A1

Technical selection, design and construction process

IN THIS APPENDIX:
- Design criteria – equipment required
- Technical solutions – description and calculations to determine and design a small-scale sand-abstraction system
- Construction of pump headworks

Design criteria

The correct design of abstraction equipment is critical to a successful installation. Equally important is identification of the right equipment for a proposed site and if necessary modification of the technology or the physical conditions of the site.

To establish a satisfactory and successful sand-abstraction scheme each part of the system requires careful design and preparation, with each component matched. The overall abstraction system and pump layout will be determined by several factors:

- the anticipated yield of the water supply
- the available power
- the height of a suitable site above the water-level
- the height of the water discharge point above the pump site.

Each factor must be matched to the conditions and to each component:

- The screen area of the abstraction system should be suitable for the sediment surrounding it, the volume of water and the pump
- The pump must be appropriate for the abstraction system and the site

- The site must be safe and convenient for users and either suitable or adapted to the pump, the point of water discharge and the source of power
- The power that is available must be appropriate to the abstraction system, the pump and the site.

Each component must be designed or altered and adapted as necessary to make each compatible with another. Well-screens can be designed for the sediment and the yield of the pump. The pump can be designed for the yield of the water supply, the power available and the site. And the pump site can be raised or lowered to best advantage in relation to the water source and the discharge point.

Small-scale systems, particularly those in dry-land areas require careful design so that the systems that are put in place are compatible one with another.

The yield of the pump should not exceed the water supply or the energy available or the design capacity of the well-point.

The quantity of water and the height to which it is to be pumped should not exceed the power available – which with small-scale systems is frequently human power and very often female, and then either very young or elderly.

In order to achieve a satisfactory installation it is most appropriate to plan the design of a water supply system commencing from the aspect over which there is least control. In many areas where sustainable, small-scale, community supply schemes are required there are old and infirm people, some of whom can be expected to be sick and weak, possibly HIV positive, but who will still be required to pump and carry water. Thus the water supply must not exceed the available energy of the community nor the source of water that is available.

Small-scale systems, particularly those in dry-land areas require careful design so that the systems that are put in place are compatible one with another.

The yield of the pump should not exceed the water supply or the energy available or the design capacity of the well-point.

The quantity of water and the height to which it is to be pumped should not exceed the power available – which with small-scale systems is frequently human power and very often female, and then either very young or elderly.

The handpump should be designed so that two people may pump together if necessary. If there is an adequate supply of water, provided it does not become over abstracted, it is more appropriate to install a second or even a third small pump system than it is to install one larger pump for which there is no suitable source of power.

In reality the starting point of a small-scale water supply system is identification of the most significant limiting factor, whether this is the yield of water, the available power or depths from, or heights to which water must be pumped. From this a correlation can be made with other components of the scheme.

Power requirements

The available power is often the limiting factor of a small-scale handpump water supply. Although a strong, healthy person is able to develop up to 1kW of power for a few minutes, only some 0.2 – 0.25kW can be developed for any period of time. A high power output cannot be maintained as muscles in the human body easily become tired. If the person is aged or lacking in health their power output will be considerably reduced, or more likely, they will use the pump for a shorter period of time.

To achieve the greatest effectiveness a pump must be as efficient as possible, thus seals and valves must be maintained and the power available maximized. One method of improving the power output of the human body is to use the larger muscles in the back or legs, together with the weight of the body when pumping – rather than just the muscles of the arms.

A handpump with an average yield of 1.00 to 2.00m^3/hr is a reasonable choice for one average to strong person or for two frail to average people to use together as a community pump water supply.

Pump requirements

An efficient pump that is in good working condition is required to optimize the quantity of water pumped and to ensure that energy, particularly human energy is not wasted. Handpumps such as the Rower pump which use back muscles and upper body weight and the Treadle pump which uses the large muscles of the leg and full body weight are both suitable pumps for small-scale sand-abstraction. Counterbalances that even out the energy required on each pump stroke also provide an advantage when pumping. A counterbalance can make pumping easier on both a direct reciprocating action pump and a rotary action pump.

