entrained into the upward flow of the water and the boring pipe sinks further into the ground with each stroke. Boring rates of 20m per hour have been achieved. Additional lengths of boring pipe are attached successively until the required depth is reached.

4.4.7 Rotary drilling

Most borehole applications in the field will require rotary drilling. Boreholes are typically excavated using either top-head rotary style, table rotary, or cable tool drilling machines, all of which use drilling stems that are turned to create a cutting action in the formation, hence the term 'drilling'. Rotary drilling machines use a segmented steel drilling string, typically made up of 6m sections of galvanized steel tubing that are threaded together, with a tool bit or other drilling device at the bottom end. Some rotary drilling machines are designed to install (by driving or drilling) a steel casing into the well in conjunction with the drilling of the actual bore hole. Air and/or water is used as a circulation fluid to displace cuttings and cool bits during the drilling. Another form of rotary style drilling, termed 'mud rotary', makes use of a specially made mud, or drilling fluid, which is constantly being altered during the drill so that it can consistently create enough hydraulic pressure to hold the side walls of the bore hole open, regardless of the presence of a casing in the well. Typically, boreholes drilled into solid rock are not cased until after the drilling process is completed, regardless of the machinery used.

Cable tool drilling is the oldest form of drilling machinery and is still used today. Specifically designed to raise and lower a bit into the bore hole, the 'spudding' of the drill causes the bit to be raised and dropped onto the bottom of the hole, and the design of the cable causes the bit to twist at approximately ¼ revolution per drop, thereby creating a drilling action. Unlike rotary drilling, cable tool drilling requires the drilling action to be stopped so that the bore hole can be bailed or emptied of drilled cuttings.

4.5 Assessing the yield of wells

Water discharged from an aquifer can be easily determined. Knowing the fall or the rise of the water in given time, and multiplying it with the average specific during this time, the change of the storage volume in unit time can be determined. The yield of an underground source can thus be measured using theoretical or practical methods, or sometimes, by carrying out a practical pumping test and then calculating it from the observation.

4.5.1 Theoretical methods

If a well is penetrated through the aquifer, water will rush into it with a velocity v. If A is the area of the aquifers opening into the well, then

$$Q=AV$$

Where
V=Vk, where v is the actual flow velocity of ground water and V is the velocity with which water rushes into the well, and is a constant

$$Q= k.A.v$$

Where
k is a constant depending upon the soil , and is known as per me ability constant.
In the above equation, the velocity of ground water flow (v) can be determined using various formulas or by actual measurements with chemicals or electrical methods

A, the area of the aquifer can be determined from the diameter of well and depth of porous strata.

K, the constant can be found by studying the sample of the soil in the laboratory.

4.5.2 Practical method

There are three practical methods: Pumping test, recuperating test and combined.

a) Pumping test

A well is first constructed through the aquifer, then huge amount of water are drawn from the well, so as to cause heavy draw-down in its water level. The rate of pumping is then changed and so condition of equilibrium, the rate of pumping will be equal to the rate of yield and hence, the rate of pumping offers an indicator of the yield of the well at a particular drawn. But it is very difficult and almost impractical to adjust the rate of pumping so as to keep the well water level constant.

b) Recuperating test

In the recuperating test, water is first drained from the well at a fast rate, so as to cause sufficient draw-down. The pumping is then stopped. The water level in the well will start to rise. The rise is noted at regular intervals of time, till the initial level is reached. Knowing the area of well and rise, the volume of water yielded in that given time interval can be worked out at different draw-downs. These tests are generally conducted during the driest periods of the year so as to know the yields under worst conditions.

c) Combined method

Both these methods described above are difficult to apply, so a third method which is a combination of the above two is generally adopted. The combined method can be used to determine the yield from an unconfined aquifer as well as from a confined aquifer. The method is based on the application of Darcy's law (See Training Manual 9) to the analysis of hydraulics of wells.

4.6 Treating water from boreholes

Water abstracted from aquifers in relatively soft ground usually contains sand or silt particles, which are liable to cause rapid wear to pump valves and cylinders (and dissatisfaction among consumers). Methods of preventing these particles from reaching the pump are of two general types:

4.6.1 Screening

Screening is nearly always needed in some form. The well can be fitted with a PVC casing. In addition more elaborate and compact screens are available commercially; some can be bolted on to pump inlets. Materials used include woven wire which can be wrapped around the pump inlet assembly.

4.6.2 Sand/gravel packing

Sand and/ or gravel packing are meant to eliminate particles from the water before they reach the screen and would otherwise have passed through the screen. Graded sand and gravel can be used, placed from the top of the borehole. More compact, pre-bonded packs of sand and/or gravel are available commercially; some of these can also form part of the pump inlet assembly.

4.6.3 Well casing

Boreholes are usually cased with a factory-made pipe, typically steel (in air rotary or cable tool drilling) or plastic/PVC (in mud rotary wells, also present in wells drilled into solid rock). The casing is constructed by welding, either chemically or thermodynamically, segments of casing together. If the casing is installed during the drilling, most drills will drive the casing into the ground as the borehole advances, while some newer machines will actually allow for the casing to be rotated and drilled into the formation in a similar manner as the bit advancing just below. PVC or plastic is typically welded and then lowered into the borehole, vertically stacked with their ends nested and either glued or splined together. The sections of casing are usually 6 m or more in length, and 6 to 12 in (15 to 30 cm) in diameter, depending on the intended use of the well and local groundwater conditions. A complete borehole after casing has features shown in Figure 4.3.

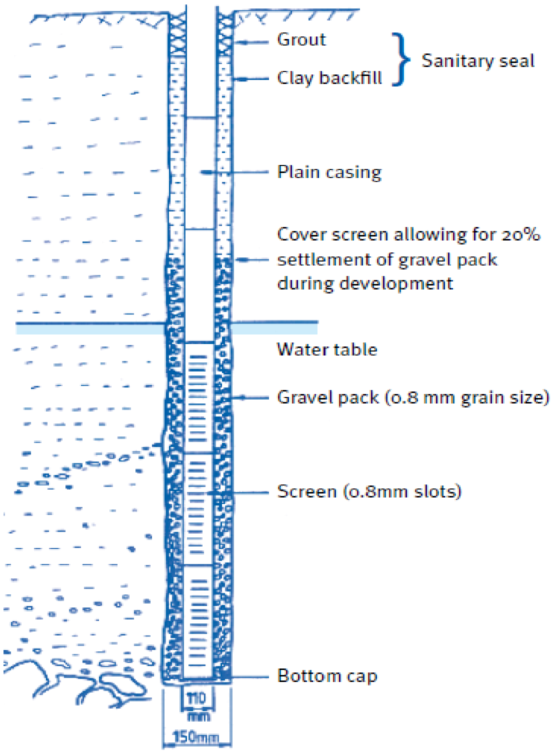


Figure 4.3: Sketch showing the salient features of a borehole *(Source: WaterAid, 2009).*

4.7 Controlling pollution in boreholes

Surface contamination of wells can be controlled by the use of a 'surface seal'. A large hole is drilled to a predetermined depth or to a confining formation (clay or bedrock, for example), and then a smaller hole for the well is completed from that point forward. The well is typically cased from the surface down into the smaller hole with a casing that is the same diameter as that hole. The annular space between the large bore hole and the smaller casing is filled with bentonite clay, concrete, or other sealant material. This creates an impermeable seal from the surface to the next confining layer that keeps contaminants from travelling down the outer sidewalls of the casing or borehole and into the aquifer. In addition, wells are typically capped with either an engineered well cap or seal that vents air through a screen into the well, but keeps insects, small animals, and unauthorized persons from accessing the well.

At the bottom of well, based on formation, a screening device, filter pack, slotted casing, or open borehole is left to allow the flow of water into the well. Constructed screens are typically used in unconsolidated formations (sands, gravels, etc.), allowing water and a percentage of the formation to pass through the screen. Allowing some material to pass through creates a large area filter out of the rest of the formation, as the amount of material present to pass into the well slowly decreases and is removed from the well. Rock wells are typically cased with a PVC liner/casing and screen or slotted casing at the bottom; this is mostly present just to keep rocks from entering the pump assembly. Some wells utilise a 'filter pack' method, where an undersized screen or slotted casing is placed inside the well and a filter medium is packed around the screen, between the screen and the borehole or casing. This allows the water to be filtered of unwanted materials before entering the well and pumping zone.

5. SPRING WATER DEVELOPMENT AND PROTECTION

5.1 What is a spring?

A spring (or seep), is a place on the earth's surface where groundwater emerges naturally. The water may appear as small water holes or wet spots on hillsides or along river banks. The flow of water from springs may come from small openings in porous ground or from joints or fissures in solid rock. Surface springs occur where groundwater emerges at the surface because an impervious layer of ground prevents further seepage downwards. Although most spring development projects target drinking water supplies, in certain cases, a spring can yield adequate water for irrigation.

5.1.1 Why do spring development and protection?

The water source of most springs is rainfall that seeps into the ground uphill from the spring outlet. Spring water moves downhill through soil or cracks in rock until it is forced out of the ground by natural pressure. The amount, or yield, of available water form springs may vary with the time of year and rainfall seasons. It is also necessary to measure the spring's flow at the end of the dry season to determine its potential reliable yield. Groundwater obtained from springs is similar to water pumped from shallow wells. Like shallow wells, springs may be used for irrigation purposes (Figure 5.1) by taking care to avoid water depletion and possible contamination by surface water or other sources on or below the ground surface. In such cases, the spring should be selected with care, developed properly, and the water abstracted sustainably, hence the need for spring protection.

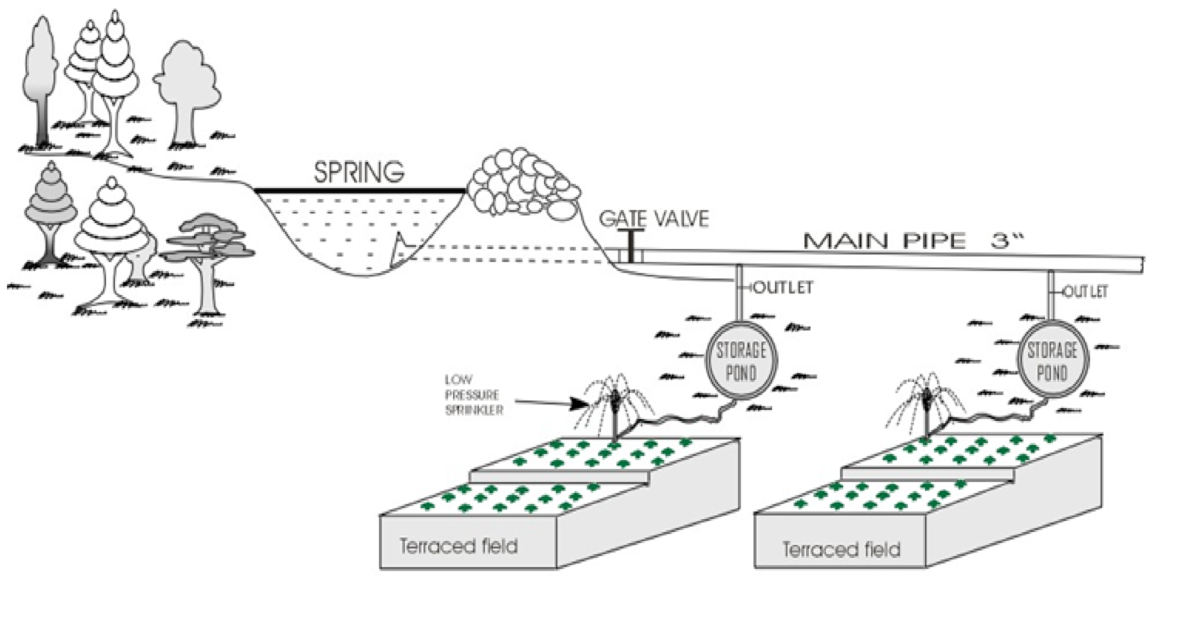


Figure 5.1. Illustration of an irrigation scheme utilising spring water

Before reaching the surface, spring water is generally considered high quality, depending on the composition of the surrounding soils and bedrock. However, springs are susceptible to contamination because the water feeding them typically flows through the ground for only a short distance, limiting the amount of natural filtering that can occur. Contamination sources include livestock, wildlife, crop fields, forestry activities, septic systems and fuel tanks located upslope from the spring outlet. Therefore, spring water sources need to be protected at the source or eye.

Springs may not be a good choice for a water supply if the area uphill where the water collects is used for industry, agriculture, or other potential sources of pollution. An inspection of the ground upstream of the spring is essential to ascertain that there is no danger of pollution or, if there is, that measures can be taken to prevent it. A spring source can be used either to supply a gravity scheme or just to provide a single outlet, running continuously, which is set at a sufficient height to allow a bucket or container to be placed below it.

The objective of spring development is to collect the flowing water underground to protect it from surface contamination and store it in a sanitary spring box. Proper development depends on the type of the spring, and whether it is a concentrated spring or a seepage spring. However, there are many types of springs, which determine the kinds of protective and spring development structures to be adopted.

5.1.2 Advantages of spring development structures

- Spring development and protection increases flow and reduces the possibility of spring water contamination.
- Water from a spring is usually fresh and free from pollution, thus requiring little if any, need for artificial purification
- Spring development is relatively low cost, especially as local labour and materials can be used. Once constructed, maintenance costs are minimal
- The technologies used for spring development are quite simple and can be easily modified fit just about any situation.
- Although protective structures such as spring boxes do not necessarily improve accessibility of the source, they can be easily adapted to work in conjunction with other technologies such as gravity fed distribution systems.

- Spring development solves many problems, including the environmental conservation of the affected area and reduction of water logging
- Spring development and well planned utilisation can be used to stabilize water availability and river flows.
- Spring water is a highly desirable source of community water supply, since the water emerges at the ground surface through internal pressure of the ground water system, and usually, no pumping is required.

5.1.3 Limitations of spring development

- For irrigation development, most springs can only supply small quantities of water or irrigate relatively small area
- Springs tend to be found mostly on hilly terrain, foothill areas or intermontane valleys, which could be too rugged or far from human habitation, and thus difficult to exploit.
- Environmental concerns in case of over-abstraction of a spring on the overall catchment hydrology
- Pollution of spring from fertilizer residues and other pollutants in case of agricultural activi-

ties within the vicinity of the spring,

- Depending on type of spring, seasonal fluctuations may occur in the amount of available water.
- Sometimes during spring development if the wrong or subsidiary spring eye is used, spring flow may divert and flow underground undetected. Consequently, the entire spring can dry out completely.

5.2 Types of springs

There are many different types of springs, but they fall under two broad categories: (a) gravity springs and (b) artesian springs. Also, springs can be either concentrated or seepage types.

5.2.1 Gravity springs

Within the gravity category, there are three principal types of springs: depression springs; contact springs; and fracture or tubular springs.

(i) **Depression springs** are formed when the land surface dips and makes contact with the water table in permeable material. Yield from depression springs is highly variable, depending on the level of the water table. In areas that experience a pronounced dry season, depression springs may not be a suitable source of drinking water if the water table drops below the level of the depression, causing the spring to become seasonally dry. A gravity depression spring may not be suitable for a drinking water source since it may dry up.

(ii) **Gravity contact springs** occur when an impervious layer beneath the earth's surface restricts surface water infiltration. Water is channelled along the impervious layer until it eventually comes in contact with the earth's surface. This type of spring typically has a very high yield and makes a good source of drinking water.

(iii) **Fracture and tubular springs** are formed when water is forced upwards through cracks and fissures in rocks. The discharge is often concentrated at one point, thereby facilitating the process of protecting the source. Fracture and tubular springs also offer a good source of water for a community supply.

5.2.2 Artesian spring

Artesian springs occur when water under pressure is trapped between two impervious layers. Because the water in these springs is under pressure, flow is generally greater than that of gravity springs. There are two types of artesian springs: fissure and artesian flow.

(i) **Artesian fissure springs** result from water under pressure reaching the ground through a fissure or joint in rocks. These springs make excellent community water sources because of their relatively high flow rates and single discharge point.

(ii) **Artesian flow springs** occur when confined water flows underground and emerges at a lower elevation. This type of spring occurs on hillsides making protection a fairly easy and also offers an excellent supply of water.

Before reaching the surface, spring water is generally free from harmful contaminants. To avoid contamination, the spring should be protected at the point where the water leaves the ground. There are three methods of developing springs as drinking water sources: spring boxes; horizontal wells; and seep development.

5.2.3 Concentrated springs

Concentrated springs occur along hillsides in mountain and piedmont areas at points where groundwater emerges naturally from openings in rock. These are the easiest springs to develop and protect from contamination. Proper development for concentrated springs consists of intercepting water underground in its natural flow path before it reaches the land surface.

A low-area spring is a type of concentrated spring found in valleys or other low areas. Low-area springs are not as easily protected as those located in higher areas where other surface water naturally drains away from the spring.

5.2.4 Seepage springs

Seepage springs occur where groundwater oozes or "seeps" from the ground over a large area and has no defined discharge point. This type of spring usually occurs when a layer of impervious soil redirects groundwater to the surface Seepage springs can be difficult to develop. Because seepage springs collect water over large areas, they are more difficult to protect from surface water contamination than concentrated springs. They need to be monitored before development to ensure that they will provide a dependable source of water during the entire year. Flow is often lower from seepage springs, making them less dependable.

5.2.5 Typical spring flow rates

Springs have relatively lower flow rates than conventional aquifers used foe wells. Thus, a flow in excess of 0.1 litres per second is considered good enough for domestic water supplies. Such a flow rate can fill a 20 litre container in just over 3 minutes, which is an acceptable waiting time. From such a spring a daily useful yield of about 3,000 litres can be expected, which is enough water for about 150 people. If the flow were to be only 0.05 litres per second it could still can be made to supply the same population by incorporating a storage tank of 1 cubic metre capacity. Spring flow rates exceeding 0.5 litres per second are considered good enough for smallholder irrigation. However, water abstraction must strictly be monitored so as to maintain some equilibrium between water removed and environmental flows, for the system to be sustainable.

5.3 Methods of spring protection

Spring water is generally free from harmful contaminants until it reaches the surface. To avoid contamination, the spring should be protected at the point where the water leaves the ground. There are three methods of developing springs as drinking water sources: spring boxes; horizontal wells; and seep development. These are explained further as follows:

5.3.1 Spring boxes

There are many different designs for spring boxes, they all share common features. Primarily, a spring box is a watertight collection box constructed of concrete, clay, or brick with one permeable side (Figure 5.2). The idea is to isolate spring water from surface contaminants such as rainwater or surface runoff and to ensure that insects, dirt or small animals cannot enter the structure. All spring boxes should be designed with a heavy, removable cover in order to prevent contamination from rainwater while providing access for disinfection and maintenance. When designed properly, a spring box can provide reserve storage during a situation when the spring flow rate is below normal. All human activities should be kept to at least 30 m from the spring box. The salient features of a spring box include:

The size of a spring box depends on the amount of storage required. The box should be at least 1 m deep and should extend at least 30 cm above the ground.

- Most spring boxes are made of concrete.
- A properly constructed spring box will have a watertight cover that fits like a shoebox lid. This prevents insects, animals, and surface water from entering the spring.
- The spring box should have and outlet pipe and an overflow pipe. The overflow pipe should be screened and located below the collector pipe or tile so that water will not back up behind the spring. The overflow may be a floating device connected to the outlet pipe.
- The installation of a drain for cleaning the box is necessary. The installation should have facility for draining it to allow the box to be cleaned periodically.

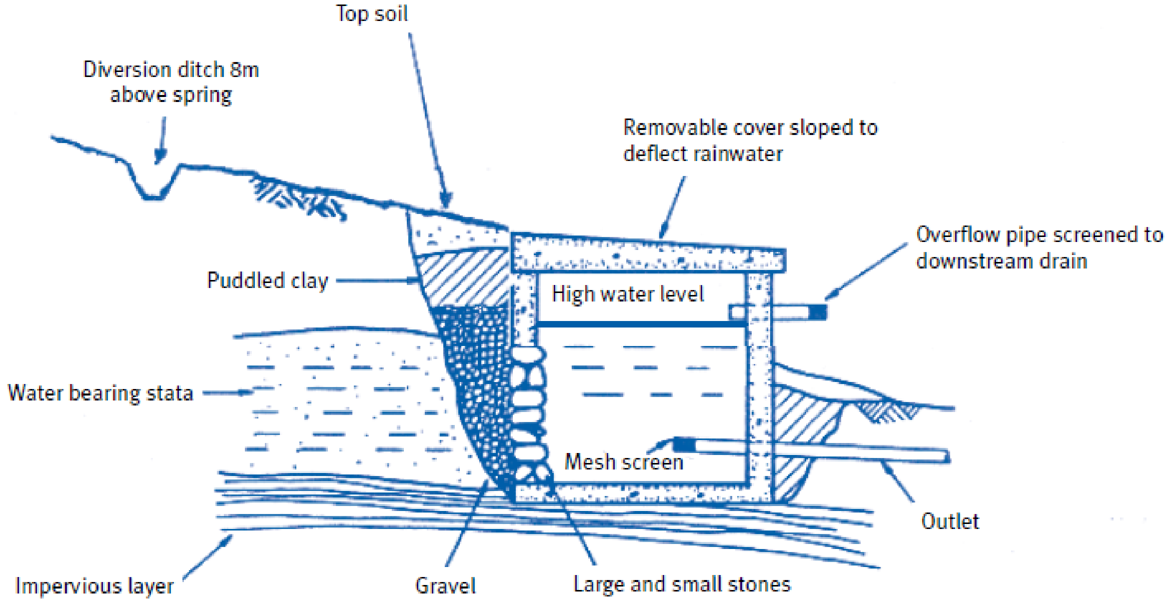


Figure 5.2 Cross-sectional view of a spring box *(Source, WaterAid, 2009)*

5.3.2 Types of spring box designs

There are two basic spring box designs (see Figures 5.3 a and b), that could be modified to meet local conditions and requirements.

(i) A spring box with a single permeable side for hillside collection, and

(ii) Spring box with a pervious bottom for collecting water flowing from a single opening on level ground. The spring box with an open bottom is typically simpler and cheaper to construct because less digging and fewer materials are required.