Designed for use on shallow tube-wells the Rower pump has been proven to be a very suitable pump for small-scale sand-abstraction use. The pump is called a rower pump as to use it requires the action of rowing a boat. This requires operating the pump from a sitting position and leaning back on the draw stroke so that the weight of the upper body and not just the arm muscles is used to raise water. With this action some people are able to pump continuously for more than 30 minutes at a time. Other advantages of the Rower pump are the minimal materials that are required and the very simple construction that helps to make it a community-sustainable pump.

The 2 inch (50mm I.D.) SWS Rower pump has been designed to deliver water at up to 1l/sec (3.6m^3/hr) and with two strong people pumping has yielded more than this. With the power generally available under practical, sustained pumping conditions the pump draws water from depths of up to 5.00m at 1 to 2m^3/hr.

Performance data provided for a Bangladesh Rower pump with a 63mm cylinder (2½" pump) from trials conducted for the World Bank by the Consumer Association in the U.K.:

- Pumping head: 7.0 metres
- Pumping rate: 15 cycles per minute
- Volume: 27 litres per minute, (1.6m^3/hr)
- Input: 48 watts
- Efficiency: 64%
- Maximum handle force: 20 kgf
- Volume discharged per stroke about 1.8 litres.

Comments provided by Richard Cansdale from his experience with the SWS Rower pump which he designed:

- The 2 inch pump is recommended to a maximum depth of 6.0 metres and the 2 ½ inch pump to a maximum of 4.5 metres.
- Flow from both pumps averages 1.0l/sec. There is a greater yield per stroke from the larger diameter pump, but this requires greater effort so in terms of work it evens out.

Pump site requirements

An ideal site for a pump is within 5 metres of the lowest level to which water will drop in the sediment of the river channel. This point will ideally be above the maximum flood level of the river. If this is not possible the pump site will require protection so that it is not unduly damaged during flood events.

The pump site should also be within some 10 metres of the highest point of water discharge – generally the top of the inlet pipe of a water tank. If this is not possible a second, booster pump installation should be installed. Although more effort is required with this triple pump system it has been shown that it is possible to raise water to an overall height of over 25 metres.

A pump site should also have easy access and importantly not be the cause of any erosion or environmental degradation. All digging, foundations and trenches must be adequately back-filled and not become water collection points. The installation must not be the cause of any water movement that will create runnels that will eventually lead to erosion of soil. Adequate fencing to protect equipment from damage or fouling by livestock or other animals should also be encouraged. In their search for water, elephants in some areas in Zimbabwe can sometimes be a significant cause of damage to pumps.

Small-scale sand-abstraction systems

Chapters 3, 4, 5 and 6 indicate the broad situations in which sand-abstraction is a suitable technology choice. Information is also provided on the wide range of sand-abstraction and pump equipment that is available and methods of selecting a suitable water abstraction system. With the technology and information available it is possible to identify the correct abstraction system within given conditions.

Although not appropriate in all situations a well-point system that is driven into river channel sediment and connected to a suction pump on the riverbank generally provides a simple, satisfactory and low-cost solution for a small-scale clean water supply. As such, an explanation and design of a typical single well-point sand-abstraction system is provided.

A simple small-scale single well-point system

The Dabane Trust has installed simple handpump technology sand-abstraction systems at more than 100 sites in Zimbabwe over a period of 15 years. The original installations put in place in 1992 are still in operation, independently managed by rural community groups.

Figure A1.1 shows the layout of a typical small-scale sand-abstraction system as developed by Dabane Trust with a single home-made well-point and a flexible connecting pipe to a rower pump on the riverbank. The rower pump is situated no more than 5 metres above the saturated river sediment level and discharges water into a sump. Water is then transferred a greater distance and height by a Joma pump to a water supply point such as a water storage tank in a garden. This can be several hundred metres distant and some 8 metres higher. The Joma pump uses rower pump components in uPVC pipe work with standard pipe fittings mounted in a steel frame. A treadle pump would provide an alternative to the Joma pump.

The following is a description of general sand-abstraction requirements with examples of the systems and design calculations for the equipment typically used by Dabane Trust.

Well-point requirements

As has been dealt with in preceding chapters a suitable well-point or infiltration gallery is required for the sediment conditions at a proposed site. The screen must have an aperture size, a diameter and a length that is suitable for the output of the pump and the grade of sediment in the river channel.

A number of commercial screens are available which have mainly been derived from the borehole screen industry. A list of some manufactures that make screens suitable for sand-abstraction use is contained in Appendix 2.

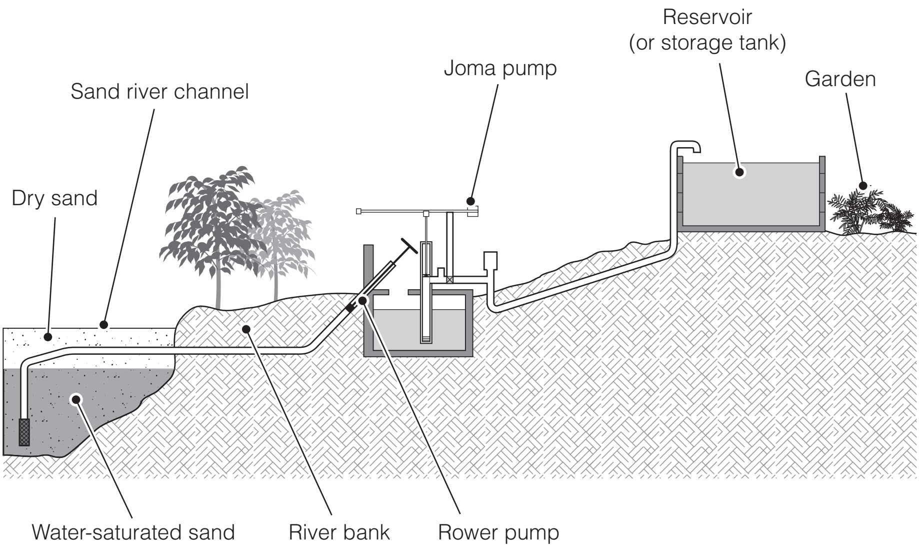

Figure A1.1. Layout of simple well-point sand-abstraction system

Calculation of screen aperture size

Correct screen aperture size is best ascertained by sieving. The ideal is to obtain an accurate grading of a sample of sediment. There are commercial companies that will carry out a sieve analysis and the Engineering Department of a University or a laboratory that analyses building materials or concrete mixtures may have a set of sieves that will provide a sediment analysis.

If such sophisticated equipment is not available approximations for gauging sediment particle size should be made as indicated in Chapter 3.

The size of apertures of a screen should ideally allow no more than 75% of the sediment to pass through, although in reality 85 or 90% may have to be acceptable. As explained in chapter 4 this will allow a natural screen pack to develop around the well-point without causing either undue wear on the moving parts of the pump or allowing the abstraction and pump system to clog up with sediment.

Thus if 10 - 25% of a sediment sample is retained on a 3.0mm sieve a screen with a 3.0mm aperture is suitable, but if less than 10% is retained then a smaller diameter aperture will be required. An assessment of the quantity of sediment that has been retained in a stack of sieves with decreasing apertures will help to determine screen slot size.

Local manufacture of a well-point screen is quite feasible. Round apertures can be formed by drilling or by pushing a red-hot wire through a uPVC pipe. These are generally clean sided, unlike slots cut with a hacksaw that tend to retain uPVC particles or kerf where the sawblade breaks through and which is relatively difficult to remove. Screens that have been formed by slots (2.35mm width) cut with a hacksaw blade in a uPVC pipe tends to fracture between the slots even if off-set, when the well-point is driven into sediment.

Realistically it is not feasible to drill holes smaller than 2.0mm. If a size smaller than this is indicated an alternative such as a screen with large apertures that is wrapped in geotextile, or a commercially available screen, such as a Boode ceramic screen will be required.

Calculation of the number and position of apertures

Having established the size of the aperture a calculation is required to determine the number of apertures that will ensure a low velocity of flow through alluvium to the screen. Not only the number but the position of each aperture is important as there must be sufficient material retained between each hole so that the screen is not unduly weakened. A further consideration in the calculation is the length of the screen which should not be too long. During periods of low water in the sediment the water-level should not drop below the level of the upper apertures which would allow air to be drawn into the system and lead to pump failure.