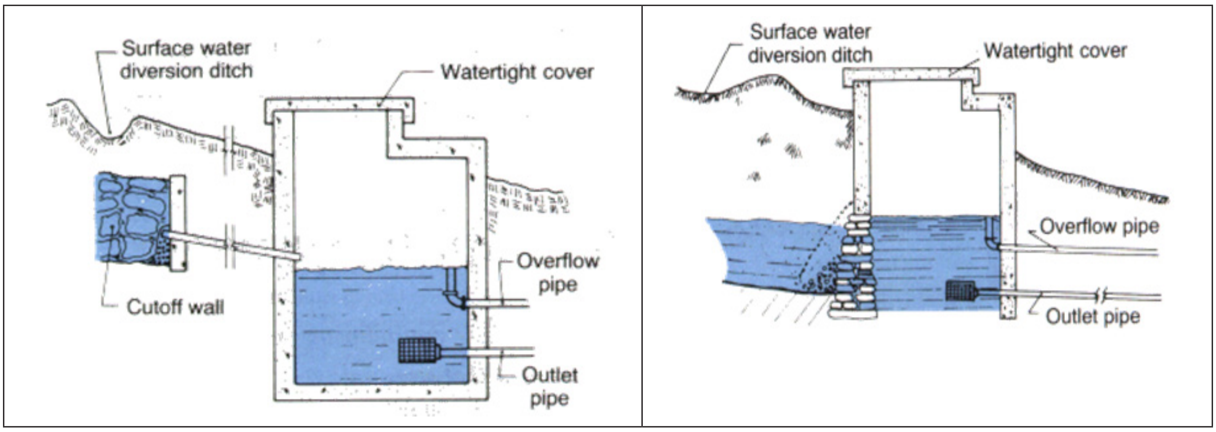


Figure 5.3 (a) Cross sectional view of a concentrated spring *(Source: Jennings, 1996)*	(b) Cross sectional view of a spring box with permeable bottom

Depending on local water requirements and conditions, a number of these spring boxes may be constructed to provide year-round supply or used to recharge other community water storage systems. During construction, a small area is dug out around the spring and lined with gravel. A concrete box with a removable cover is placed over the spring to collect and store the water. The cover prevents outside contamination and should be heavy enough to keep people from removing it to dip buckets and cups into the collection box. A tap and an overflow to prevent a back up in the aquifer should be installed. The cost of developing a spring box is minimal and the system is relatively maintenance free. Disinfection is seldom required. Since springs are generally located on hills, a simple gravity flow delivery system can be installed.

5.3.3 Developing a concentrated spring

Concentrated springs are usually visible and are often found along hillsides where groundwater is forced through openings in fractured bedrock. This type of spring is relatively easy to develop (Figure 5.4) and is usually less contaminated than other types of springs. The development of a concentrated spring usually adapts these steps:

- The land upslope the spring discharge is excavated until at least 1 m depth of water is flowing.
- A rock riprap is installed to form an interception reservoir.
- •A collecting wall of concrete or strong plastic is built down slope from the spring discharge. The spring box design should include an overflow pipe that is screened for mosquito and small animal control.
- A pipe is installed low in the collecting wall to direct the water from the interception reservoir to a concrete or plastic spring box, taking care to avoid too much water to stand behind the wall. It is also important to provide some measure of erosion prevention at the overflow pipe.
- Potential sources of contamination are removed and surface water diverted away from the spring box or collection area. To achieve this, a diversion ditch is made for diverting surface runoff away from the spring box at least 8 meters upslope from the spring box. In addition, a fence should be constructed around the spring box and the spring catchment area. This protects the water source from livestock and wildlife contamination, as well as from soil compaction that could lead to reduced yields. Deep-rooted trees and plants should be avoided as their root systems could damage protective structures and reduce spring flow.

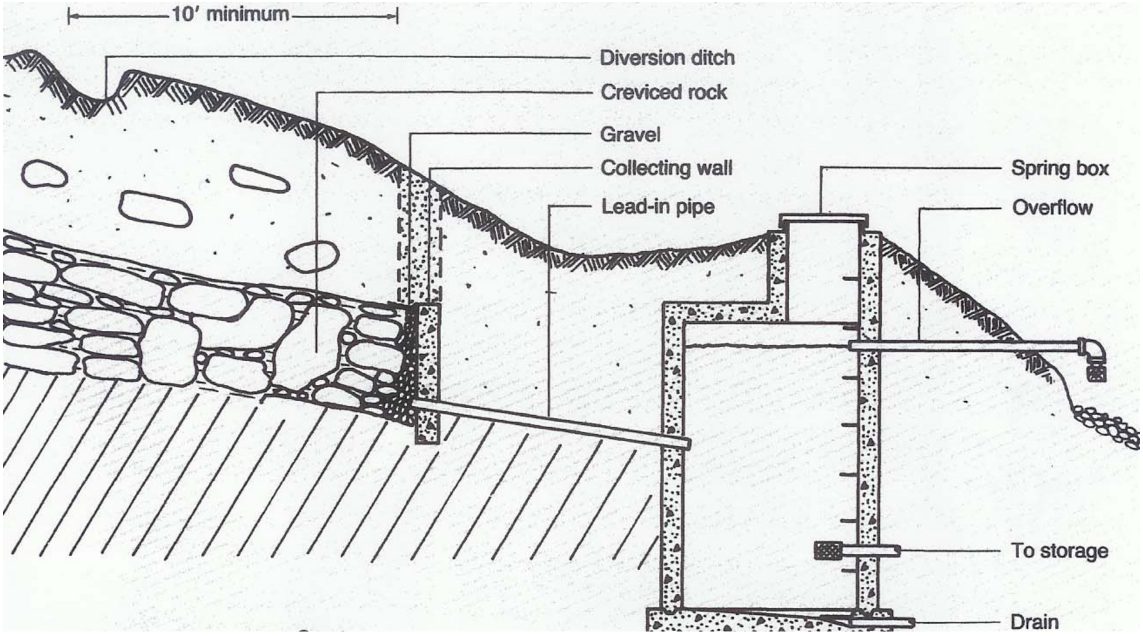
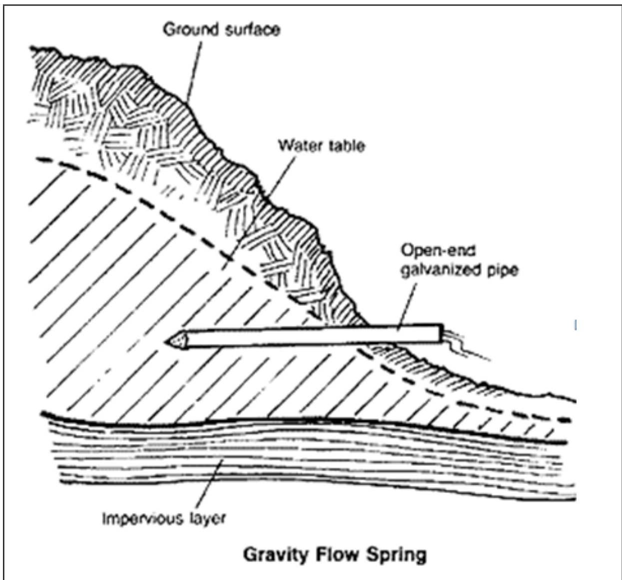


Figure 5.4 Cross-sectional view of a developed concentrated spring
(Source: Clemens et. Al, 2007)

5.3.4 Horizontal wells

Horizontal wells are developed in situations where a spring has a steeply sloping water table or a steep hydraulic gradient. Pipes with open ends or with perforated drive points or well screens can be driven into an aquifer horizontally or at a shallow slope to tap it at a point higher than the natural discharge (Figure 5.5). Horizontal wells are installed in a manner similar to driven and jetted wells (see Chapter 4) but care must be taken to prevent flow through the annular space outside the pipe. Any flow can be stopped by grouting or by constructing a concrete cut-off wall packed with clay backfill. Springs with flat water tables are not suitable for the use of horizontal wells since the water flows out by gravity.



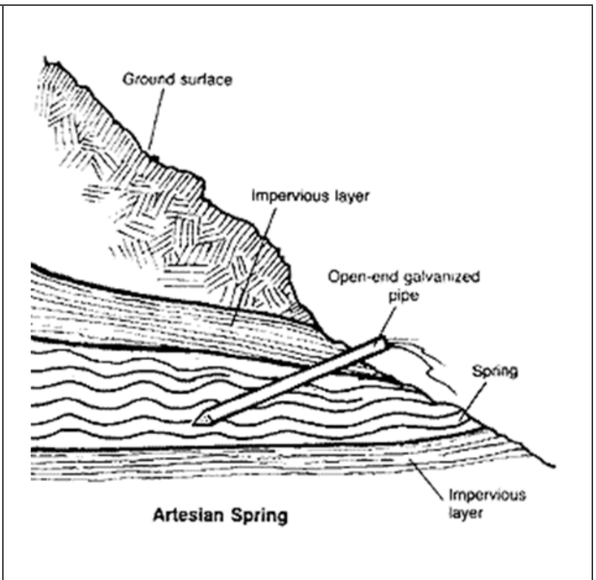


Figure 5.5 (a) Horizontal wells for gravity spring (*Source: USAID, 1982, www.lifewater.org)*	**(b) Horizontal well for artesian spring**

5.3.5 Seep spring development

The development process for seepage springs consists of intercepting flowing groundwater over a wide area underground and channelling it to a collect ion point. Seepage springs are more difficult to develop because water seeps from the ground and covers an area of several square meters. A concrete wall just down-slope of the pipes traps the water for more efficient collection. Pipes are laid to collect the underground water and transport it to a collection box (Figure 5.6) as described below.

- Test holes are dug upslope from the seep until the point where the impervious layer is at least 1 m deep is located
- •A trench is excavated measuring about 60 cm wide across the slope. Trench should be extended at least 15 cm into the impervious layer (below the water-bearing layer) and should extend 1.5-2 m beyond the seepage area. A collection tile measuring about 10 cm is installed and surrounded with gravel.
- Installation of a collecting wall will help prevent water from escaping the collection tile. This collecting wall should be constructed of 10 to 15 cm of concrete.
- Collection tile should be connected to 10 cm pipe that leads to the spring box. Box inlet must be below the elevation of the collector tile.
- Any potential sources of contamination are removed and surface runoff diverted away from spring box or collection area.

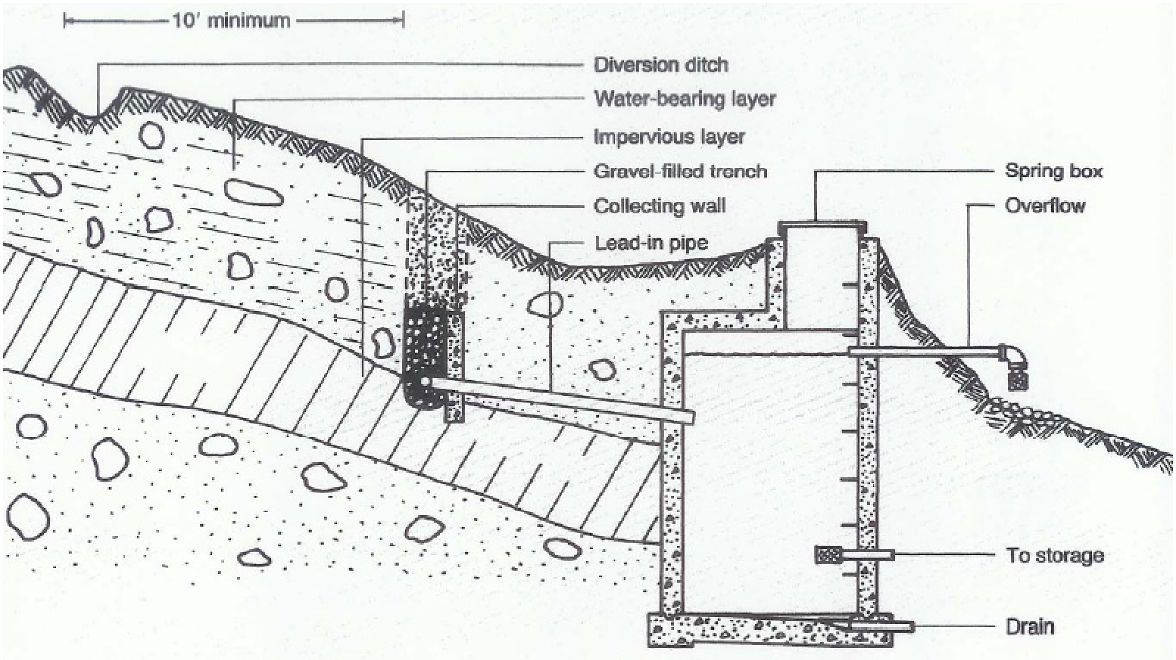


Figure 5.6 (a) Spring development in a seep area *(Source: Clemens, 2007)*

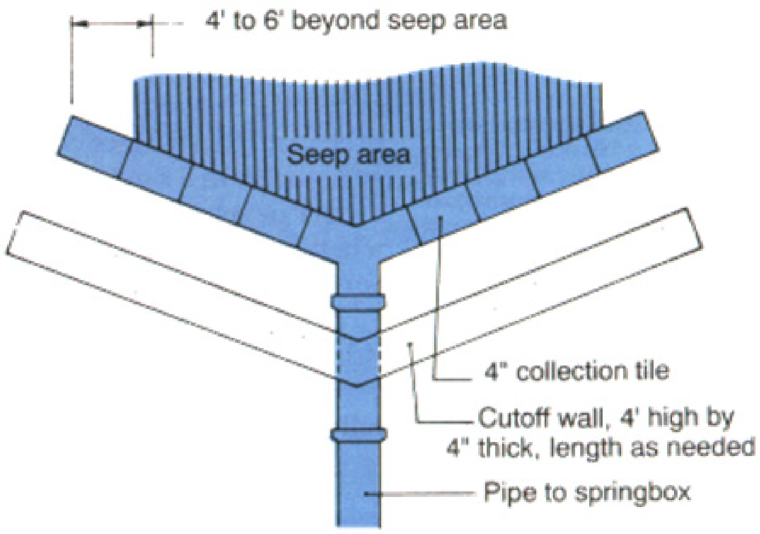


Figure 5.6 (b) Overhead view of a seepage spring development *(Source: Jenningss, 1996)*

With this method, maintenance costs are higher as pipes often clog with soil or rocks. Also, the expense and difficulty of construction may prohibit its use. Unless the seep supplies abundant quantities of water, this method should not be considered.

5.3.4 Infiltration galleries

Infiltration galleries are perforated pipes laid horizontally within a water bearing formation. The system comprises a set of long perforated pipes or box (5 cm or more in diameter) placed across the water-bearing layer of a hillside spring to gather water. Backfilled with gravel or another sufficiently porous medium, the pipe or box is connected to an outflow pipe(s) and can transmit appreciable quantities of water. Infiltration galleries are commonly used in sand storage reservoirs for water abstraction (see Training Manual 5 of these series for further details).

5.4 Construction works for spring protection

Before construction of spring development system, a physical and hydro-geologic investigations are done to ensure the spring will yield enough water and sustainably. Other site specific preparations include the following:

5.4.1 Preparatory checks for spring development

The following points should be considered when investigating a potential spring source:

(i) Checking all indicators to determine that the spring is truly ground water and not a stream which has gone underground and is re-emerging

(ii) Making sure that the source and the collecting area are not likely to be polluted by surface runoff

(iii) Checking that there are no latrines within 30 metres upstream of the spring

(iv) Fencing the area around the spring tank to prevent pollution by human activities e.g. farming or livestock grazing

(v) Making sure that if the spring is to be connected to a piped water system it is on higher ground than the area to be supplied

(vi) Taking care that the spring tank is not built on swampy ground or on land which is subject to erosion or flooding

(vii) Ensuring that the flow from the protected spring itself will not cause erosion or damage.

5.4.2 Construction procedure

The construction of the spring protection works can be viewed as a three stage activity encompassing the following steps:

a) **Stage 1- Site preparation**

This involves:

(i) Clearing vegetation above the eye of the spring
(ii) Construction of a cut-off drain to divert surface water
(iii) Construction of a temporary diversion of the spring water to allow construction of the collection chamber

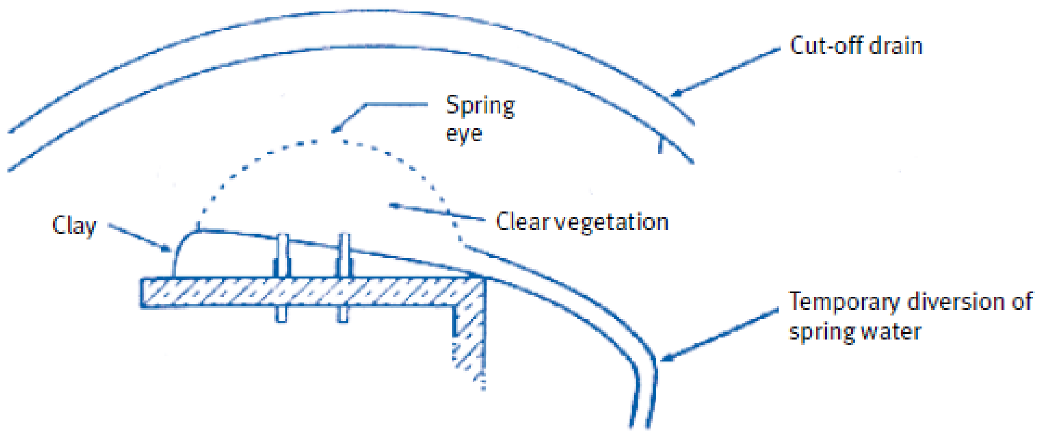


Figure 5.7 Site preparation for spring development *(Source: WaterAid, 2009)*

b) **Stage two – construction of reservoir and spring box**

(i) The area around the spring eye is excavated
(ii) Large stones are placed above the eye of the spring
(iii) The collection chamber or spring box is constructed

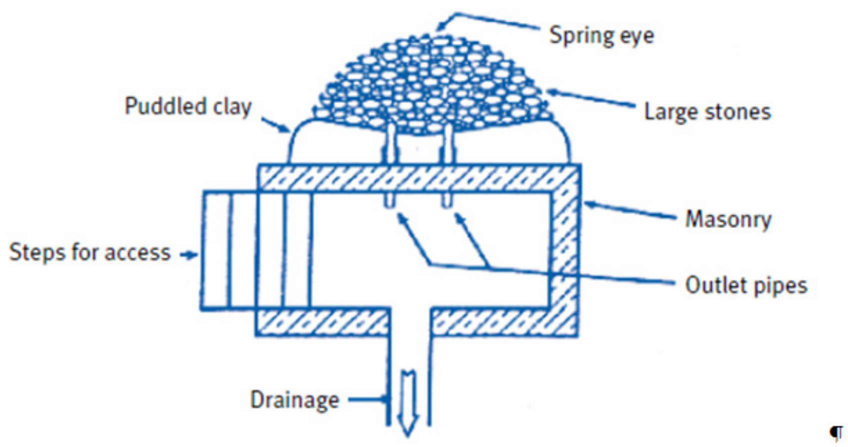


Figure 5.8 Construction of spring eye and collection chamber
(Source: WaterAid, 2009)

c) **Stage three – Water off-take and completion**

(i) For further protection of the eye by layers of impervious material above it.
(ii) Install water off-take infrastructure
(iii) Fencing the area and protection from pollution

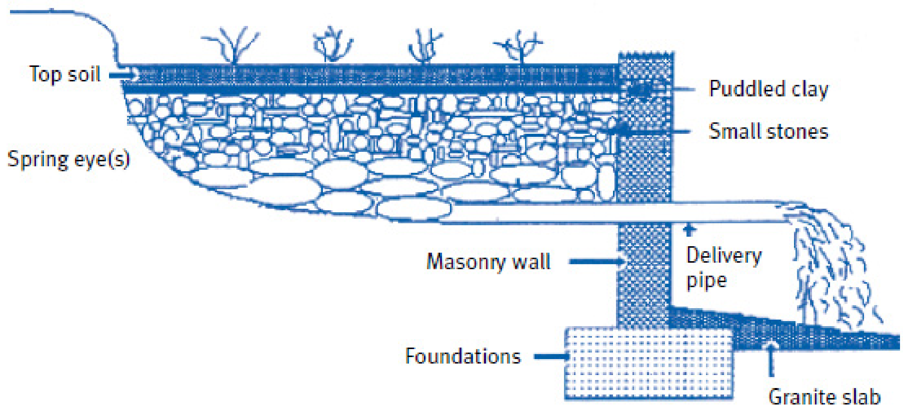


Figure 5.9 Cross sectional view of the developed spring components
(Source: WaterAid, 2009)

If the flow from the spring is not sufficient to meet peak demands during the day, a storage tank can be incorporated into the structure of the spring protection. This enables the flow from the spring over the full 24 hours to be stored, and then used throughout the day to meet intermittent demands by means of a tap in the structure.

5.5 Operation and maintenance of protected springs

5.5.1 Care and safety

Regardless f the types of spring developed, it is critical that potential sources of contamination from the spring's drainage area, i.e. the area upslope of the spring discharge point, are removed. Surface water draining into that area should be redirected and all activities should be limited within the drainage area. Springs are susceptible to contamination by surface water, especially during rainy season. Contamination sources include livestock, wildlife, crop fields, forestry activities, septic systems, and fuel tanks located upslope from the spring outlet. Changes in colour, taste, odour, or flow rate indicate possible contamination by surface water. The following measures are taken protect spring:

(i) Diverting all surface water away from the spring as far as possible and no flooding should be allowed near the spring.
(ii) Construction of a U-shaped surface drainage diversion ditch or an earth berm at least 20 m uphill form the spring to divert any surface runoff away from the spring. Care is taken not to dig too deep as to uncover flowing groundwater. The diversion ditch should be free draining and should not pond water.
(iii) An earth berm adjacent the spring or a second U-shaped diversion ditch lined with concrete tile can be constructed for added protection.
(iv) The area is fenced for an area at least 30 m in all directions around the spring box to prevent contamination by animals and people who are unaware of the spring's location.
(v) There should not be any heavy vehicle traffic over the uphill water bearing layer of the spring to prevent compaction as this could reduce water flow.

5.5.2 Water testing and disinfection

For drinking water systems, it is necessary to reduce contamination of the water. In most cases, a spring may get contaminated due to poor spring development, construction of from direct flow of surface water into the shallow groundwater feeding the spring. Once the spring is developed and nearby sources of contamination eliminated, it is important to disinfect the entire water system and then submit a water sample water testing laboratory for water quality analysis. Spring water should be tested before and after heavy rains each year for bacteria, pH, turbidity, and conductivity to determine if surface-water contamination is a problem. If water levels change frequently when it rains, the spring is very susceptible to contamination. If bacteria are found at any time in the water, properly disinfect the system and retest the water before using it again. Springs are susceptible to contamination by giardia, cryptosporidium, and other microorganisms that are not detected by standard bacterial tests. Test for these microorganisms if spring water is suspected as a source of illness.

5.5.3 Maintenance

Proper management and maintenance of the area around the spring and its catchment area is necessary. There should be no cultivation upstream of the spring and natural vegetation should be maintained. Water depleting trees such as eucalyptus should not grow anywhere near the spring. The selection of trees and shrubs to cover the spring area s made with care to allow only plants that encourage water ponding e.g. reeds.

Properly installed spring boxes require little maintenance. However, it is important to check that the uphill diversion ditch is adequately diverting surface runoff away from the spring box and is not eroding. It is also recommended that a fence is installed and in good repair. Although some grazing area may be lost, the loss in grazing area is preferable to a contaminated water source or compacted soil that could lead to decreased flow rates. For hillside collection boxes, it is important to check that the uphill wall is not eroding and is maintaining structural integrity. The cover should be checked frequently to ensure that it is in place and appears to be watertight. The water should not seep out from the sides or from underneath the spring box and the screen should be in place on the overflow pipe. Most importantly, the water users should be educated on the proper use and management of their developed spring water resource.

6. MOTORIZED IRRIGATION PUMPS

6.1 The basics about pumps

A pump is a device used to move fluids, such as liquids, gases, slurries or water, usually at some pressure. To generate this pressure requires energy/power. This energy can be obtained from various sources including fuels such as diesel, petrol or biogas, electricity, mechanical energy from human or animal power, or renewable energy sources such as wind, solar, or flowing water.

Motorized pumps are operated by prime movers, engines and electric motors, whereas manual pumps are operated by people or animals. In general, the principles of operation of pumps are the same. The discharge and pumping head relationship of all pumps is dependent on the type of pump and the amount of energy that the manual operator or prime mover can transfer to the pump, among other factors.

6.1.1 What is an irrigation pump?

An irrigation pump is any type of pump used to direct water from a source to a section of land, usually for agricultural purposes. There are many different types of pumps for various uses such as rotary pumps, diaphragm pumps, piston pumps, and manual pumps. However, the most common pumps used for irrigation include centrifugal, deep well turbine, submersible and propeller pumps. Also, centrifugal pumps have many variants such as hydraulic rams, solar pumps, sprinkler pump, booster pumps and certain manual pumps. Centrifugal pumps are the most commonly used in irrigation due to their ability to lift large quantities of water (Figure 6.1). Generally, pumps fall into three major groups: direct lift, displacement, and gravity pumps.

Figure 6.1 (a) A typical portable pump generally used for irrigation

(b) Motorized pump being used for irrigation *(Photo by B. Mati)*

6.1.2 The need for irrigation pumps

In a pumping system, the objective, in most cases, is either to transfer a liquid from a source to a required destination. A pressure is needed to make the liquid flow at the required rate and this must overcome head 'losses' in the system. Losses are of two types: static and friction head. Most systems have a combination of static and friction head. Pumps should be sized appropriately since an oversized pump would need to be throttled back, which adversely affects the pump motor and wastes energy. Before selecting an irrigation pump, a careful and complete inventory of the conditions under which the pump will operate must take place. The inventory must include:

- The source of water (well, river, pond)

- The required pumping flow rate
- The total suction head
- The total dynamic head

The choice of the source of the water could be either surface water or well water and availability will be determined by the local geology and hydrologic conditions. However, the flow rate and total dynamic head will be determined by the type of irrigation system, the distance from the water source and the size of the piping system.

6.2 Terminology used in pump operating heads

Before selection of a pump, it is important to understand some of the basic terminology relating to types of pumps and their operating characteristics. These are described as follows:

6.2.1 Pump operating head

Pump head or simply *"Head"*, is a term commonly used to mean the difference in elevation between the suction level and the discharge level of the liquid being pumped. It is equivalent to the height of a vertical column of water the water will rise at a given pressure. Pressure and head are interchangeable concepts in irrigation. The total head of a pump is composed of several types of heads that help define the pump's operating characteristics. These can be summed up as the total dynamic head.

6.2.2 Suction head

A pump operating above a water surface must first lift the water to the pump level. This is known as suction head. Thus a suction lift exists when the liquid level is below the centreline of the pump suction. The term **static suction head** is used to describe the vertical distance from the centreline of the pump up to the free level of the liquid source above the pump.

The **total static head** is the total vertical distance the pump must lift the water. When pumping from a well, it would be the distance from the pumping water level in the well to the ground surface plus the vertical distance the water is lifted from the ground surface to the discharge point. When pumping from an open water surface it would be the total vertical distance from the water surface to the discharge point. The **dynamic suction lift includes** static suction lift, friction head loss and velocity head, while the **dynamic suction head** includes static suction head minus friction head and velocity head.

The suction head includes not only the vertical suction lift, but also the friction losses through the pipe, elbows, foot valves and other fittings on the suction side of the pump. There is an allowable limit to the suction head on a pump and the net positive suction head (NPSH) of a pump sets that limit. To minimise the suction pipeline friction losses, the suction pipe should have a larger diameter than the discharge pipe. Typically, atmospheric pressure limits vertical suction lift of pumps to about 7.5 m at sea level. However, this lift could be increased to about 90 m of suction pipe, so long as the water source is not lower than 7.5 m below the pump centerline.

6.2.3 Pressure head

Pressure head is a function of the energy used to pump water and depicts the height to which that water would rise assuming no losses. This is particularly important in sprinkler and drip irrigation systems as they require pressure to operate. Centre pivot systems require a certain pressure at the pivot point to distribute the water properly.

6.2.4 Static head

Static head or **discharge head** describes the vertical distance that that a pump is able to lift water. It is the difference in elevations of the outlet vs. the inlet point of the system or height of the supply and destination reservoirs. Static head is the pressure of the fluid in the system, and is the quantity measured by conventional pressure gauges. The height of the fluid level can have a substantial impact on system head.

6.2.5 Friction head

Friction head is the energy loss or pressure decrease due to friction when water flows through pipe networks. It is a function of the resistance to fluid movement and is proportional to the square of the flow rate, pipe diameter and viscosity. The velocity of the water has a significant effect on friction loss. Loss of head due to friction occurs when water flows through straight pipe sections, fittings, valves, around corners, and where pipes increase or decrease in size. Values for these losses can be calculated or obtained from friction loss tables. The friction head for a piping system is the sum of all the friction losses.

The **head loss in pipes due to friction** is expressed as a "hydraulic gradient", i.e. head per length of pipe (m per m) as follows:

$$\boxed{\mathbf{H_f = K \frac{(L \times Q^2)}{(C^2 \times D^5)}}}$$

Where

H_f = Head (pressure) loss in the pipe due to friction (m)

Q = Flow rate

C = Coefficient of friction for the pipe

D = Internal diameter of pipe (m)

Pipe flow is subject to a hydraulic gradient which becomes steeper if the flow is increased. Thus, a higher head/pressure is needed to overcome the increased resistance to a higher flow. The power demand, and hence the energy costs will generally be directly related to total head for a given flow rate, and sometimes, friction losses in the pipe can account for about half the energy costs.

6.2.6 Total dynamic head

The dynamic head is the pressure required by the system to overcome head losses caused by flow rate resistance in pipes, valves, fittings, and mechanical equipment. Dynamic head losses are approximately proportional to the square of the fluid flow velocity, or flow rate. If the flow rate doubles, dynamic losses increase fourfold. The dynamic head includes the dynamic discharge head plus dynamic suction lift. The total dynamic head of a pump is the sum of the total static head, the pressure head, the friction head, and the velocity head.

$$TDH = Hs + Hf + Hp + Hv$$

Where
TDH = Total dynamic head
Hs = Total static head,
Hf = Total friction head, and
Hp = Pressure head.
Hv = Velocity head.

The **velocity head** is the energy of the water due to its velocity. This is a very small amount of energy and is usually negligible when computing losses in an irrigation system.

6.2.7 Total system head

The total system head has three components: static head, elevation (potential energy), and velocity (or dynamic) head. The total head can be described as the difference between the head at the discharge vs. the head at the inlet of the pump. Total head is a measure of a pump's ability to push fluid through a system. This parameter (with the flow) is a more useful term than the pump discharge head since it is independent of a specific system. The total head produced by a pump is independent of the nature of the liquid (i.e. specific gravity or density) as is the head in any part of the system.

6.2.8 Pump power requirements

The hydraulic power required tolift or pump water is a function of both the apparent vertical height lifted and the flow rate at which water is lifted. Generally, the power requirements of a pump are related to the head (height water is lifted) and the flow rate. The general relationship between power, pressure and flow rate that applies to any water lifting technique is given as follows:

Power = (Head x flow rate)

and

Energy = (Head x total weight of water lifted)

In reality, the actual pumping head imposed on a pump, or "gross working head", is usually greater than the actual vertical distance, or "static head", water has to be raised. This is expressed in a formula known as Bernoulli's equation, relating the different energies in the fluid. The power, P, required by the pump is determined as:

$$P = (\rho x g x \Delta H x Q)/\eta$$

Where:
P = Power consumption in KWH = KW input x operating hours

ρ = Density of water, usually taken as unity

g = acceleration due to gravity (m/s^2)
ΔH = Change in head (or total pressure) between the inlet and outlet (in Pa),
Q = the fluid flow rate is given in m^3/s
η = Pump efficiency.

The change in total pressure (ΔH) may have gravitational, static pressure and kinetic energy components; i.e. energy is distributed between change in the fluid's gravitational potential energy (going up or down hill), change in velocity, or change in static pressure. The pump efficiency (η) may be given by the manufacturer's information, such as in the form of a pump curve and has a value between 0 and 1. The power input will depend on the motor efficiency and pump power requirement.

6.2.9 Pump efficiency

Pump efficiency is defined as the ratio of the power imparted on the fluid by the pump in relation to the power supplied to drive the pump. Its value is not fixed for a given pump; efficiency is a function of the discharge and therefore also operating head. This is because the actual power and energy needs are always greater than the hydraulic energy need, as losses. A truly frictionless pumping system would in theory be 100% efficient; i.e. all the energy applied to the pump reappears as hydraulic energy output. However, in reality, inefficiencies inevitably occur when producing and transmitting power or energy and also due to friction as water flows through the pipe and around bends and joints. The lower the friction losses, the better are the quality of a pumping system. The quality of a system in terms of minimizing losses is defined as its "efficiency", calculated as follows:

$$\boxed{\textbf{Efficiency} = \frac{\textbf{(Hydraulic energy output)}}{\textbf{(Actual energy input)}}}$$

One important part of system design involves matching the pipeline head loss-flow characteristic with the appropriate pump or pumps in order to operate at or close to the point of maximum efficiency. Manufacturers determine using various tests the operating characteristics/ efficiencies of their pumps and publish the results in pump performance charts commonly called "pump curves."

For centrifugal pumps, the pump efficiency tends to increase with flow rate up to a point midway through the operating range (peak efficiency) and then declines as flow rates raise further. Pump performance data such as this is usually supplied by the manufacturer before pump selection. Pump efficiencies tend to decline over time due to wear (e.g. increasing clearances as impellers reduce in size) and/or loose parts.

Drive Efficiency – This is the efficiency of the drive unit between the power source and the pump. For direct connection this value is 1, for right angle drives the value is 0.95 and for belt drives it can vary from 0.7 to 0.85.

6.2.9 Best efficiency point

Best efficiency point (BEP) is the head, flow, and speed at which a pump is designed for optimal performance. A pump should be selected so that it always operates near its BEP. Operating a pump at less than or more than its BEP will lower the operational efficiency and place additional stress on the pump shaft and bearing because of increased thrust and radial load. Higher flows increase required net positive suction head (NPSH) and may result in erosion attributed to cavitation, as well as increased noise and vibration. Pumps are variable-torque machines that follow the affinity laws. The affinity laws predict changes in pump performance resulting from changes in speed or impeller diameter. If pump performance is unnecessarily high, energy savings can be achieved through use of a variable-speed drive or the matching of impeller trim to system resistance. Throttling adds resistance to a system, but is not as efficient as reducing speed or impeller diameter.

6.3 Common types of irrigation pumps

6.3.1 General features

There are various designs and sizes of pumps for a wide range of applications. However, most irrigation pumps fall within the category of pumps that use kinetic principles that is centrifugal force or momentum in transferring energy. This category includes pumps such as centrifugal pumps, vertical turbine pumps, submersible pumps and jet pumps. Most of these pumps operate within a range of discharge and head where the discharge will vary as the head fluctuates.

The second category of pumps is that of positive displacement pumps, whereby the fluid is displaced by mechanical devices such as pistons, plungers and screws. Mono pumps, treadle pumps and most of the manual pumps fall into this category. The first category of pumps is called turbo pumps and depending on the type of discharge subdivides these pumps into:

- radial flow pumps (centrifugal action)
- axial flow pumps (propeller-type action)
- Mixed flow pumps (variation of both).

Positive displacement pumps are normally suitable for small discharges and high heads and the head is independent of the pump speed. Some types of these pumps should only be used with water free of sediments. The vertical turbine and the centrifugal pumps are the most commonly used pumps in irrigation. They can operate with reasonable amounts of sediments, but periodic replacement of impellers and volute casing should be anticipated. Turbine pumps are more susceptible to sediments than centrifugal pumps. Mixed flow pumps cover a good range, from moderately large to large discharges, and moderately high heads. They have the same susceptibility to sediments as do centrifugal pumps. Axial flow pumps are suitable for low heads and large discharges.

In principle, any liquid can be handled by any of the pump designs. Where different pump designs could be used, the centrifugal pump is generally the most economical followed by rotary and reciprocating pumps. Although, positive displacement pumps are generally more efficient than centrifugal pumps, the benefit of higher efficiency tends to be offset by increased maintenance costs.

6.3.2 Centrifugal pumps

Centrifugal pumps are the most commonly used for irrigation. In design, a centrifugal pump is a roto-dynamic pump that uses a rotating impeller to increase the pressure and flow rate of a fluid (Figure 6.2). This means that the water is spun rapidly in a "casing", "chamber", or "housing" (any of those terms may be used). The spinning action moves the water through the pump by means of centrifugal force. Centrifugal pumps may be "multi-stage", which means they have more than one impeller and casing, and the water is passed from one impeller to another with an increase in pressure occurring each time (Figure 6.3). Each impeller/casing combination is referred to as a "stage". All centrifugal pumps must have a "wet inlet", that is, there must be water in both the intake (inlet) pipe and the casing when the pump is started. They can't suck water up into the intake pipe. They must be "primed" by adding water to the intake pipe and case before the first use. To prime them water is simply filled in the intake pipe and the pump quickly turned on. To put it simply, this type of pump can't suck air, only water, so if there is no water already in the pump it won't pull any water up into it. Once it gets water in it the first time, most centrifugal pumps are designed to hold the water with a small valve so the pump doesn't need to be primed again every time.

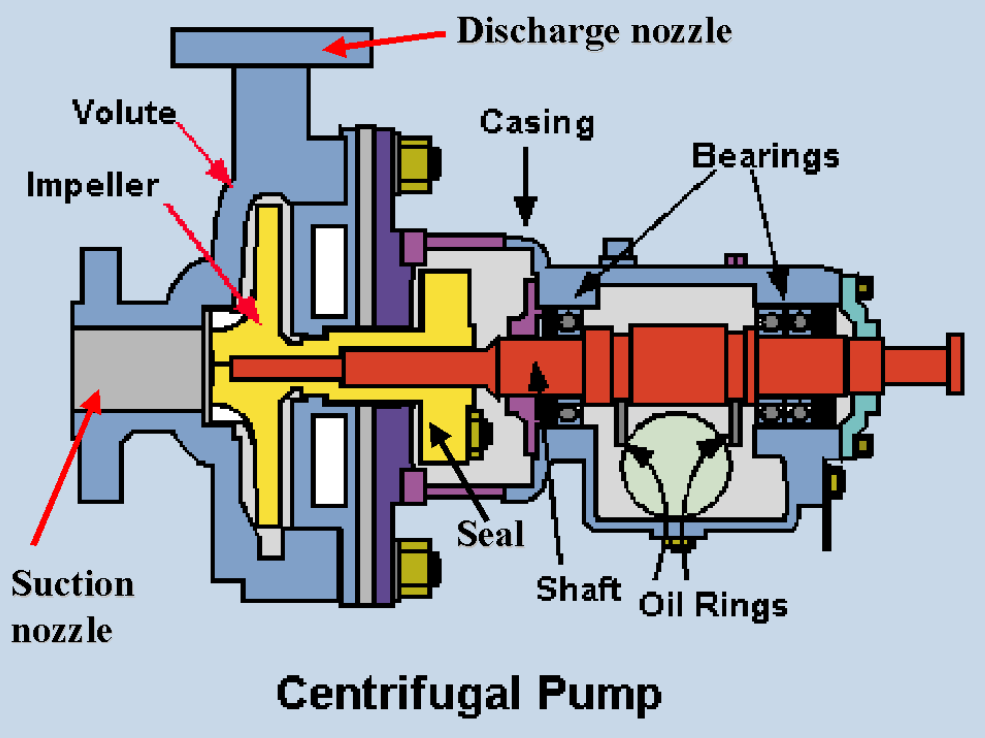
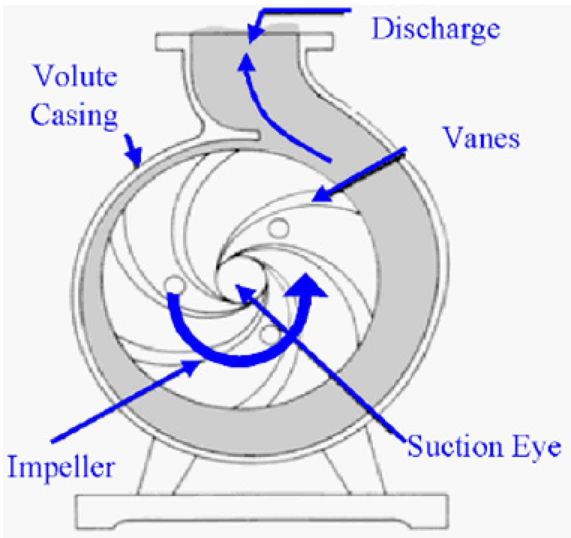


Figure 6.2: General components of Centrifugal Pump *(Source: Mukesh, 2010)*



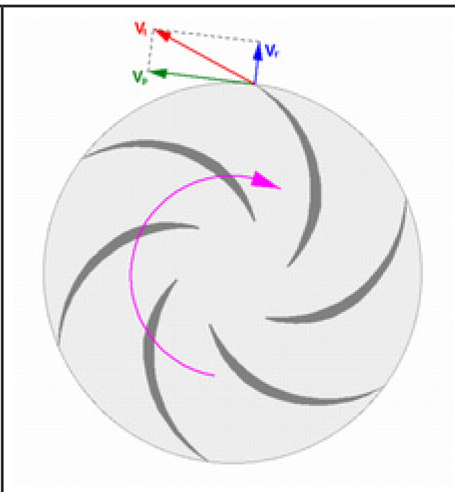


Figure 6.3 (a) Centrifugal pump flow path **(b) Energy conversion** *(Source: Mukesh, 2010)*

Centrifugal pumps are mostly used to lift large quantities of flow while utilising relatively smaller heads, and are thus popular for pumping water from reservoirs, lakes, streams and shallow wells. They are also used as booster pumps in irrigation systems.

Centrifugal pumps are designed for either horizontal or vertical operation. The horizontal centrifugal has a vertical impeller connected to a horizontal drive shaft. Horizontal centrifugal pumps are the most common in irrigation systems. They are generally less costly, require less maintenance, easier to install and more accessible for inspection and maintenance than a vertical centrifugal. Vertical centrifugal pumps may be mounted so the impeller is under water at all times. This makes priming unnecessary, which makes the vertical centrifugal desirable for floating applications. This feature is useful for areas where power is unstable or lower off-peak electrical price are available to enable automation.

Almost all centrifugal pumps must be completely filled with water or "primed" before they can operate. The suction line as well as the pump has to be filled with water and free of air. Air tight joints and connections are extremely important on the suction pipe. Priming a pump can be done by hand operated vacuum pumps, internal combustion engine vacuum, motor powered vacuum pumps or small water pumps that fill the pump and suction pipe with water. However, there are self-priming horizontal centrifugal pumps, but they are special purpose pumps and not normally used with irrigation systems. Self priming is useful in cases where automatic restart is a programmable function. Since the bearings are constantly under water, a higher level of maintenance may be required for centrifugal pumps.

6.3.3 Turbine pumps

A turbine pump is a special type of centrifugal pump which uses turbine-like impellers with radially oriented teeth to move fluid. Turbine pumps are also referred to as vortex, periphery, or regenerative pumps (Figure 6.4). These pumps combine the high discharge pressures of positive displacement or multi-stage centrifugal pumps with the flexible operation of centrifugal pumps. In addition, the flow rate of turbine pumps is not highly variable with large changes in pressure like in most centrifugal pumps. They are preferred in applications where high head, low flow, and compact design are desired, such as in deep-well pumping.

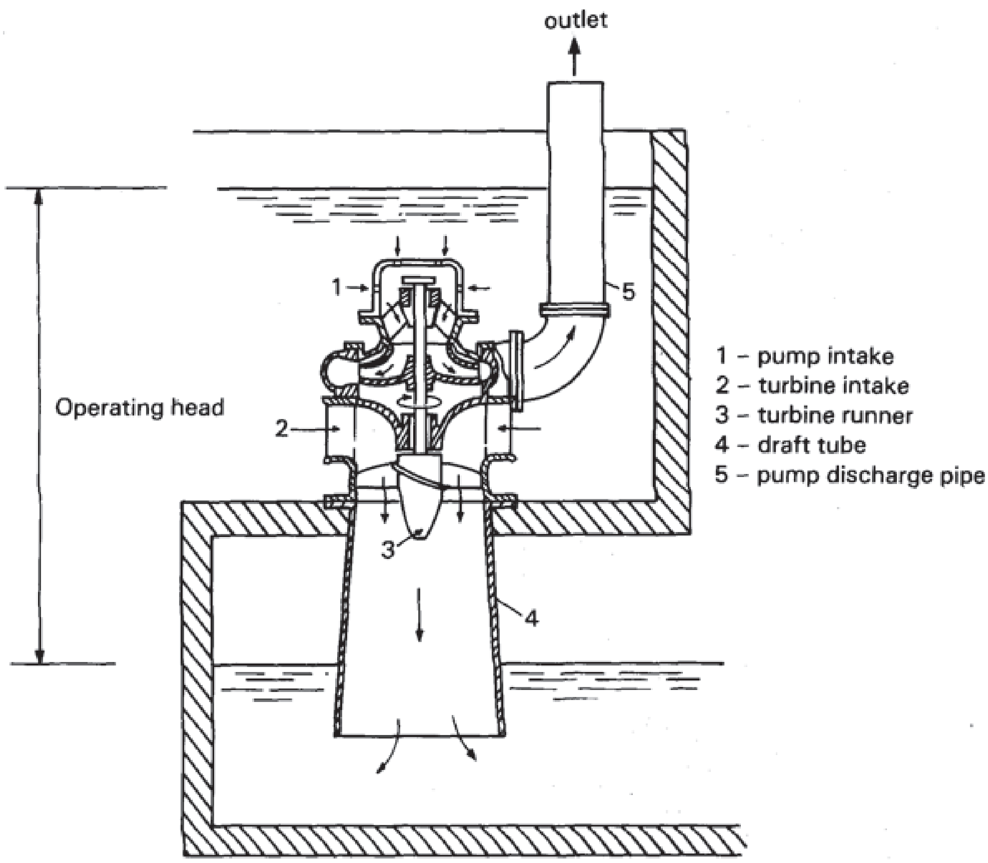


Figure 6.4: Typical turbine pump installation

Deep well turbine pumps are adapted for use in cased wells or where the water surface is below the practical limits of a centrifugal pump. The shaft usually extends down the centre of a large pipe. The water is pumped up this pipe and exits directly under the motor. The turbine pump has three main parts: (i) the head assembly, (ii) the shaft and column assembly and (iii) the pump bowl assembly as shown in Figure 6.5. The head is normally cast iron and designed to be installed on a foundation. It supports the column, shaft and bowl assemblies and provides a discharge for the water. It also will support an electric motor, a right angle gear drive or a belt drive. Often a turbine pump consists of multiple stages, each stage is essentially another pump stacked on top of the one below it.

Turbine pumps are also used with surface water systems. Since the intake for the turbine pump is continuously under water, priming is not a concern. Turbine pump efficiencies are comparable to or greater than most centrifugal pumps. They are usually more expensive than centrifugal pumps and more difficult to inspect and repair.

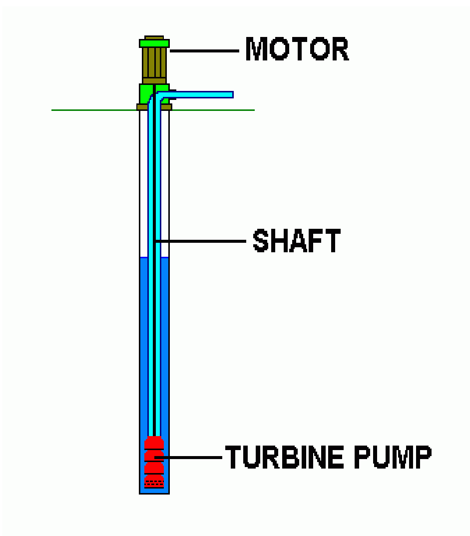
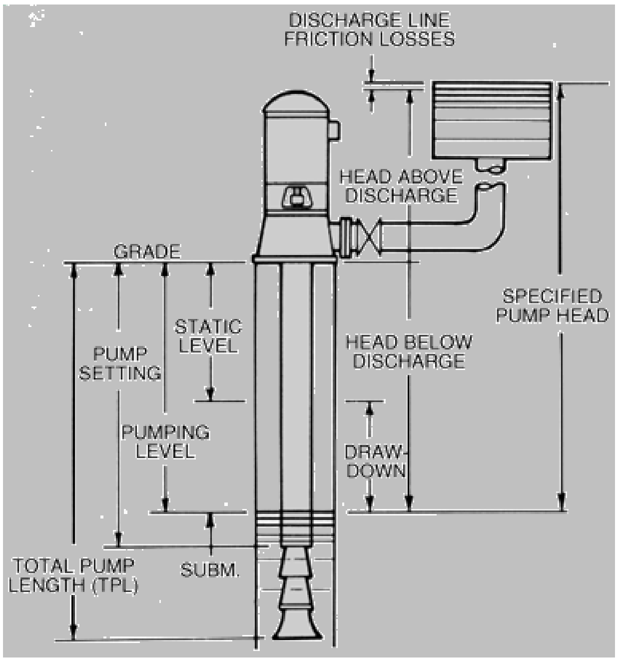


Figure 6.5 (a) Arrangement of a turbine pump installation



(b) Details of a vertical turbine pump

a) **Advantages of turbine pumps**

- Generates high head and high discharge pressure
- Better handling of gas-liquid mixtures
- Flow rate less variable with pressure change
- Compact design

b) **Limitations**

- Low flow rate
- Tight internal clearances require clean (no-solids) liquids
- Particularly susceptible to damage from improper assembly
- No easy way to adjust performance.

c) **General types of turbine pumps**

As with pumps, there are families of different types of turbine to deal with different types of situation. Briefly, these can be characterized as; (i) Low head e.g. propeller/Kaplan pumps, (ii) medium head e.g. Francis/Banki turbine and (iii) high head e.g. Pelton/Turgo turbine (Figure 6.6). Where variable flow and power is needed, adjustable gates are provided and the turbine runner may have fixed or adjustable pitch blades. The latter is known as a Kaplan turbine and is more efficient over a wider range of flows than a fixed pitch propeller turbine. But the complication of adjustable pitch runner blades is expensive, and therefore is only normally applied for larger-scale installations.

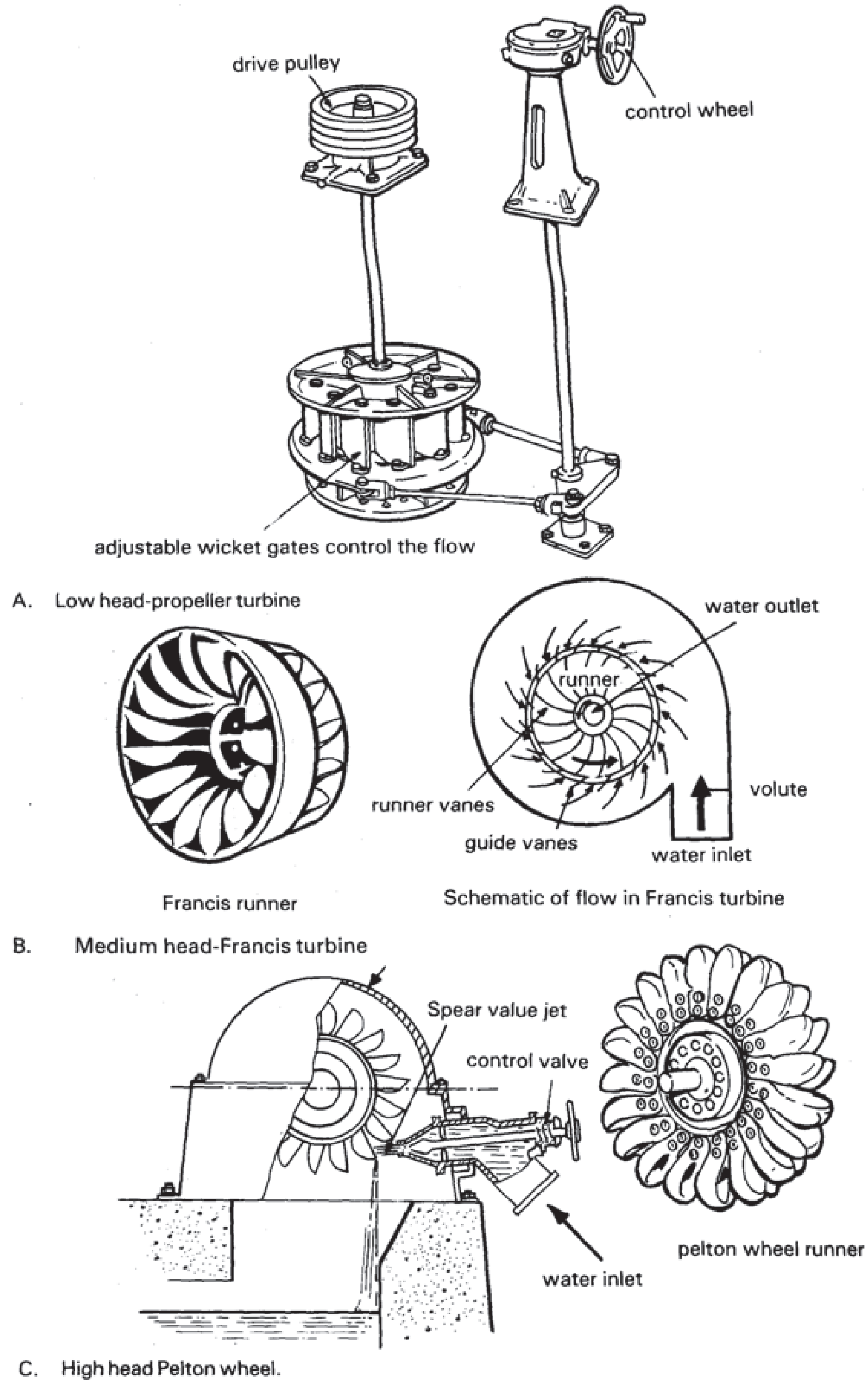


Figure 6.6 Illustration of major types of hydro-turbines for low, medium and high heads

d) **Design features of turbine pumps**

Designs and features of turbine pumps provide different facets of capability and functionality that may be important to consider.

- *Balanced impellers* - Turbine pumps with balanced or floating impellers generate very little axial thrust on the motor shaft, promoting longer bearing life.
- *Double-sided impellers* -Double-sided impeller design helps to reduce impeller wear by building pressure equally on both sides and creating a thin fluid film between the impeller and casing. This film also causes the impeller to self-adjust to its optimum axial position.
- *Close-coupled* - Close-coupled pumps have the pump end mounted directly on the motor shaft for a more compact design.
- *Multi-stage* - Multi-stage turbine pumps move the compressed fluid through multiple successive chambers or stages of pressurization. While most turbine pumps are single stage (one impeller and chamber) because of their high head impeller design, some implement multiple stages to generate even higher pressure levels.
- *Self-priming* - Certain turbine pumps may be design for self-priming or seamless operation, meaning they are constructed so they can create and maintain a sufficient vacuum level to draw fluid into the inlet with no external assistance.
- *Thermal overload protection* - Some pump motors include devices which will shut the pump off if the motor becomes too hot or exceeds a certain temperature.
- *Vertical orientation* - Turbine pumps with a vertical orientation, also called deep well pumps, are designed to pump media vertically through the pump body. They are specially designed for pumping water from deep water sources such as wells, and are mainly used over other types of pumps in applications where the water surface fluctuates regularly.
- *Submersible* - The motor on a turbine pump is typically above the liquid level, but some can be designed to be submerged in the media on a shorter drive shaft.

e) **Pump operation**

Turbine pumps are dynamic pumps, meaning they utilise fluid momentum and velocity to generate pump pressure. Specifically, they are centrifugal pumps, which generate this velocity by using an impeller to apply centrifugal force to the moving liquid. The main difference between a turbine pump and centrifugal pump is its impeller design. Compared to most centrifugal pumps, turbine pumps have smaller diameter impellers with rows of numerous small vanes. These vanes re-circulate the fluid as it travels from the suction end to the outlet. Specifically, fluid enters at the edge of an impeller blade (not through the eye) and is accelerated not only tangentially in the direction of rotation, but also radially outward into the casing channel by centrifugal force. As the fluid strikes the casing wall it is redirected back onto an adjacent blade (vane) where additional energy is imparted. This recirculation has the same effect as a multi-stage centrifugal pump, since it adds energy to the fluid at multiple points in the system, giving the turbine pump its characteristic high head capability, and hence the term "regenerative" pump.

6.3.4 Submersible pumps

A submersible pump is a turbine pump close-coupled to a submersible electric motor as shown in Figure 6.7. Both pump and motor are suspended in the water, thereby eliminating the long drive shaft and bearing retainers required for a deep well turbine pump. Because the pump is located above the motor, water enters the pump through a screen located between the pump and motor.

The pump components include the impeller, the pump casing and the required connection parts for different installation alternatives. These include a guide shoe for submersible installation onto a matching connecting base plate, a stand for portable pumps and the necessary connection flanges, stand for dry-installed pumps and seat ring for column-installed pumps. The motor is a dry squirrel-cage electric motor matching a range of pump parts for various duties. Motor and pump have a common shaft with the bearings and shaft seals housed in the motor. Power to the unit is fed through one or more flexible cables, supplied with the pump in lengths suitable for the installation. The motor also includes watertight cable inlets and a handle for lifting the unit.

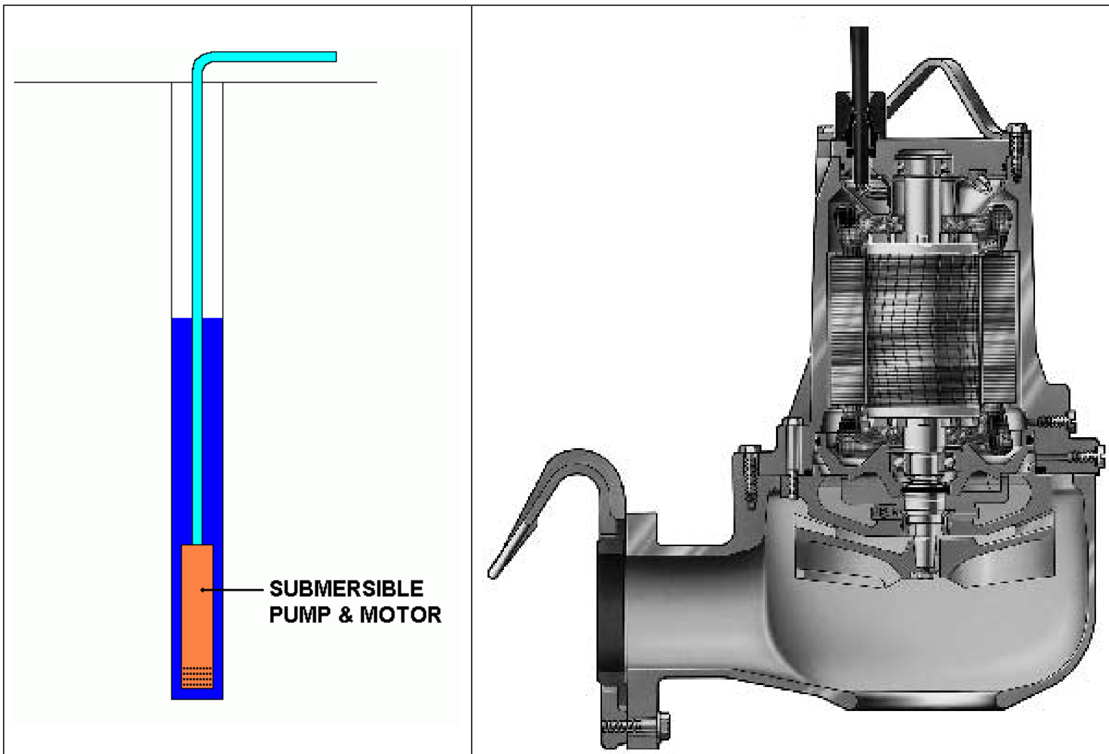


Figure 6.7 (a)General view of a submersible pump installation	(b) Section of a submersible pump showing details of motor and pump *(Source: Grundfos, 2010)*

Submersible pumps are installed completely underwater, including the motor. The pump consists of an electric motor and pump combined in a single unit. Typically the pump will be shaped like a long cylinder so that it can fit down inside of a well casing. Although most submersible pumps are designed to be installed in a well, many can also be laid on their side on the bottom of a lake or stream. Another common installation method for lakes and rivers is to mount the submersible pump underwater to the side of a pier pile (post). Submersible pumps don't need to be primed since they are already under water. They also tend to be more efficient because they only push the water, they don't need to suck water into them.

Submersible motors are smaller in diameter and much longer than ordinary motors. Because of their smaller diameter, they are lower efficiency motors than those used for centrifugal or deep well turbine pumps. Submersible motors are generally referred to as dry or wet motors. Dry motors are hermetically sealed with a high dielectric oil to exclude water from the motor. Wet motors are open to the well water with the rotor and bearings actually operating in the water.

Most submersible pumps must be installed in a special sleeve if they are not installed in a well, and sometimes they need a sleeve even when installed in a well. The sleeve forces water coming into the pump to flow over the surface of the pump motor to keep the motor cool. Without the sleeve the pump will burn up. Because the power cord runs down to the pump through the water it is very important that it be protected from accidental damage.

6.3.5 Propeller pumps

Propeller pumps are used for low lift, high flow rate conditions. They come in two types, axial flow and mixed flow. The difference between the two is the type of impeller. The axial flow pump uses an impeller that looks like a common boat motor screw and is essentially a very low head pump. A single-stage propeller pump typically will lift water no more than 6 m. By adding another stage, heads from 10 to 15 m are obtainable. The mixed-flow pump uses either semi-open or closed impellers similar to turbine pumps.

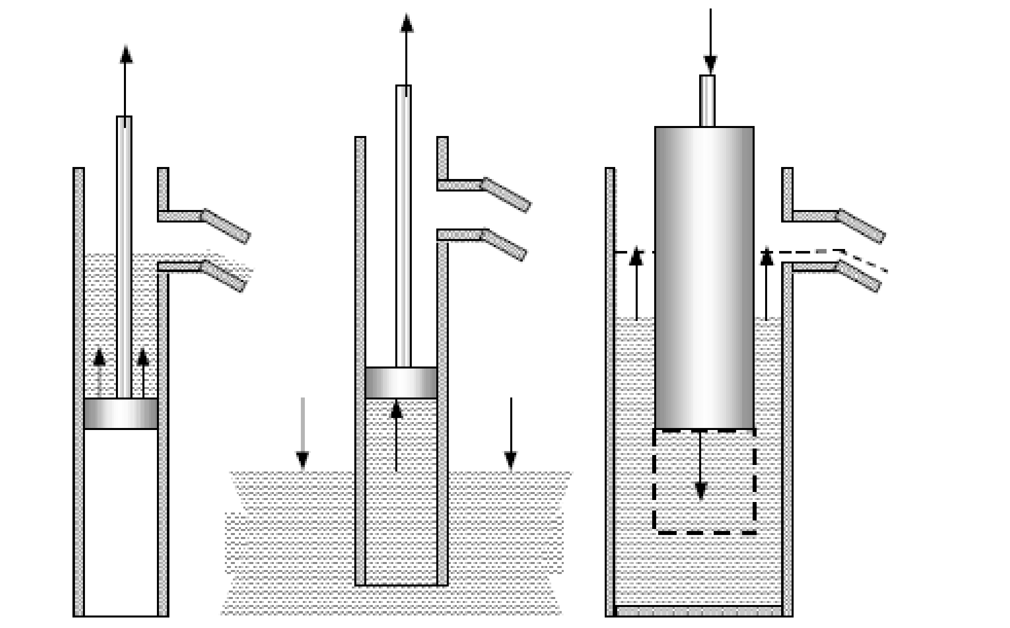
In permanent installations, propeller pumps are mounted vertically mounted. For portable pumping platforms, they are mounted on trailers or they are mounted on pontoons for use as floating intakes. Portable propeller pumps are commonly mounted in almost horizontal positions (low angles) to allow them to pump into pipelines easily as well as to be backed into a water source. Portable propeller pumps are commonly powered by the power-take-off (PTO) of a tractor. On many farms, propeller pumps are used to pump out waste storage lagoons.

Propeller pumps are not suitable for suction lift. The impeller must be submerged and the pump operated at the proper submergence depth. The depth of submergence will vary according to various manufacturers' recommendations, but generally, the greater the diameter of pump, the deeper the submergence. It is necessary to use the recommended submergence depths so that the flow rate is not reduced due to vortices. Also, failure to observe required submergence depth may cause severe mechanical vibrations and rapid deterioration of the propeller blades.

6.3.6 Positive displacement pumps

A positive displacement pump (or volumetric pump) is a type of pump which is driven by a shaft from a surface-mounted motor, and is suitable for high head and low flow rate applications (Figure 6.8). Positive displacement pumps are categorized into two types: submersible (diaphragm) and non-submersible (jack, piston, and rotary vane). They have seals or mating surfaces that can wear, so most require regular maintenance to replace or repair worn parts. Such parts can easily wear with dirty water even though filters are sometimes used. The most common is the Jack pump. Generally, positive displacement pumps are best for low flows (less than 15 m3/d) and high pumping heads (30–150 meters).

The water output of a positive displacement pump is almost independent of head but is directly proportional to speed, meaning that the efficiency of a pump of fixed piston diameter increases with head. Different diameters of pumps need to be used for different heads to result in optimum efficiency. At high heads the frictional forces become small relative to the hydrostatic forces. At high speeds positive displacement pumps can be more efficient than centrifugal pumps. At low heads (below about 15 meters), the total hydrostatic forces are low in relation to the frictional forces. Therefore, these pumps are less efficient and are less likely to be used.



(a) Direct Lift (b) Suction (c) Displacement

Figure 6.8 Basic operating principles of positive displacement pumps

a) Jack pumps

Jack pumps function much like windmills except that they are powered by electric motors. Like the windmill, the reciprocating jack is connected by a long sucker rod to a cylinder. Jack pumps require regular maintenance, especially because the leathers on the plunger at the end of the long sucker rod can wear out easily and must be replaced every 6 to 24 months depending on the hours of use. The leather is used to create seal against the cylinder. Jack pumps are generally used for medium applications at medium depth.

b) Piston pumps

Piston pumps are generally connected to a surface-mounted motor and used to pump water from shallow wells, surface water sources, and pressurized storage tanks, or through long pipes. The suction head is limited to 6 meters. They are not tolerant to silt, sand, or abrasive particles because the piston seals are easily damaged. Filters may be used to remove the dirt.

c) Diaphragm pumps

Diaphragm pumps are sometimes called submersible positive displacement pumps and are often used for small applications, such as pumping small quantities of water from deeper wells or water tanks where surface pumps are limited by their suction head. Such pumps can also be used for pressurized storage tanks to lift water to a discharge head above the ground surface. Diaphragm pumps generally use DC motors. They require periodic maintenance depending on the depth of head pumped and their operational hours. The brushes of the DC motor must be changed every 2,000–4,000 hours and the elastic diaphragm must be replaced every 12 to 24 months depending on the hours of use.

d) Rotary vane pumps

Rotary vane pumps (sometimes called helical rotor pumps) operate according to a displacement principle for lifting or moving water by using a rotating form of dispenser. They contain spinning rotors with vanes that seal against the casing walls. Such pumps are mostly surface-mounted because of suction head limitations. The suction head is limited to 6 meters. They produce a continuous or sometimes a slightly pulsed water output. Types of rotary vane pumps include flexible toothed rotor (or flexible vane pumps), progressive cavity (mono) pumps, Archimedean screw and open screw pumps, and coil and spiral pumps.

The unique advantage of helical rotor pumps over centrifugal pumps is their ability to operate efficiently over a wide speed ranges and heads, whereas the efficiency of centrifugal pumps deteriorates from the rated speed. A main advantage of helical rotor pumps is their ability to pump water at either low or higher motor speed levels, which correspond to higher or low, pump speeds, which lead to higher volumes of pumped water per day even at low motor speeds. Unlike reciprocating devices, rotary vane pumps have steady drive conditions, which may eliminate the problem of water hammer and cavitations. Rotary vane pumps are not tolerant to silt, sand, or abrasive particles, so filters may be used to remove dirt.

6.3.7 Floating pumps

A floating pump is simply a submersible pump or a turbine pump that is attached to the bottom of a float. The pump hangs below the float, and the float is anchored in a lake, pond, or river. A flexible pipe is used to take the water from the pump to the irrigation system. A floating pump is a good option to look into for installing a pump in a pond or lake. It is often much easier to install than a standard submersible, jet-pump, or turbine and is much more energy efficient than an end-suction centrifugal. Floating fountains and pond aerators are another utilisation of floating pump technology.

6.3.8 Booster pumps

A booster pump is any type of pump used to increase the pressure of water that is already on its way. It differs from other types of pumps which are used to take water from a standing (or non-pressurized) source and move it to another location. For example, a pump might take water from a reservoir and move it to a sprinkler system. But a booster pump may be used to increase the pressure of the water within the farm so that the sprinklers can rotate. Booster pumps are also used in canal irrigation to lift the water from the canal to the field where gravity flow is problematic. They are used in ground water pumping to increase delivery pressure and push the water to an elevated tank.

6.4 Pump selection and installation

6.4.1 Identifying type of pump for irrigation

The design and/or selection of an irrigation water pump is based almost entirely on the relationship between pump efficiency and the total dynamic head (TDH) that the pump will provide at a specific flow rate. These parameters are also the basis of the pump characteristic curve. Table 6.1 shows the various advantages and disadvantages of types of pumps commonly used in irrigation, and can be used to narrow the selection of a pump type.

Table 6.1 Factors considered in selecting an irrigation pump

Item	Advantages	Disadvantages
	Centrifugal pump	
	High efficiency over a range of operating conditions	Suction lift is limited. It needs to be within 7 m of the water surface.
	Easy to install	Priming required
	Simple, economical and adaptable to many situations	Loss of prime can damage pump
	Electric, internal combustion engines or tractor power can be used.	If the TDH is much lower than design value, the motor may overload
	Does not overload with increased TDH.	
	Vertical centrifugal may be submerged and not need priming	
	Vertical Turbine Pump	
	Adapted for use in wells.	Difficult to install, inspect, and repair.
	Provides high TDH and flow rates with high efficiency	Higher initial cost than a centrifugal pump
	Electric or internal combustion power can be used	To maintain high efficiency, the impellers must be adjusted periodically
	Priming not needed	Repair and maintenance is more expensive than centrifugal pumps
	Can be used where water surface fluctuates	
	Submersible Pumps	
	Can be used in deep wells	More expensive in larger sizes than deep well vertical turbines
	Priming not needed	Only electric power can be used
	Can be used in crooked wells	More susceptible to lightning
	Easy to install	Water movement past motor is required
	Smaller diameters are less expensive than comparable sized vertical turbines	
	Propeller Pumps	
	Simple construction	Not suitable for suction lift
	Can pump some sand	Cannot be valved back to reduce flow rate
	Priming not needed	Intake submergence depth is very critical
	Efficient at pumping very large flow rates at low TDH	Limited to low (less than 25 m) TDH
	Electric, internal combustion engine and tractor power can be used.	
	Suitable for portable operation.	

6.4.2 Pump performance curve

A pump's performance is usually presented in terms of a characteristics performance curve, as the pump capacity i.e. flow rate is plotted against its developed head (Figure 6.9). The capacity and pressure needs of any system can be defined with the help of a graph called a *system curve*. Similarly the capacity *vs.* pressure variation graph for a particular pump defines its characteristic *pump performance curve*. The pump performance curve also shows its efficiency (BEP), required input power, NPSH, speed (in RPM), and other information such as pump size and type, impeller size, etc. This curve is plotted for a constant speed (rpm) and a given impeller diameter (or series of diameters). It is generated by tests performed by the pump manufacturer. Pump curves are based on a specific gravity of 1.0, being the value for clean water.

The pump suppliers try to match the system curve supplied by the user with a pump curve that satisfies these needs as closely as possible. A pumping system operates where the pump curve and the system resistance curve intersect. The intersection of the two curves defines the operating point of both pump and process. However, it is impossible for one operating point to meet all desired operating conditions. For example, when the discharge valve is throttled, the system resistance curve shift left and so does the operating point.

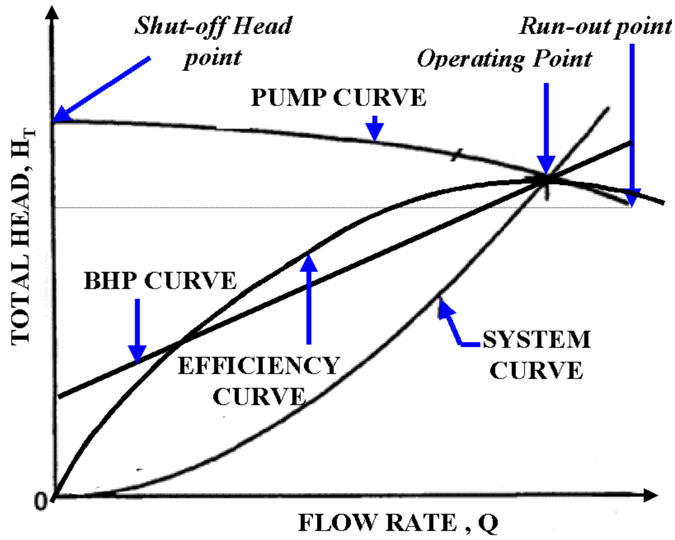


Figure 6.9: Typical system and pump performance curves *(Source: Mukesh, 2010)*

When the desired flow rate and total dynamic head are known, these curves are used to select a pump. The pump curve shows that a pump operates over a wide range of conditions. However, it will operate at peak efficiency only in a narrow range of flow rate and total dynamic heads. But for many pumping systems, total system head requirements vary. For example, in wet well or reservoir applications, suction and static lift requirements may vary as the water surface elevations fluctuate and it is necessary to know a pump's net positive suction head requirements. Centrifugal pumps require a certain amount of fluid pressure at the inlet to avoid cavitation. A rule of thumb is to ensure that the suction head available exceeds that required by the pump by at least 25% over the range of expected flow rates. Process requirements may be met by providing a constant flow rate (with on/off control and storage used to satisfy variable flow rate requirements), or by using a throttling valve or variable speed drive to supply continuously variable flow rates. The correct type of pump can be decided based on the pump characteristics which are usually provided by the manufacturer.

When a pump has been selected for an irrigation installation, a copy of the pump curve should be provided by the installer. In addition, if the impeller(s) was trimmed, this information should also be provided. This information will be valuable in the future, especially if repairs have to be made.

6.4.3 Identifying pump specific speed

Specific speed as a measure of the geometric similarity of pumps.

It is a non-dimensional design index that identifies the geometric similarity of pumps. It is used to classify pump impellers as to their type and proportions. Pumps of the same specific speed but of different size are considered to be geometrically similar, one pump being a size- factor of the other. Normally, pumps are rated by their power requirement, flow rate, outlet pressure and inlet/suction head needed. However, the total head can be simplified as the number of metres the pump can raise a column of water at atmospheric pressure. From an initial design point of view, the specific speed of a pump is used to identify the most suitable pump for a given combination of flow rate and head.

6.4.4 Pump operating efficiency

The pump operating efficiency is usually specified by the manufacturer based on pumping of clear water at known temperatures. The major factors that affect pump efficiency include specific speed, pump size, net positive suction head (NPSH) available and NPSH required, viscosity of the fluids being pumped, temperature, specific gravity, and pump type(Figure 6.10).

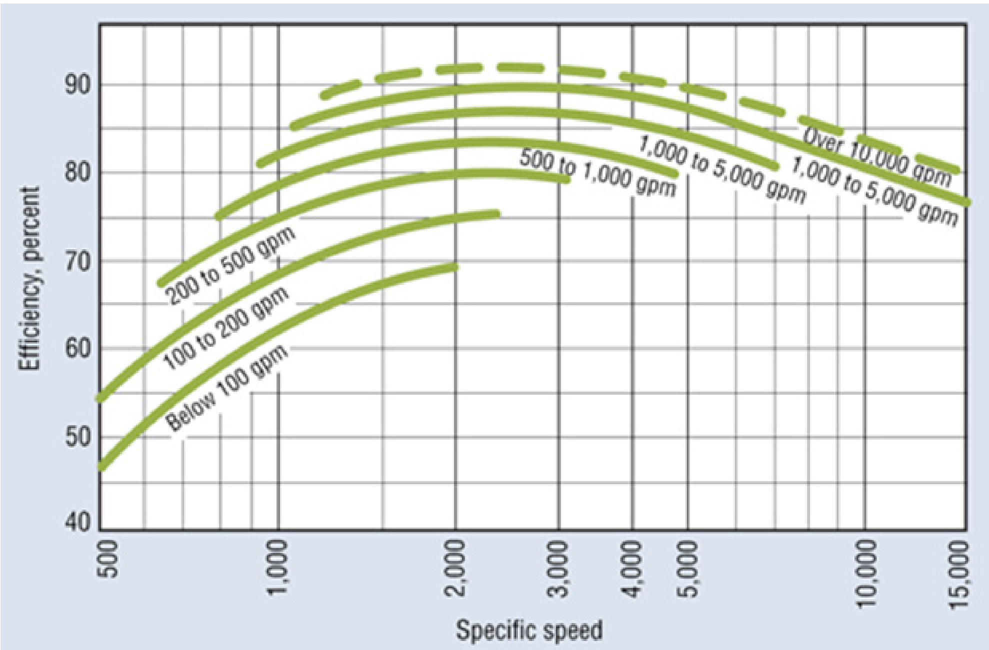


Figure 6.10: Typical pump characteristic chart relating specific speed with efficiency
(Source: Hydraulic Institute)

A good high-flow-and-head pump would have an optimum generally attainable efficiency of 89 percent with no correction factor. Factors affecting deviation from optimum pump efficiency include its operational surface roughness; internal clearances; mechanical losses, such as those related to bearings, lip seals, mechanical seals, and packing; high suction specific speed; impeller trim; and the viscosity of the fluid pumped. Low-specific-speed pumps are affected most by surface roughness, internal clearances, and mechanical losses. High-specific-speed pumps are affected most by high-suction-speed requirements, impeller trim, and viscosity.

6.4.5 Pump power transmission

There are four types of transmission usually applied to irrigation pumps: direct coupling, flat belt, V-belt and gear. Direct coupling generally implies negligible or no loss of power. The loss of power through flat belt varies from 3- 20%. Transmission losses for V-belt and gear drive, as a rule, do not exceed 5%. Thus, the choice of power transmission has great impact on pump performance.

6.4.6 Siting of a pump

After the required pump has been identified, it must be installed properly to give satisfactory service and be reasonably trouble-free. Pumps are usually installed with the shaft horizontal, occasionally with the shaft vertical. A piping system if improperly designed or poorly installed can promote the formation of air pockets or vortices that may impede flow. Piping that runs into the suction inlet should be very straight since disrupted flow can impair pump efficiency and performance. In addition, the piping should be well aligned with the pump connections. The careful selection of a suitable location for a pumping station is also very important in irrigation development. For permanent pumping stations pumps are installed on concrete plinth or foundation, the size of which varies in relation to the size of the pumping unit. The cost of a pumping station is divided into investment costs, costs of operation and costs of maintenance and repair. These costs are carefully assessed during the various stages of the design process in order to make comparisons for the different options more meaningful.

6.4.7 Pipes and piping

A pipe is a closed conduit which transmits water normally at some pressure. This makes pipes ideal for water transmission from pumped systems. However, a pipe can operate like a channel with a roof on it, i.e. it can be unpressurized, often with water not filling it. Compared to canals, piped water delivery has many advantages. For instance a pipe need not follow the hydraulic gradient like a canal. It does not suffer seepage losses and uses almost no space on the land since it can be buried. Although pipes are more expensive than canals in relation to their carrying capacity, they generally do not require accurate leveling and grading or maintenance and are therefore more cheaply and simply installed. They are of course essential to convey water to a higher level or across uneven terrain. Generally, piping systems are connected to a pump; (i) the suction pipe, and (ii) the delivery pipe.

a) Suction pipe

The suction pipe connects the pump inlet to the water source. The diameter of a suction pipe should be bigger than the inlet opening of the pump and it should be as short and direct as possible. If a long suction pipe must be used, then the diameter should be increased. Air pockets and high spots in a suction pipe should not be allowed as they cause problems. The suction pipe should be flushed out with clear water before connection. This is done so as to ensure that it is free of materials that might later clog the pump. After installation, the suction pipe should be blanked off and tested hydrostatically for air leaks before the pump is operated. A strainer should be placed at the end of the inlet pipe to prevent clogging. Ideally the strainer should be at least four times as wide as the suction pipe. A foot valve may be installed for convenience in priming. The size of the foot valve should be such that frictional loses are very minimal.

b) Delivery pipe

The delivery pipe connects the pump outlet to the water point of use, irrigated fields or water storage. It should be as short and free of elbows as possible, in order to reduce friction. A gate valve followed by a check valve should be placed at the pump outlet. The non-return valve prevents backflow from damaging the pump when the pumping action is stopped. The gate valve is used to gradually open the water supply from the pump after starting and to avoid overloading the motor. The same valve is also used to shut off the water supply before switching off the motor.

6.4.8 Coupling

Most pumps are delivered to the user when already mounted. Thus, it is usually not necessary to remove either the pump or the driving unit from the base plate. The unit should be placed above the foundation and supported by short strips of steel plate and wedges. A spirit level can be used to ensure a perfect levelling. Levelling is a prerequisite for accurate alignment. To check the alignment of the pump and drive shafts, place a straightedge across the top and side of the coupling, checking the faces of the coupling halves for parallelism. The clearance between the faces of the couplings should be such that they cannot touch, rub or exert a force on either the pump or the driver.

6.4.9 Grouting

The grouting process involves pouring a mixture of cement, sand and water into the voids of stone, brick, or concrete work, either to provide a solid bearing or to fasten anchor bolts. A wooden form is built around the outside of the bedplate to contain the grout and provide sufficient head for ensuring flow of mixture beneath the only bedplate. The grout should be allowed to set for 48 hours; then the hold-down bolts should be tightened and the coupling halves rechecked.

6.5 Operation and maintenance of pumping units

All pump manufacturers provide users with operation and maintenance manuals, which are specific to their pumps. These have to be closely adhered to in order to ensure the most efficient operation of the pump and avoid unnecessary pump breakdowns. There are certain procedures that are recommended by pump manufactures before any pump start-up. Some of the pre-start-up inspections recommended immediately after pump installation are checking for correct pump-motor wiring connections, valve connections, shaft and gland clearance. Different manufacturers also have specific instructions for pump shut down after operation. These have to be adhered to strictly.

6.5.1 Parallel pumping

An energy efficient method of flow control, particularly for systems where static head is a high proportion of the total head, is to install two or more pumps to operate in parallel. Variation of flow rate is achieved by switching on and off additional pumps to meet demand. It is possible to run pumps of different sizes in parallel provided that their closed valve heads are similar. By arranging different combinations of pumps running together, a larger number of different flow rates can be provided into the system.

6.5.2 Series pumping

Pumps in series double the head at the same flow condition point. One pump discharge is piped into the suction of the second pump producing twice the head capability of each pump separately. The second pump however must be capable of operating at the higher suction pressure, which is produced by pump number one. For instance, two identical centrifugal pumps operating at the same speed with the same volumetric flow rate contribute the same pump head. Since the inlet to the second pump is the outlet of the first pump, the head produced by both pumps is the sum of the individual heads. However, the volumetric flow rate from the inlet of the first pump to the outlet of the second remains the same. Series pumping is a cost effective way of overcoming high discharge heads when the flow requirement remains the same.

6.5.3 Stop–start control

A minimum-flow control arrangement for pump protection can be achieved using a flow switch to start and stop the pump but this requires instrument air for the control valve. In this method switching pumps on or off controls the flow. It is necessary to have a storage capacity in the system e.g. a wet well, an elevated tank or an accumulator type pressure vessel. The storage provides a steady flow to the system with an intermittent operating pump. The stop/start operation causes additional loads on the power transmission components and increased heating in the motor. The frequency of the stop/start cycle should be within the motor design criteria and checked with the pump manufacturer. It may also be used to benefit from "off peak" energy tariffs by arranging the run times during the low tariff periods. To minimise energy consumption with stop-start control it is better to pump at as low flow rate as the process permits. This minimises friction losses in the pipe and an appropriately small pump can be installed. For example, pumping at half the flow rate for twice as long can reduce energy consumption to a quarter.

6.5.4 Flow control valves

In this approach, the pump runs continuously at the maximum process demand duty, with a permanent by-pass line attached to the outlet. When a lower flow is required the surplus liquid is by-passed and returned to the supply source. An alternative configuration may have a tank supplying a varying process demand, which is kept full by a fixed duty pump running at the peak flow rate. This is even less energy efficient than a control valve because there is no reduction in power consumption with reduced process demand.

6.5.5 Pump priming

Priming is the removal of air from the pump and the suction during start up. This is done by filling the pump and suction pipe with water to displace the air. This can be achieved by connecting a tank to the pump and a foot valve to the suction pipe. The tank is filled with water before the system is switched on; the water from the tank is diverted to the pump and suction pipe via a valve. Another popular priming method is the use of a manually operated vacuum pump. At times, horizontal centrifugal pumps are installed at a dam outlet. In this case no priming is required since the water level inside the dam is higher than the level of the impeller, which forces the water to remove all the air from the suction pipe and the volute of the pump. The pump must not be run unless it is completely filled with water; otherwise there is danger of damaging some of the pump components. Wearing rings, bushings, seals or packing and internal sleeve bearings all need liquid for lubrication and may seize if the pump is run dry. Therefore, pumps that are not self-priming or those with a positive suction lift should be primed before they are started.

6.5.6 Starting the pump

The pump is started with the gate valve closed. This is because the pump operates at only 30-50% of full load when the discharge gate valve is closed. In cases where the pump is below the water source, the pump can be started with an open gate valve. To avoid water hammer, the gate valve has to be opened gradually until it is fully open.

Cavitation is a problem caused by operating a pump with suction lift greater than it was designed for, or under conditions with excessive vacuum at some point in the impeller. Cavitation is the implosion of bubbles of air and water vapour and makes a very distinct noise like gravel in the pump. The implosion of numerous bubbles will eat away at an impeller and it eventually will be filled with holes.

6.5.7 Pump testing

Pumps are usually tested by fitting a flow meter, measuring the pressure difference between inlet and outlet, and measuring the power consumed. Another method is thermodynamic pump testing where only the temperature rise and power consumed are measured. Pumps and pumping stations should be regularly tested to minimise energy use and to ensure that they are correctly matched to the water demands expected. When used for water supply applications fitted with centrifugal pumps, individual large pumps should be at least 70 - 80% efficient. Each pump should be individually tested to ensure they are in the appropriate range, and replaced or prepared as appropriate. Pumping stations should be tested collectively, because where pumps can run in combination to meet a given demand, it is often possible for very inefficient combination of pumps to occur. For example, it is possible to have a large and a small pump operating in parallel, with the smaller pump not delivering any water, but consuming energy.

6.5.8 Pump problems and remedies

The following Table 6.2 shows some general causes of pump malfunctioning and their remedies that can be used for on-spot trouble-shooting when pump problems are encountered.

Table 6.2 Summary of pump problems and possible corrective measures

Symptoms	Causes	Corrective Measures
Failure to pump	• Pump not properly primed • Speed too low or high • Not enough head to open check valve • Air leak • Plugged section • Excessive suction lift	• Prime pump correctly • Check speed, check calculations, consult with manufacturer • Check speed, check calculations, consult with • manufacture Check and rework suction line • Unplug section • Check NPSH and consult manufacturer
Rapid wear of coupling	o Misalignment o Bent shaft	o Align o Replace
Reduced performance	• Air pockets or small air leaks in suction line • Obstruction in suction line or impeller • Insufficient submergence of suction pipe • Excessively worn impeller or wear ring • Excessive suction lift • Wrong direction of rotation	• Locate and correct • Remove obstruction • Extend suction line to deeper water to the extent that NPSH allows you or excavate and deepen the area where the suction basket is located • Replace impeller and/or wear ring • Calculate NPSH, consult with manufacturer • Ask contractor to rectify

Driver overloaded	o Speed higher than planned o Water too muddy o Too large an impeller diameter o Low voltage o Stress in pipe connection to pump o Packing too tight	o Reduce speed o Raise suction o Trim impeller o Consult power authority o Support piping properly o Loosen packing gland nuts
Excessive noise	• Misalignment • Excessive suction lift • Material lodged in impeller • Worn bearings • Impeller screw loose or broken • Cavitation • Wrong direction of rotation	• Align all rotating parts • Check NPSH, consult with manufacturer • Dislodge obstruction • Replace bearings • Replace • Check NPSH, correct suction piping • Ask contractor to rectify
Premature bearings failure	o Worn wear ring o Misalignment o Suction or discharge pipe not properly supported o Bent shaft	o Replace o Align all rotating parts o Correct support o Replace shaft
Electric motor failure	• High or low voltage • High electric surge • Poor electric connection • Overloads • Bearing failure • Cooling vent plugged (rodent, dirt, leaves) • Moisture or water in motor	• Check voltage and consult power authority • Monitor voltage and consult power authority • Turn power off, clean and check connections • Check amperage, do not exceed full load amperage • Change motor bearing • Install proper screen • Send for blow-dry and protect from environment

Source: Andreas & Karen, 2001

6.5.9 Stopping the pump

The first step is to close the gate valve. This eliminates surges that may occur in case of an abrupt closure. When this has been done, the prime mover is then closed or shut down. If the pump remains idle for a long time after it is stopped, it gradually loses its priming. Thus the operator should re-prime the pump every time before start-up.

6.5.10 Maintenance of pumps

Regular maintenance is necessary for all kinds of pumps. Keeping up with maintenance can reduce the costs of repairs and expensive replacements, while also having the added benefits of reducing fuel/energy costs and minimizing pumping time. Pump maintenance checks should be performed regularly. Keeping pumps operating successfully for long periods of time requires careful pump design selection, proper installation, careful operation, the ability to observe changes in performance over time, and in the event of a failure, the capacity to thoroughly investigate the cause of the failure and take measures to prevent the problem from re-occurring.

The suction line, fittings and pipe plugs should be airtight. The suction line should be checked for air leaks by using a vacuum gauge. All leaky seals or hoses that have deteriorated should be replaced. The suction strainer should be inspected and cleaned to keep from clogging. The pump cover panel should be removed and checked including the impeller vanes and wear plate or wear rings for the recommended clearance. Other components to be inspected include the main pump seal, which is usually a pressurized double seal with either a spring-loaded grease cup or titanium carbide seal. The seal should be air and water-tight. Pump bearings should be checked for wear, which can cause overheating issues if not promptly replaced. The pump bearings should be lubricated. The pump motor should be checked to ensure that it is functioning correctly

The operating condition of the discharge line, as well as any air release devices, valves, check valves and shock control devices should be regularly checked. The discharge line should be checked to find out if it is rusting or pitting. All components that have deteriorated should be replaced to avoid excessive friction, which can lead to pump overheating and eventual failure.

7. RENEWABLE ENERGY AND MANUAL PUMPS

7.1 Why renewable energy for pumps

Pumping is work done to move a certain amount of fluid/water up, some distance or height. This work requires a source of energy, which can be the most expensive component in a pumped irrigation enterprise. The rising cost of fuel and environmental concerns associated with use of fossil fuels requires the need to explore other energy sources for pumping, which are more cost effective, easily adaptable by smallholder farmers and eco-friendly. These alternative sources of energy are sometimes referred to as **appropriate technologies** or **renewable energy** sources. The pumps using these technologies carry the respective name of the prime mover and range from simple **manually operated pumps** to those utilising renewable energy sources such as solar, wind and flowing water. These are briefly described as follows:

7.1.1 Benefits of renewable energy for irrigation

Most sources of renewable energy tend to be relatively predictable because the energy available over a period of a few days in a given location at a given time of the year does not vary much from year to year. Renewable energy can be excellent options in remote areas where electric pumping is not available or is unviable. Renewable energy sources are also a good option when only a small amount of water needs to be pumped. Moreover, after installation, most renewable energy pumps have minimal operating costs. The manual methods of pumping make use of idle labour during the long dry season typical of many parts of Africa, thus creating employment while increasing productivity of water and land. Renewable energy sources are climate-smart and most of them do not impact negatively on the environment. Furthermore, since renewable energy increases the opportunity for sustainable pumped irrigation.

7.1.2 Limitations of renewable energy for irrigation

A major limitation of renewable energy as compared to fuels is the apparent randomness of wind or solar availability. Whereas the provision of fuel can usually be arranged by the user, nobody can make the wind blow or make the sun shine on demand. There is therefore an obvious qualitative difference between wind and solar powered devices which can only function under certain weather conditions. The problem is more one of covering a mismatch that can occur between the rate at which energy is available and the demand. This can often be overcome either by choice of technique or by including a storage facility. Where pumping is for irrigation, a cost-effective solution is to introduce a storage tank between the pump and the field; (in some cases the field itself can act as a storage tank). Another method for small scale energy storage is to use lead-acid electrical batteries, but this becomes prohibitively expensive except when small amounts of energy of less than about l-2KWh need to be stored. However, batteries require replacing from time to time and they also need maintenance.

7.2 Solar pumps

7.2.1 What is a solar pump?

A solar pump is one that is powered by the sun's energy, either directly by converting the solar resource into electricity or indirectly by using solar-thermal heat collectors. A pump powered by directly converting solar energy into electricity is called a PV pump, and is one of the most reliable technologies for pumping water from boreholes, rivers, lakes, shallow wells, and canals. Because of the PV array's modularity, the pumps can be redesigned as the demand increases by changing the motor-pump subsystem as long as the borehole yield is sufficient. Generally, a typical solar powered pumping system consists of a solar panel array that powers an electric motor, which in turn powers a bore or surface pump. The water is often pumped from the ground or stream into a storage tank that provides a gravity feed, so energy storage is not needed for these systems. Solar-powered photovoltaic pumps (PVPs) have the potential to promote rural development by simultaneously delivering a reliable water source while reducing dependence on expensive fossil fuels. This is because solar energy can be directly converted into electricity for water pumping and other applications with thermoelectricity or PV cells.

7.2.2 Components of a solar pump

Solar power is a renewable source of energy for pumping irrigation water. When the sun is shining the solar power is available during the day when water can be pumped and utilised or stored in tanks and reservoirs (Figure 7.1). By adding a suitable battery, power can be made available 24 hours per day enabling watering in the evenings or at night. A typical solar-powered pumped irrigation system is made up of the following components: (i) the water sources, usually a shallow well, borehole, river or reservoir, (ii) an array mounting bracket and rack, (iii) pump controller, (iv) electrical ground for controller, (v) DC pump with safety ropes, mount, and well seal, (vi) wiring, (vii) discharge tubing or piping, (viii) storage tank, (ix) tank flotation switch, and, (x) water taps or access points.

Figure 7.1 A solar powered pump with surface tank *(Source: ClimateTechWiki)*

Solar powered water pumping systems are similar to any other pumping system, only the power source is solar energy. PV pumping systems have, as a minimum, a PV array, a motor, and a bore pump. Solar water pumping arrays are fixed mounted or sometimes placed on passive trackers (which use no motors) to increase pumping time and volume. AC and DC motors with centrifugal or displacement pumps are used.

The switch to turn on the pump can be located beside the secondary tank so that it can be switched on and off easily. This can be achieved using a run of cheap bell wire or a wireless doorbell can be converted to activate the pump remotely. The panel and battery can easily be located in the farm and the main tank can be above ground or underground with piping to the irrigated area (Figure 7.2).

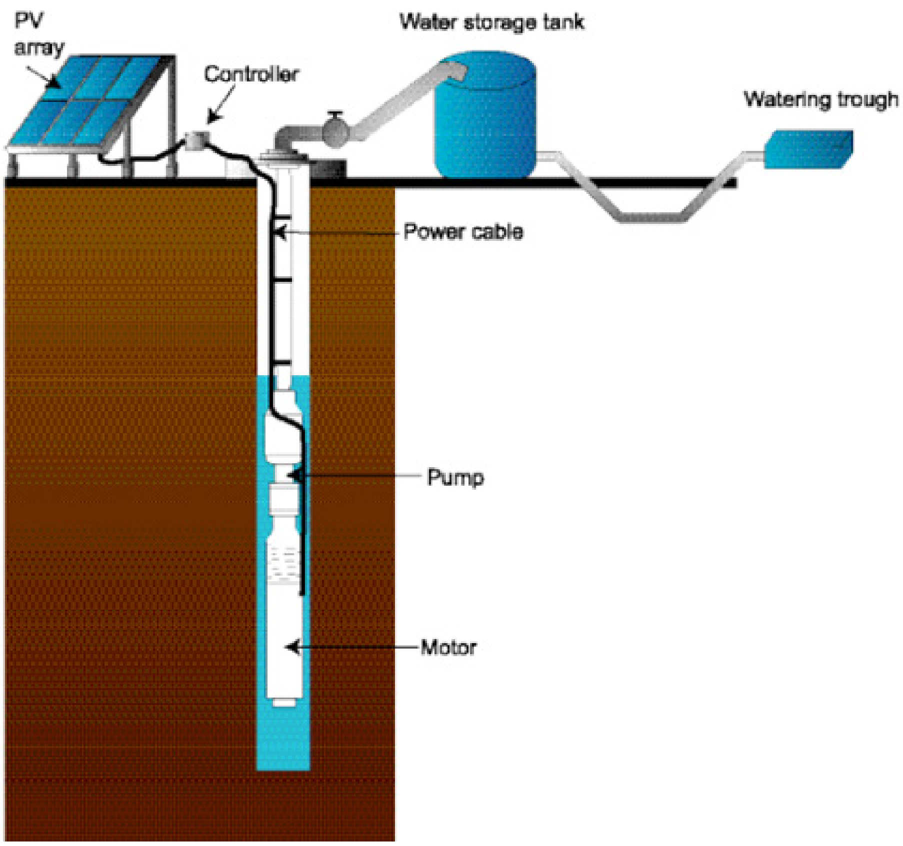


Figure 7.2 Components of a solar powered pump with well *(Source: Enciso and Mecke, 2001)*

7.2.3 Determining TDH for a solar pump

As the sun's incident energy on a photovoltaic cell changes during the day, positioning of the solar array is critical for full performance of the system. The location selected for the installation of the solar array should have unrestricted sun exposure throughout the day and through the year. The solar array can be placed several hundred metres or more from the well head. There is no loss of performance if the electrical wire is sized properly, but naturally, the cost of wire increases significantly with increase in distance. The following calculation is used to determine the total dynamic head (TDH) of the solar pump using ground water.

$$\mathbf{TDH = (D_s + D_d + \Delta H) \times 1.1}$$

Where:
TDH = Total dynamic head of the solar pump
D_s = Depth from static water table to top of well
D_d = Drawdown at sustainable or desired pumping rate
ΔH = Elevation difference from top of well to top of storage tank
The value of 1.1 is used since the desired pumping rate should not exceed the sustained well yield. An estimate of the required flow rate of the pump can be determined by the following equation:

$$\boxed{\mathbf{Q = \frac{V \times T}{PSH \times 3600}}}$$

Where
Q = Flow rate in m^3/s
V = Volume of water needed (delivered) from the pump in a day

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T = Duration of pumping (hours)
PSH –Peak sunshine hours

The size of the pump depends on several factors. They include: available water supply, power, available storage, total dynamic head (TDH), diameter of well, and water need. It is assumed that the pump operates during peak sunlight hours. The most efficient and simplest system that meets the irrigation demands should be designed. It is important to determine the total dynamic head. For a solar-powered pumping system, total dynamic head can be referred to as the head pressure required to overcome the sum of the static lift of the water, the static height of the storage tank, and the frictional losses in the pipe network.

7.2.4 Benefits of solar pumps

There are many advantages of solar pumps. For instance, they are reliable, easy to install, can be long lasting (20+ years), low maintenance, simple repair if related to solar array, clean and no fuel is needed. In addition, photovoltaic (PV) systems are used to pump water for irrigation, livestock, or domestic use. Solar powered pumps enable better pasture management as livestock can access water at multiple distribution points. Photovoltaic (PV) powered pumping systems are a cost-effective alternative to agricultural wind turbines for remote area water supply. In Africa, the sun is the most abundant source of energy, although not often tapped. Few smallholder farmers have access to electricity while the purchase of petrol or diesel is too expensive. Solar power is freely available and could be used.

Other benefits include the fact that PV technology can be put to multiple purposes, e.g. to charge batteries which supply electrical power for other uses. The modular system can be closely matched to individual needs and power is easily adaptable to changing demands. Pumping water using PV technology is simple and requires almost no maintenance. In irrigated agriculture, water is most needed during the hot sunny days, when solar energy is at its optimum, making it an obvious choice for this application. Unlike wind pumps, PV pumps can be easily moved with little dismantling and low reinstallation costs.

7.3 Wind powered pumps

Wind power is a renewable and clean source of energy which can be relatively predictable, and is commonly used for water pumping applications. Wind energy can be harvested with either mechanical machines (windmills) or electrical machines (turbines). There are many areas in Africa which are open and with high wind speeds, particularly in the lee sides of mountains and interior dryland areas. Windmills are well adapted for use with submersible water pumps.

Wind pumps offer a competitive source of energy for small or medium-scale irrigation schemes and individual use (Figure 7.3). However, the wind speed should be at least 3.5 m/s for a month. In remote areas where diesel fuel transport costs are high, wind pumps can be economical at even lower wind speeds. The speed of the wind across any surface is influenced by the friction it encounters, which is greater where there are trees or tall buildings near the wind pump. This friction is gradually reduced when the rotor is high above the source of that friction. A dense (multi-bladed) rotor extracts torque from the wind at low wind speeds and shaft rotations per minute.

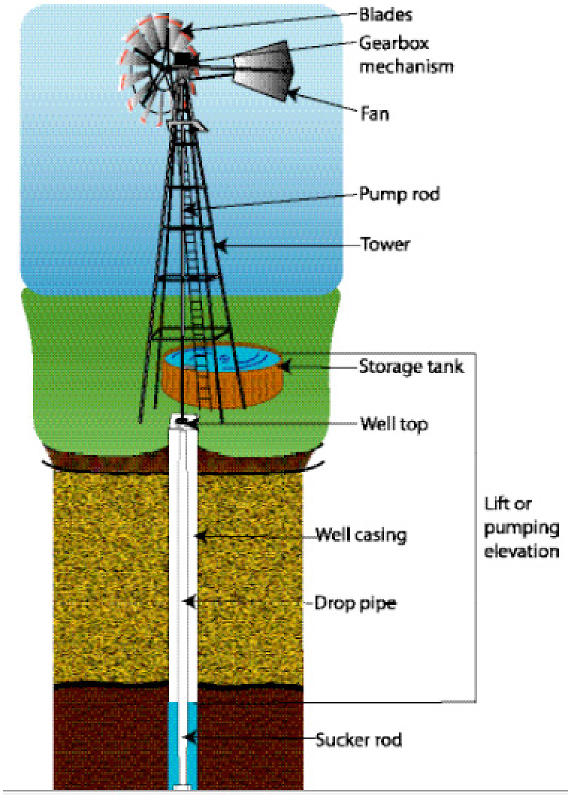


Figure 7.3: Sketch of a wind pump (Source: (Enciso and Mecke 2001)

a) Determining the wind power

The power in the wind is proportional to the area of windmill being swept by the wind, the cube of the wind speed and the air density - which varies with altitude. The output of any wind-powered machine is directly proportional to the square of the rotor diameter and to the cube of the wind speed passing through it. The formula used for calculating the power in the wind is as follows:

$$P_W = \frac{1}{2} \rho A V^3$$

where,

P_W is power in watts available in the wind (W)

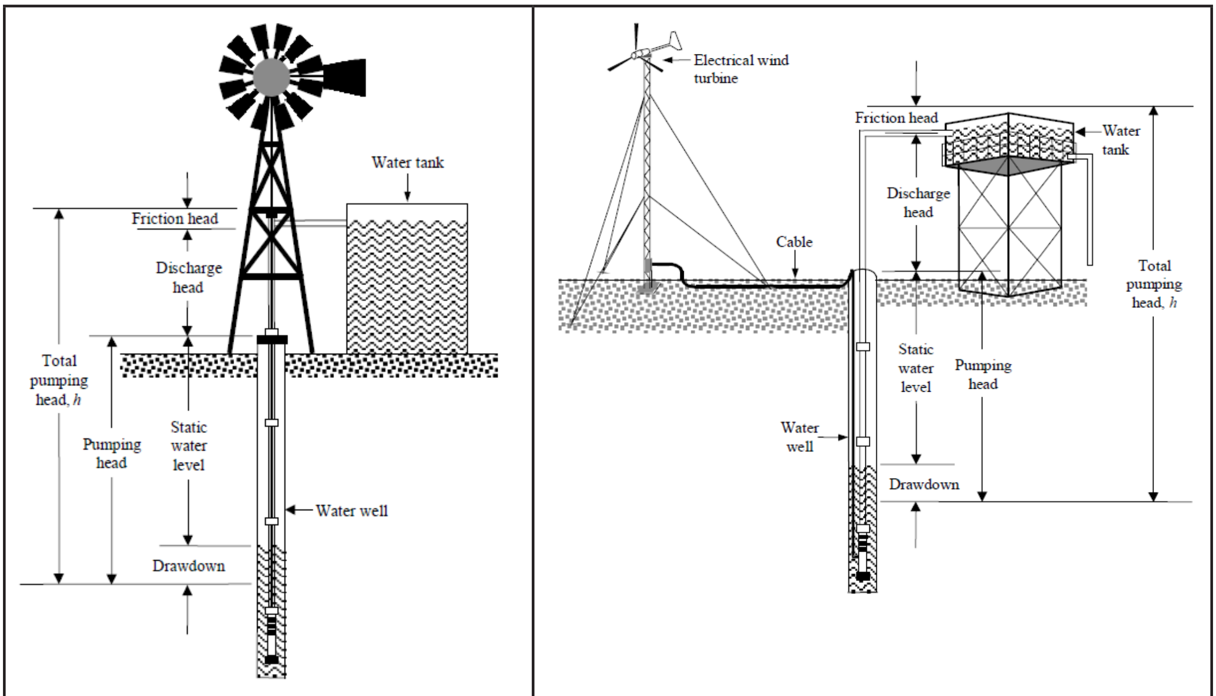
ρ is the air density in kilograms per cubic metre (kg/m^3)

A is the swept rotor area in square metres (m^2)

V is the wind speed in metres per second (m/s)

b) Energy conversion by wind mills

To pump water, wind pumps can be used to convert wind energy into mechanical energy (Figure xxx) in which case, the wind mill directly pumps water. Alternatively, wind energy can be converted into electrical energy (Figure 7.4) whereby the wind generates electricity which then pumps water. Water tanks for solar and wind systems need to be designed differently from conventional water pumping systems since power from genset is always there. However, this energy is not available on demand, thus, long-term weather data are required to design a sustainable system.



a) Mechanical wind pump	b) Electrical wind pump
Figure 7.4 Schematic diagram of typical wind pumps *(Source: Foster and Ellis, 2001)*	

c) Limitations of wind pumps

The main limitation with wind powered pumps is the availability of winds with sufficient speed to turn/rotate the turbine. Another constraint includes maintenance and operation of wind pumps, which can also be high and requires specialized technical knowhow. Generally, higher failure rates have been recorded for wind turbines, making them less popular option as prime movers for irrigation pumps.

7.4 Hydram pumps

7.4.1 What is a hydram pump?

A hydram pump (hydraulic ram pump, ram pump, or hydrant) is a water pump powered by hydropower. It is an automatic device which uses the energy contained in free flowing water to pump the same water without using any electricity or fuel. It functions as a hydraulic transformer that takes in water at one "hydraulic head" (pressure) and flow-rate, and outputs water at a higher hydraulic-head and lower flow-rate. The device uses the water hammer effect to develop pressure that allows a portion of the input water that powers the pump to be lifted to a point higher than where the water originally started (Figure 7.5).

Figure 7.5 A hydram pump installation in a river *(Photo by B. Mati)*

The hydram is a very old technology which despite it being unbelievable never had the real chance to spread since it had a wrong timing in history. In recent years, however, there has been renewed interest in the technology necessitated by the need for cheaper and clean energy and availability of alternative models. A ram pump can be locally made using door hinges, old car tyres, valves and drums.

7.4.2 Advantages of the hydram pump

- A ram pump combines high technical performance and low cost.
- Once installed, the pump can be operated,
- Pumps 24 hours per day automatically
- Can pump to very high elevation (up to 200 metres)
- Does not consume fuel or electricity
- Does not pollute (no Co_2)
- Spare parts locally available.
- Easily maintained and repaired by locally trained technicians

7.4.3 Components and operation of a hydram pump

The components of a hydraulic ram pump, or hydram (Figure 7.6) comprise an automatic pumping device which utilises a small fall of water to lift a fraction of the supply flow to a much greater height. In other words, as with the turbine pump, it uses a larger flow of water falling through a small head to lift a small flow of water through a higher head. The main advantage of the hydram is that it has no substantial moving parts, and is therefore mechanically simple, which results in high reliability, minimal maintenance requirements and a long operational life.

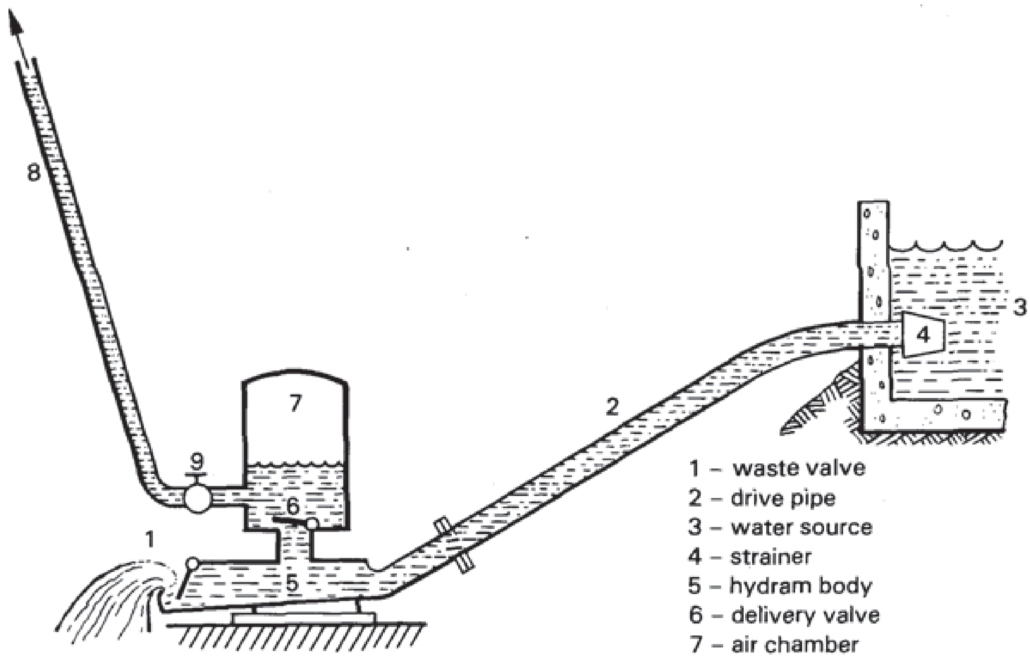


Figure 7.6 Schematic diagram of hydram installation

Its mode of operation depends on the use of the phenomenon called water hammer and the overall efficiency can be quite good under favorable circumstances. Fig. 147 illustrates the principle; initially the waste valve (1) opens under gravity, and water flows down the drive-pipe (2) from the water source (3) (having been drawn through a strainer (4) to prevent debris entering the hydram). As the flow accelerates, the hydraulic pressure under the waste valve and the static pressure in the body of the hydram (5) increases until the resulting forces overcome the weight of the waste valve and it starts to close. As soon as it starts to close and the aperture decreases, the water pressure in the valve body builds up rapidly and slams the waste valve shut. The moving column of water in the drive pipe is no longer able to exit via the waste valve so its velocity must suddenly decrease; this continues to cause a considerable rise of pressure which forces open the delivery valve (6) to the air-chamber (7). Once the pressure in the air chamber exceeds the static delivery head, water discharges through the delivery pipe (8). Air trapped in the air chamber is simultaneously compressed to a pressure exceeding the delivery pressure. Eventually the column of water in the .drive pipe stops and the static pressure in the casing falls to near the static pressure due to the supply head. The delivery valve then closes, due to the pressure in the air chamber exceeding the pressure in the casing. Water then continues to be discharged through the check valve (9), after the delivery valve has closed, until the compressed air in the air chamber has expanded to a pressure equal to the delivery head. At the same time, as soon as the delivery valve closes, the reduced pressure in the casing of the hydram allows the waste valve to drop open, thereby allowing the cycle to start all over again.

The air chamber is a vital component, as apart from improving the efficiency of the process by allowing delivery to continue after the delivery valve has closed, it is also essential to cushion the shocks that would otherwise occur due to the incompressible nature of water. If the air chamber fills with water completely, not only does performance suffer, but the hydram body, the drive pipe or the air chamber itself can be fractured by the resulting water hammer. Since water can dissolve air, especially under pressure, there is a tendency for the air in the chamber to be depleted by being carried away with the delivery flow. Different hydram designs overcome this problem in different ways. The simplest solution requires the user to occasionally stop the hydram and drain the air chamber by opening two taps, one to admit air and the other to release water.

This cycling of the hydram is timed by the characteristic of the waste valve. Normally it can be either weighted or pre-tensioned by an adjustable spring, and an adjustable screwed stop is generally provided which will allow the maximum opening to be varied. The efficiency, which dictates how much water will be delivered from a given drive flow, is critically influenced by the valve setting. This is because if the waste valve stays open too long, a smaller proportion of the throughput water is pumped, so the efficiency is reduced, but if it closes too readily, then the pressure will not build up for long enough in the hydram body, so again less water will be delivered. There is often an adjustable bolt which limits the opening of the valve to a predetermined amount which allows the device to be tuned to optimize its performance. A skilled installer should be able to adjust the waste valve on site to obtain optimum performance for that particular hydram and site. Therefore, the output of a hydram is constant, 24 hrs/day, and cannot readily be varied. A storage tank is usually included at the top of the delivery pipe to allow water to be drawn in variable amounts as needed.

7.4.4 Installation of a hydram pump

During the installation of a typical hydram, a supply head is created either by digging a small contoured diversion canal bypassing a river, or in some cases, particularly with small streams, it is normal simply to create a weir and to install the hydram directly below it. Where greater capacity is needed, it is common practice to install several hydrams in parallel. This allows a choice of how many to operate at any one time so it can cater for variable supply flows or variable demand.

The size and length of the drive-pipe must be in proportion to the working head from which the ram operates. Also, the drive-pipe carries severe internal shock loads due to water hammer, and therefore normally should be constructed from good quality steel water pipe. Normally the length of the drive-pipe should be around three to seven times the supply head. Also, ideally the drive-pipe should have a length of at least 100 times its own diameter. The drive pipe must generally be straight; any bends will not only cause losses of efficiency, but will result in strong fluctuating sideways forces on the pipe which can cause it to break loose.

The hydram body needs to be firmly bolted to a concrete foundation, as the beats of its action apply a significant shock load. It should also be located so that the waste valve is always above flood water level, as the device will cease to function if the waste valve becomes submerged. The delivery pipe can be made from any material capable of carrying the pressure of water leading to the delivery tank. In all except very high head applications, plastic pipe can be considered; with high heads, the lower end of the delivery line might be better as steel pipe. The diameter of the delivery line needs to allow for avoiding excessive pipe friction in relation to the flow rates envisaged and the distance the water is to be conveyed. It is recommended that a hand-valve or check-valve (non-return valve) should be fitted in the delivery line near the outlet from the hydram, so that the delivery line does not have to be drained if the hydram is stopped for adjustment or any other reason. This will also minimise any back-flow past the delivery valve in the air-chamber and improve the efficiency.

74.5 Choice of hydram design

Traditional hydram designs, such as Figure xxx, were developed a century ago in Europe and are extremely robust. They tend to be made from heavy castings and have been known to function reliably for 50 years or more. A number of such designs are still manufactured. The hydram in Figure 7.7 differs from the schematic diagram of Fig. 147 in having its waste valve on the same side as the drive pipe, but its principle of operation is identical.

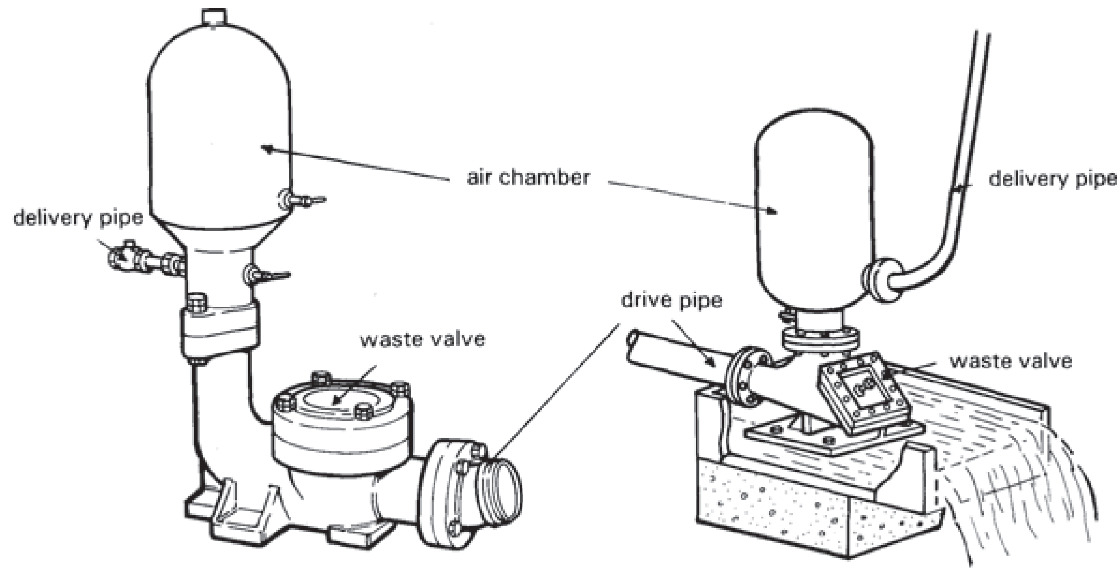


Figure 7.7 (a) Traditional (Blakes) hydram design	**(b) South-East Asian type of hydram**

Lighter designs, fabricated using a welded sheet steel and oil drums are made in Kenya by local artisans. These are cheaper, and made from thinner material which will probably eventually corrode; nevertheless they offer good value for money and are likely to perform reliably for a respectably long time. However, hydrams are mostly intended for water supply duties, operating at higher heads and lower flow rates than are normal for irrigation. Therefore the most useful hydrams for irrigation purposes will be the larger sizes having 100-150mm drive pipes.

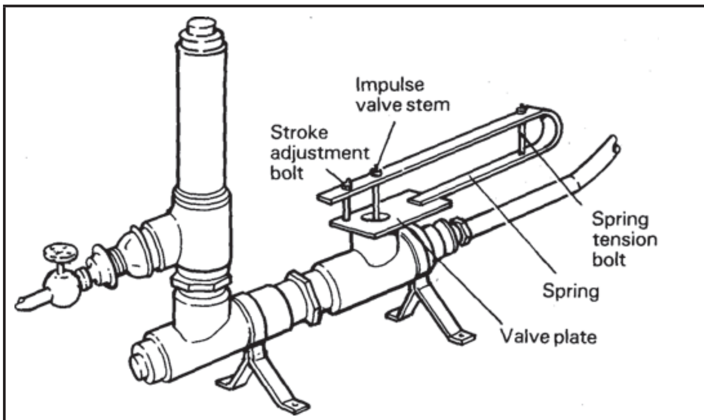


Figure 7.8 (a) Sketch of a low-cost hydraulic ram using standard pipe fittings.	**(b) Locally made (in Kenya) piston ram pump in action** *(Photo by B. Mati)*

7.4.6 Performance characteristics

The input capacities of different sizes of hydram are shown in Table 7.1. The input energy determines the delivery flow at a given delivery head. The lower limit indicates the minimum input flow required for practical operation, while the upper limit represents the maximum possible flow a hydram can handle.

Table 7.1 Hydram input capacity

Nominal diameter of drive pipe			Hydram capacity									
	mm. bore		32	40	50	65	80	100	125	150	175	200
Volume of water required to operate hydram	litres per minute	from	7	12	27	45	68	136	180	364	545	770
		to	16	25	55	96	137	270	410	750	1136	1545

Source:

Although the costs of hydrams are apparently low, as soon as high flow rates are needed at lower heads, the size of hydram and more particularly of drive pipe begins to result in significantly higher costs. Therefore hydrams are best suited to relatively low flow rates and high head applications, while a turbine-pump, and are more attractive for the lower heads and high flow rates that are more common for irrigation of commercial crops on low-land farms.

7.5 Hand pumps

7.5.1 What is a hand pump?

A hand pump is any gadget used to lift water manually. In its simplest form, a hand pump can be a simple bucket and rope, used to draw water from a well. Using a bucket and rope can be made easier if the well is provided with a windlass to help to lift the bucket. However, although easy to operate and repair, the bucket and windlass arrangement has serious disadvantages: it does not allow the well to have a cover slab which can be sealed to prevent ingress of polluted water or other contaminants, and the bucket and rope themselves are continually being polluted by mud and dirty hands. Therefore if the water to be raised from a well or borehole is for people to drink, it is preferable to install a hand pump.

7.5.2 Components and operation of a hand pump

A majority of hand pumps are positive displacement pumps and have reciprocating pistons or plungers. In a piston pump, the piston is fitted with a non-return valve (the piston valve) and slides vertically up and down within a cylinder which is also fitted with a non-return valve (the foot valve). Raising and lowering the handle of the pump causes vertical movement of pump rods which are connected to the piston. When the piston moves upwards, the piston valve closes and a vacuum is created below it which causes water to be drawn into the cylinder through the foot valve, which opens. Simultaneously, water above the piston, held up by the closed piston valve, is displaced upwards; in a simple suction pump it emerges through the delivery outlet; in a pump with a submerged cylinder it is forced up the rising main. When the piston moves downwards, the foot valve closes, preventing backflow, and the piston valve opens, allowing the piston to move down through the water in the cylinder.These pumps can have adjustable pin positions on the handle. This allows the user to obtain the optimum ease of pumping verses volume of water, for the individual pumping distance and physical strength. The shorter the stroke, the easier it is to pump. The pump cylinder is a barrel with a plunger inside. When one pumps on the handle of the hand pump, it makes the cylinder plunger go up and down. This forces the water up the pipe and out the hand pump. With just a few strokes of the handle, water starts to come out the spout of the hand pump.

7.5.3 Range of lift for hand pumps

There are many different types of hand pumps, offering various performance and lift capabilities (Table 7.2). The ranges over which water can be lifted are grouped in the following categories:

Table 7.2 Types of hand pumps according to depth of suction

Type of pump	Depth (m)
Suction pumps	0 – 7
Low lift pumps	0 – 15
Direct action pumps	0 – 15
Intermediate lift pumps	0 – 25
High lift pumps	0 – 45

Figure 7.9 (a) Locally made hand pump *(Source Dealfish, 2012)* **(b) Locally made (in Ethiopia) hand pump** *(Photo by B. Mati)*

7.5.4 Suction hand pumps

Suction pumps are commonly designed as hand pumps. At shallow lifts the cylinder and piston operate by suction and can be housed in the pump-stand above ground. In practice, the maximum suction lift is about seven metres (i.e. atmospheric pressure less about 30% system losses due to the ineffectiveness of seals, friction etc) and defines the working range of the suction pump. These pumps have to be primed and thus can be contaminated by dirty priming water. They have a limited range of application, but are the most numerous hand pumps in the world, mainly because they are relatively cheap and are suitable for use as a household pump (Figure 7.10).

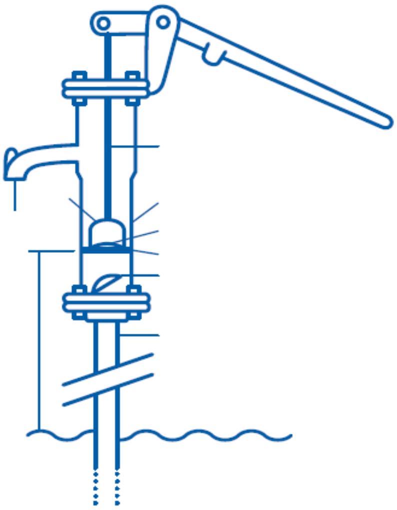


Figure 7.10 Sketch of shallow well suction lift hand pump *(Source: WaterAid, 2009)*

(b) Manual suction lift hand pump used on shallow well *(Photo by B. Mati)*

7.5.5 Low lift hand pumps

These operate in the range 0–15 metres. With lifts above seven metres, the cylinder and piston have to be located down the well, or borehole, and preferably below water level in order to provide a positive suction head. Theoretically, the lift could be achieved by operating with the cylinder seven metres above the water table but it is usually better to provide a positive suction head, as this assists pumping.

7.5.6 Direct action hand pumps

In the low lift range some piston hand pumps are designed to operate as simple direct action pumps, i.e. ones which operate without the help of leverage, linkages and bearings. Direct action pumps depend upon the strength of the operator to lift the column of water.. Some designs use very small diameter cylinders and rising mains to pump smaller quantities from greater depths. In general, direct action pumps, being simple in action, are cheaper to buy and operate than high lift hand pumps. Other designs (Figure 7.12-a) make this easier by using as the pump rod a plastic pipe filled with air, the buoyancy of which helps the upstroke operation.

7.5.7 Intermediate and deep well hand pumps

An intermediate lift pump operates in the range 0 – 25 metres and a high lift one in the range 0 – 45 metres. Some of the high lift hand pumps can operate at lifts of 60 metres or more, albeit with reduced output. Intermediate and high lift piston hand pumps are designed so as to reduce, by means of cranks or levers, the physical effort required when pumping. They have to be more robust and are provided with bearings and components capable of handling the larger stresses which are imparted by the pumping efforts required (Figure 7.12-b). The Afridev hand pump is shown in the following diagram and a more detailed one, showing the component parts, is given at the end of this section.

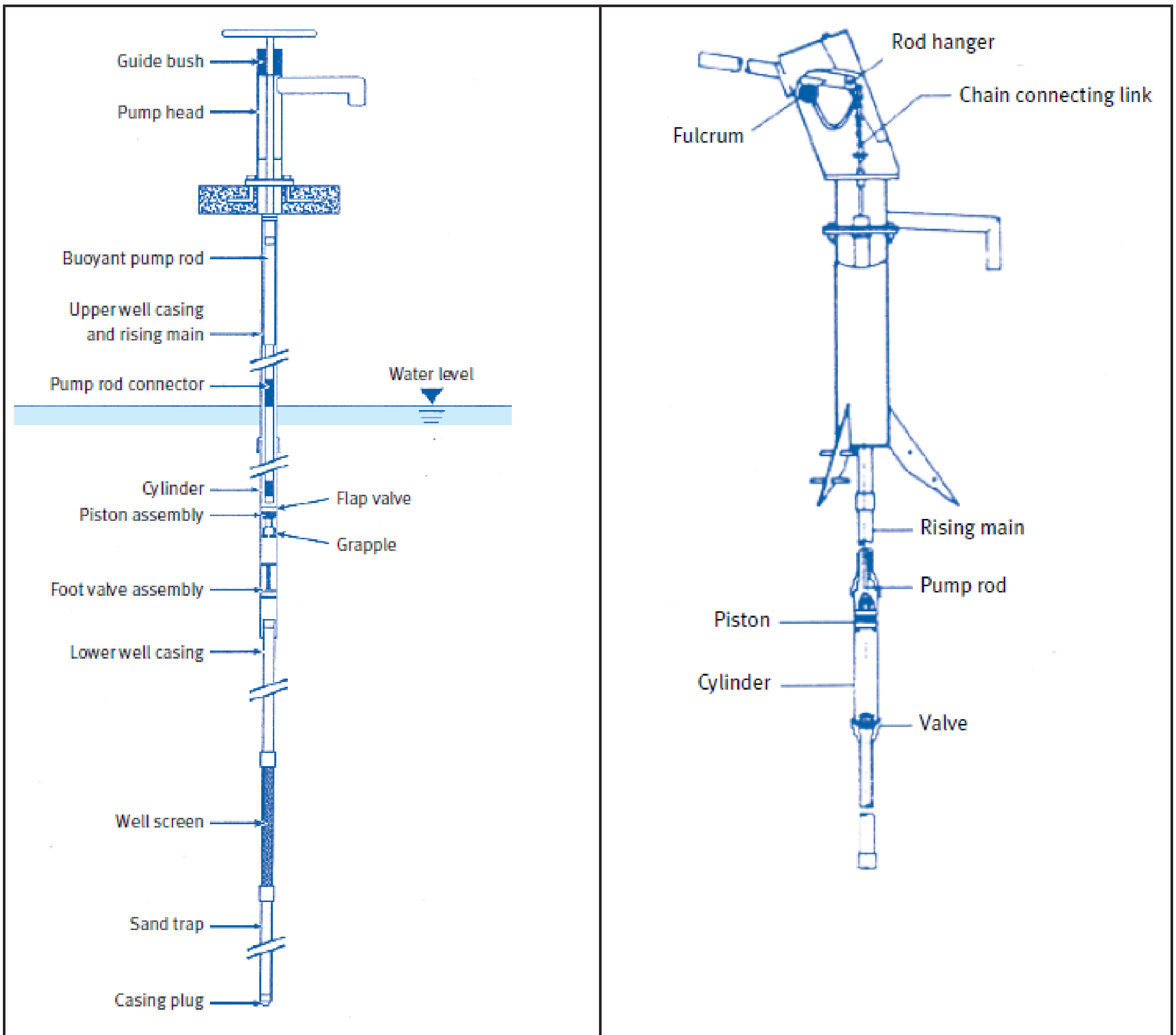


Figure 7.12 (a) Sketch of a high lift pump **(b) Deep well reciprocating pump** *(Source: WaterAid, 2009)*

7.5.8 Non-piston hand pumps

A high lift pump that is not a piston pump is the Mono progressing cavity hand pump; which has a rotating pump rod in the rubber stator within the pump cylinder, thereby producing a progressing cavity, which screws the water upwards. The meshing surfaces provide a moving seal. Although a very reliable hand pump, any maintenance task that requires removal of the rods and rotor assembly requires special lifting equipment.

7.5.9 Piston hand pumps

The most common and well-known form of displacement pump is the piston or "bucket" pump, a common example of which is illustrated in Figure 7.13. In action, water is sucked into the cylinder through a check valve on the up-stroke, and the piston valve is held closed by the weight of water above it simultaneously, the water above the piston is propelled out of the pump. On the down-stroke, the lower check valve is held closed by both its weight and water pressure, while the similar valve in the piston is forced open as the trapped water is displaced through the piston ready for the next up-stroke.

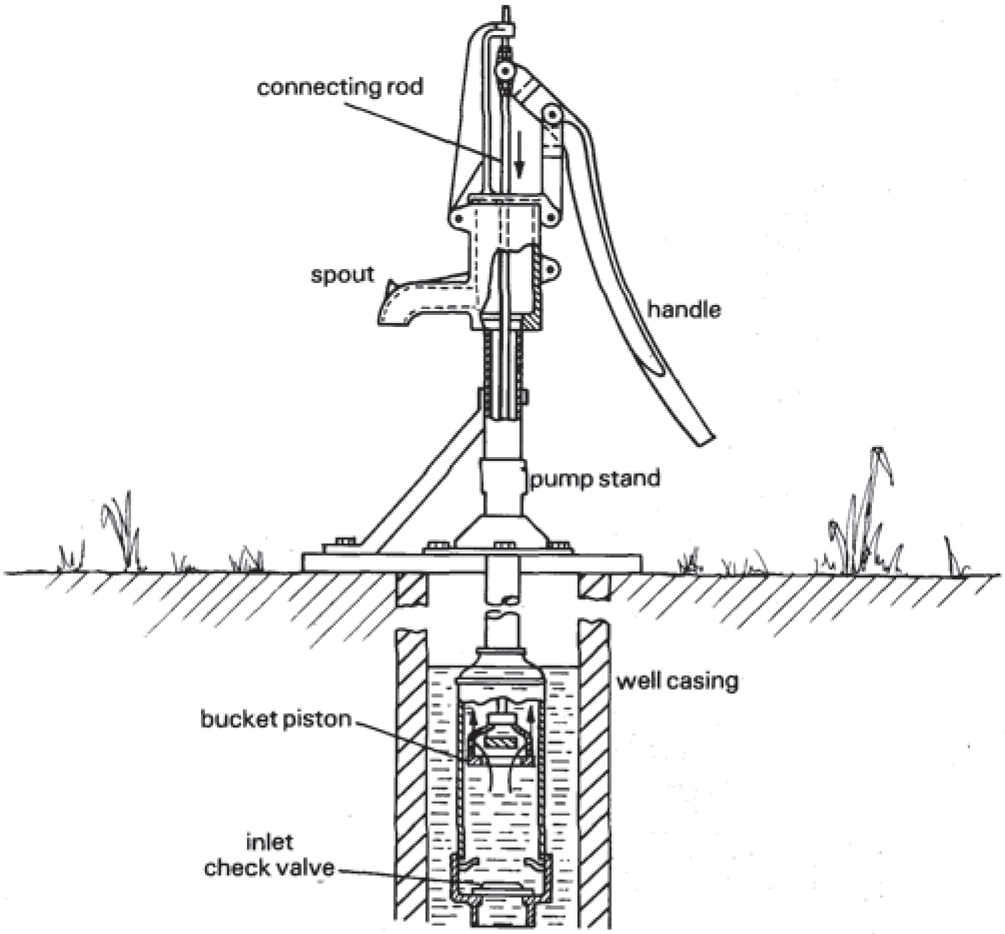


Figure 7.13 Hand pump with single-acting, bucket piston

(piston valve shown open as on the down-stroke, and foot valve or inlet valve is closed)

7.5.10 Maintenance of hand pumps

Hand pumps deteriorate easily due to manual operation, wear and tear. They therefore require regular maintenance, repairs and replacement of various parts. The pump and the site around it should be kept clean. This is part of preventive maintenance which also involves a daily check. The pump should be greased weekly and all parts of the pump stand must be checked monthly. Pump rods that have corroded must be replaced; under normal conditions, a galvanized steel pump rod needs to be replaced every five to six years. Rising mains consisting of galvanized iron should be dismantled and checked, and pipes with badly corroded threads must be replaced. Small repairs include replacement of bearings, cup seals and washers, straightening bent pumping rod etc. Major repairs may involve the replacement of the plunger, foot valve, cylinder, pump rods, rising main, pump handle, fulcrum and various movable parts.

7.6 Pedal powered water pump

A pedal pump utilises a stationary bicycle which is manually rotated to lift water. It can pump water from wells and boreholes up to 30 meters in depth. The main components include a bicycle, wheels removed, attached to strong angled uprights, set in a concrete base. The flywheel is made from a bicycle wheel with side walls from a car tire attached with wire. Concrete gives the flywheel weight. The flywheel stand is also set in a concrete base. The pump and a bike are attached by belt and the station is positioned over shallow well. Mechanical energy produced by pedalling the bike draws water (Figure 7.14) The piston pump oscillates by rotational energy of bike. When piston goes down, vacuum is created which pulls in water and when piston goes up, water is pushed out. They can be built using locally available materials and can be easily adapted to suit the needs of local people. They free the user from rising energy costs, can be used anywhere, produce no pollution and provide healthy exercise.

Figure 7.14 (a) A bicycle powered water pump *(Source: Carlos, 2010)*

(b) A pedal powered rope and washer pump
(Photo by B. Mati)

7.7 Treadle pumps

A treadle pump is a foot operated single acting double cylinder piston pump for low lift irrigation. It consists of two metal or uPVC cylinders with pistons that are operated by a natural walking motion on two treadles. The efficient step-action operation makes it possible to pump the large volumes of water necessary for irrigation. The pump works with a leg-operated treadle, using a motion similar to exercising on a stair-stepping machine. This drives a piston at the bottom of the well, which lifts the water up through the cylinder and pressurizes it through a hose. The pump's key innovation is its long, loose-fitting piston, which doesn't require the tight, sliding seals.

Figure 7.15 (a) A treadle pump made of metal *(Photos by B. Mati)*

(b) A wooden treadle pump

7.7.1 Performance

Like all manual pumps, treadle pumps can be tiresome to the operator. But a typical treadle pump can lift five to seven cubic meters of water per hour from wells and boreholes up to seven meters deep, as well as from surface water sources such as lakes and rivers. There are two types: those that lift water from a lower level to the height of the pump commonly called *suction pumps* (Figure 7.16) and those that lift water both from a lower level and lift it to a height greater than the height of the pump, known as *pressure pumps*.

In all forms, water is pumped by two direct displacement pistons, which are operated alternately by the stepping motion of the user. The maximum suction capacity of the pump is limited in practice to about 5 metres. The layout of the pump limits the pressure a 70 kilogramme person to about 90% of body weight. This is because the piston is at the end of the treadle and the operator stands between the fulcrum and the piston. A 70 Kg operator can put about 63 Kg of force on the piston without having to pull upwards on the hand rest. In practice an operator can put far more than their own weight onto the piston because they can use the hand rest. A simple equation to estimate the volume of water that a person can pump is provided as follows:

$$Q = (Bm \times 0.07)/H_T$$

Where
Q = Sustainable flow output (litres/s)
Bm = Body mass in kg
H_T = Total head required for pumping

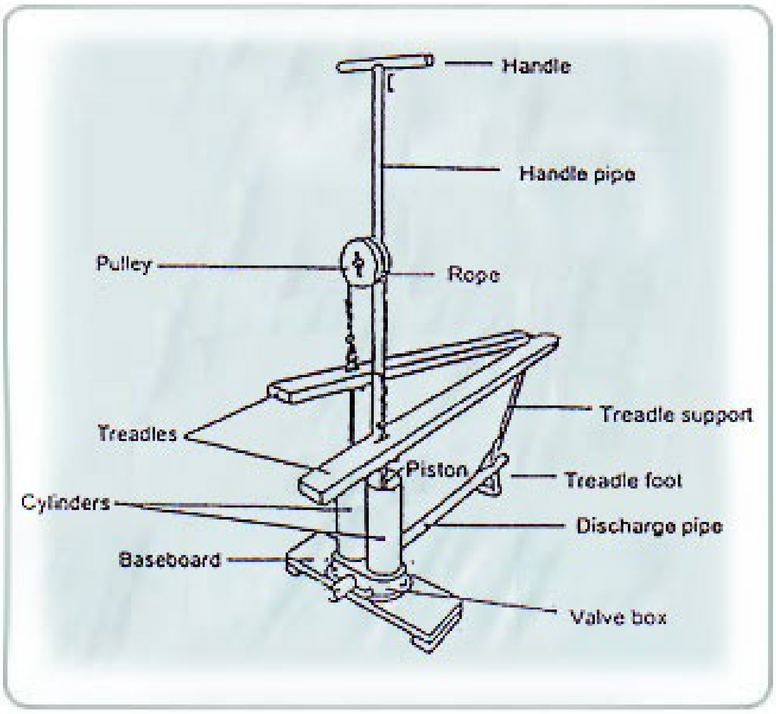


Figure 7.16 Parts of a treadle pump *(source: BRD Engineering & Contracting Company, 2011)*

Generally, it is the total pumping pressure head that matters with treadle pumps. This is the sum of the suction head and the delivery head. They cannot be separated. It should be noted that treadle pump design is not an exact science, because of the difficulty of standardizing the power input, which depends both on the physical strength of the operator and the ability to sustain this power over a period of time. Deciding the best treadle pump is not just a question of technical performance. Judgement must be based on a wide range of factors, including costs and benefits, reliability, maintenance, availability of spares and a complex range of local social issues.

7.7.2 Pressure treadle pump

The pressure treadle pump is a variation on the standard treadle pump that allows water to be lifted above the level of the pump itself. This greatly increases the versatility of the pump: water can be lifted to elevated plots of land, it can be pumped through hoses over long distances (up to 500 m), it can be used to fill the elevated tanks of drip and sprinkler irrigation systems. The pressure treadle pump retains the advantages of the standard treadle pump, including low cost (albeit slightly more expensive than the standard version), efficient foot-powered operation, locally manufactured, easily maintained.

7.8 Other types of manual pumps

The use of human and animal power, for source of energy for pumps makes use of available labor which would otherwise be idle, particularly during the dry season. It has a major advantage in that it requires a steady rotary power input which suits the use of a crank drive with a flywheel, which is a mechanically efficient as well as a comfortable way of applying muscle power. This is the principle of all manually operated pumps.

7.8.1 Water wheel

The water wheel has many variants such as bucket elevators, Persian wheels or Norias. It is an improvement of the simple bucket and rope system, whereby several small buckets are organized around the periphery of an endless belt to form a continuous bucket elevator. The original version of this, which is ancient in origin but still widely used, was known as a "Persian wheel" (Figure 7.17-a); the earliest forms consisted of earthenware pots roped in a chain which is hung over a drive wheel. A "noria" is a water wheel with pots, buckets or hollow bamboo containers set around its rim (Figure 7.17-b) and is similar in principle except the containers are physically attached to the drive wheel circumference rather than to an endless belt suspended from it.

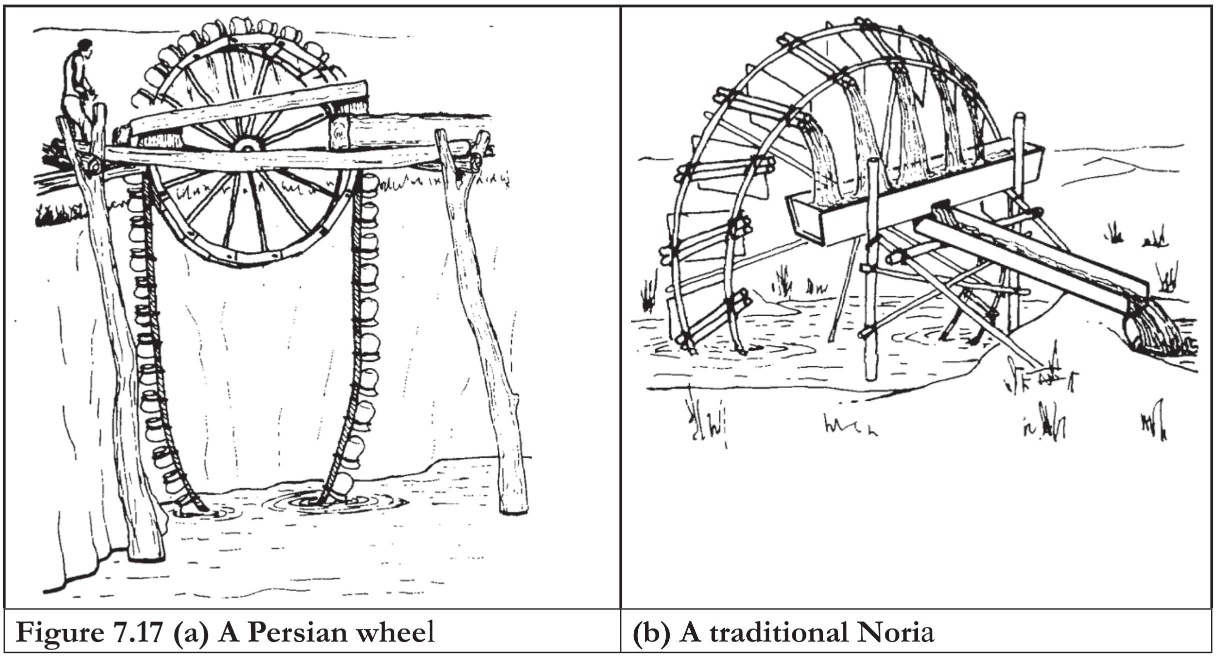


Figure 7.17 (a) A Persian wheel **(b) A traditional Noria**

The flow with any of these early types of pumps is a function of the volume of each bucket and the speed at which the buckets pass across the top of the wheel and tip their contents into a trough set inside the wheel to catch the output from the buckets. Therefore, for a given power source and speed of operation roughly the same number of containers are needed regardless of head. Thus, to achieve a higher head Persian wheel, the buckets should be proportionately more spaced out.

Although Persian wheels and norias are mechanically quite efficient, the main source of loss from these types of device is that some water is spilled from the buckets and also there is a certain amount of friction drag caused when the buckets scoop up water, which again reduces efficiency. Also, the Persian wheel is obliged to lift the water at least 1 m (or more) higher than necessary before discharging it into a trough, which can significantly increase the pumping head, particularly in the case of low lifts. The traditional wooden Persian wheels also inevitably need to be quite large in diameter to accommodate a large enough collection trough to catch most of the water spilling from the pots; this in turn requires a large well diameter which increases the cost.

The Persian wheel has been, and still is, widely used particularly in the north of the Indian sub-continent and is being replaced by more modern mechanical water lifting techniques as they are old-fashioned and low in output. It should be noted that the term "Persian wheel" is sometimes used to describe other types of animal powered rotary pumps.

7.8.2 Manual diaphragm pumps

A diaphragm pump operates by the expansion and contraction of a flexible diaphragm within a closed system actuated by a secondary piston pump, itself actuated by a foot pedal or hand lever. The primary rigid cylinder has a suction valve and a delivery check valve. On the contraction of the diaphragm the suction valve opens to draw water into the primary cylinder and the discharge valve closes. When the diaphragm is expanded by operating the secondary system, the suction valve closes and the discharge valve opens to pump water up a flexible rising main. Although the pump is easy to maintain, replacement diaphragms are required at relatively short intervals; these are expensive and the cost is often beyond the capacity of communities to fund repeatedly.

a) **Advantages of a diaphragm pump are:**

- Very good sealing (except for any shortcomings of the two check valves);
- high mechanical efficiency, since flexing a diaphragm involves much less friction then sliding a piston with seals up and down a cylinder;
- No seal is needed at the pump rod which also reduces friction losses still further compared with piston pumps;
- They are self-priming, can hold their prime very well and often handle a higher than average suction head;
- They often function well with gritty or muddy water which could damage a piston pump.

b) **Disadvantages:**

- o Diaphragms need to be high quality rubber if they are to last, and are therefore expensive;
- o Diaphragm pumps are often dependent on specialized spare parts that cannot easily be improvised in the field;
- o A diaphragm pump is similar to a large diameter piston pump with a short stroke; so the pump rod forces are high in relation to the head and swept volume. This imposes a high load on transmission components and on the point of attachment of the pump rod to the diaphragm;

- Diaphragm pumps (of the kind in Figure 7.18) are only suitable for low head pumping in the 5-10 m range.

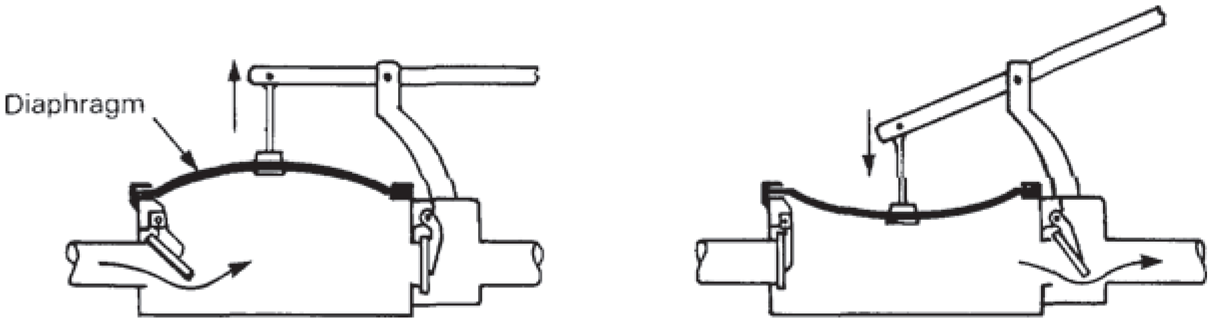


Figure 7.18 (a) Section of a diaphragm pump sucking water, (b) Compression mode

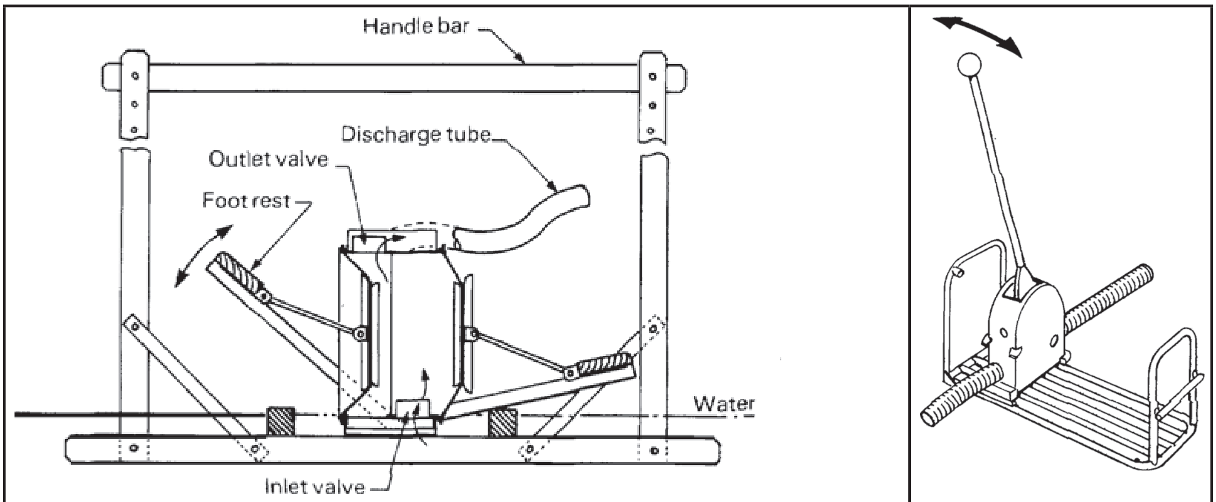


Figure 7.19 (a) Sketch of a foot-operated diaphragm pump

(Source IRRI)

(b) Portable double acting diaphragm pump

Figure 7.19(a) shows a foot-operated, double-acting diaphragm pump for irrigation purposes. Unlike traditional devices such as Shadoofs, this pump is portable (by two men) and can therefore be moved along an irrigation canal in order to flood one paddy after the other. However it is less efficient than the better traditional water lifters.

Figure 7.19(b) shows a commercially manufactured, double-acting diaphragm pump that is mostly used for purposes such as dewatering building sites; it has the advantage of being portable, reasonably efficient and well suited to low heads and can deliver quite high outputs, so it, or similar designs, could equally be used for irrigating small landholdings.

7.8.3 Rope and washer pumps

A rope and washer pump comprises a PVC pipe, a rope and old car parts. It can be used either vertically, to pump from wells, or at an angle to pump from ponds or rivers. The rope and washer pump is an ancient pumping technology that goes back over 2000 years. There are various modern developments of the ancient design but the basic design of all pumps is a continuous loop of rope with pistons (or plastic washers) attached to it, the rope passes up through a plastic pipe with only a small clearance, thus allowing the pistons to push the water up and out of the top of the pipe. Rope pumps can be used to draw water from wells, boreholes, tanks and ponds (Figure 7.20). Applications include communal wells, households, irrigation, and cattle watering. Also, rope pumps can be powered by hand, bicycle, motor, horse, or wind power. For wells down to 35 m, rope pumps are often five times cheaper and more sustainable than standard piston pumps.

Figure 7.20 (a) Rope and washer pump used with shallow well	**(a) Rope and washer pump used with surface water pond** *(Photos by B. Mati)*

a) **Components and operation of a rope and washer pump**

Many different types of rope pump exist, powered by hand, bicycle, wind, animal draught, however, they are similar to piston pumps. The rope pump can be produced with locally available standard materials and local skills, such as an artisan workshop. The ropes are made of Polyethylene, Polypropylene, or Polyamide fibres varying from a diameter of 4 to 8 mm. Natural fibres are not suitable, as they will lengthen when wet, and degrade too fast. The pistons are injection molded plastic with no seal. The rising main are PVC pipes ranging from 20-50mm diameter (depending on lift). The guide box can be made of concrete with a ceramic insert.

The frame is welded from mild steel. The handle axle is a mild steel pipe (some design use bearings, either ball bearings or wooden bearings, other employ a steel bushing. The pulley wheel is assembled by fitting the cut-off sides of a tyre on a rim, which generates a nice ‘v’ shape which provides good traction on the rope.

The capacity of a rope and washer pump is a function of the diameter of the riser pipe and of the upward speed of the rope. The joggle pump depends on being worked at the correct speed to make it resonate. Each stroke of a resonant joggle pump makes a column of water of a certain mass bounce on the cushion of air at the top of the column. Depending on the size of the air chamber and the mass of the water, this combination will tend to bounce at a certain resonant frequency. Once it has been started, a pump of this kind needs just a regular “tweak” of the handle at the right frequency to keep the water bouncing.

The rope and washer pump is operated by using a handle to turn a wheel supported by a metal frame. Wrapped around the wheel is a long loop of rope which descends into the well through a PVC pipe and connects to a guide at the bottom. Washers are attached to the rope about every 90 cm. As the wheel is turned, the loop of rope moves in a circle and columns of water trapped between the washers and the PVC cylinder are lifted upwards and out of the pump's outlet.

b) Advantages of rope and washer pumps

The main advantage of the rope and washer pump is that it can be used over a wide range of pumping heads; in this respect it is almost as versatile as the commonly used reciprocating bucket pump as it is applicable on heads ranging from 1m to over 100m. For low lifts, loose fitting washers are good enough to lift water efficiently through the pipe, since back-flow will remain a small and acceptable fraction of total flow. At higher lifts, however, tighter fitting plugs rather than washers are necessary to minimise back-leakage; many materials have been tried, but rubber or leather washers supported by smaller diameter metal discs are commonly used. Most rope and washer pumps have a bell mouth at the base of the riser pipe to guide the washers smoothly into the pipe. With higher lift units where a tighter fit is needed, this is only necessary near the lower end of the riser pipe; therefore the riser pipe usually tapers to a larger diameter for the upper sections to minimise friction.

Rope and washer pumps are significantly cheaper (up to 5 times) than piston pumps. They can supply large quantities of water, if properly constructed and installed are easy to maintain. They can be operated by inexperienced users and can be made locally and using local materials, Rope and washer pumps are ideal for use with shallow wells and small water storages, as well as for irrigation. Moreover, they can be operated by hand, windmill, motor, bicycle or animals.

c) Limitations

- The rope pump is requires some expertise to make and use strong materials
- Susceptible to wearing out or breakage of pump parts
- A "blocking system" is needed on the handle to avoid return of the handle, if not the "spinning back" of the handle can be dangerous, especially for children.
- Compared to piston pumps the rope pumps splash water more.
- -Not suitable for heavy duty pumping or a community exceeding 20 families.
- Requires regular maintenance and repairs

c) Installation

The installation of the Rope pump is easy and does not need any lifting equipment or special tools. The pumps are generally installed in dug wells but also versions that fit into boreholes are available. A cement slab and a good soak away are usually installed to avoid splash water becoming a cause for pollution.

d) Maintenance

The maintenance of a rope and washer pump is relatively simple and can easily be done at village level. All spare parts can, like the whole pump, be manufactured in any small town with only the most basic welding machine, other standard hand tools and a basic supply of standard items like PVC pipe, GS pipe and round bar. The most frequent repairs are simple and consist mainly of repairing the rope or handle. Although easy and simple to maintain it is important the user is instructed in why and how to maintain and repair their pump. Rope pumps used with communal wells can be maintained by the users under certain conditions. The pumps can be shared amongst large groups so long as they exercise responsibility. If well managed and maintained, rope and washer pumps can last several years, even after many years.

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Nile Equatorial Lakes Subsidiary Action Program
Regional Agricultural Trade and Productivity Project
5th Floor Kigali City Tower, Avenue Du Commerce, Kigali-Rwanda
P.O Box 6759; Tel: +250788307334
Fax: +250252580100; Url: www.nilebasin.org/nelsap