Well-point design

Step 1 – Pump yield

Determine an appropriate pump yield for the water source. A suitable output for a handpump is 1 to 2m^3/hr. Depending on the permeability of the sediment 1 to 2m^3/hr is also a sustainable yield for a single well-point. For yields larger than this multiple well-point systems are required.

Step 2 – Diameter and wall thickness of a well-point screen

Determine the inside diameter of the pipe to be used as a well-point. Suppliers and/or technical brochures should have information on the outside diameter and the wall thickness. A suitable pipe is a 50mm uPVC pipe. uPVC is measured by its outside diameter (O.D.) and thus irrespective of the class, (the wall thickness), will always be of the same diameter. A 50mm uPVC pipe will fit within a 50mm (2 inch) steel water pipe, (often referred to as a 2 inch, or 50mm galvanized steel water pipe), as the internal diameter of a 2 inch steel pipe is nominal and closer to 2.125 inches than 2 inches. The O.D. of the uPVC pipe is 50mm and the steel pipe has a nominal bore of 54mm.

Step 3 – Diameter of apertures

Calculate the aperture size from a sample of sediment – as above

NOTE: In order to avoid any confusion when joining uPVC pipe to steel water pipe it should be noted that because uPVC pipe is classified by its outside diameter and steel pipe by its inside diameter the same size uPVC and steel pipes do not join together without adaptors.

A uPVC pipe always joins to a smaller size steel pipe.

Thus for example a 63mm uPVC pipe couples with a 50mm (2 inch) steel pipe, which depending on the class and thus the I.D of the uPVC pipe, may create a restricted flow.

Step 4 – Internal velocity

Decide the velocity of flow through the internal diameter (I.D.) of the well-point pipe. A recommended flow is 0.03m/sec.

Step 5 – Material between the apertures

Determine a suitable distance between the sides of each aperture to maintain sufficient strength in the pipe. This will depend on the size of the apertures, large diameter apertures require a greater space between them than smaller apertures. As a useful guide the width of the material between the apertures should be twice the diameter of the aperture.

Step 6 – Number of apertures around the pipe

Calculate the number of apertures around the pipe at the distance decided in step 5. Adjust the distance to an even measurement between each aperture and rounddown.

D = pipe circumference/(aperture diameter + distance between apertures)

$$D = rounddown\left(\left(\pi * d_p\right)/\left(d_a + L_a\right)\right)$$

Step 7 – Total number of apertures in the screen

Calculate the number of apertures to be made that will achieve the same velocity of flow through the screen, as through the well-point pipe.

Na = ((yield in m³/s)/velocity)/(area of aperture)

$$N_a = \left(\frac{Y}{3600 * v}\right) / \left(\frac{\pi * d^2}{4}\right)$$

Particularly in screens with a large number of small diameter apertures this could be increased by a nominal 10% to compensate for the friction created in the flow of water against the side of the apertures. However this would also lead to an increase in the overall length of the screen, which might then make the screen too long to be practical.

Step 8 – Number of rows of apertures

Calculate the number of holes required along the pipe at the same distance as determined in step 6. If possible increase by about 25% to compensate for apertures that are likely to block during the life of the screen. Check that the final screen is not an unreasonable length for the depth of sediment at the site. A rough guide is 10 to 20% of the depth of sediment.

Number of rows (Nr) = Na/D

Adjustment = Nd

Actual number of rows M = Nr + Nd

Actual number of apertures N= D*M

$$N = D * \left(\frac{N_a}{D} + N_d \right)$$

Step 9 – Check calculation for overall suitability

From the number of apertures finally decided on, recalculate the velocity of water through the screen to ensure that this has not become significantly greater than that determined in step 4.

Velocity = (yield in m^3/s)/(Num apertures * area of aperture)

$$v_1 = \left(\frac{Y}{3600} \right) / \left(N_a * \frac{\pi * d^2}{4} \right)$$

From this data a well-point can be fabricated or purchased that will have suitable size apertures and will ensure the water abstracted from the sediment is at a velocity that will not cause any breakdown or deterioration in the equipment. Photograph A1.1 shows the aperture arrangement of a driven well-point and the use of a simple jig to achieve the correct distribution of apertures where several well-points are required. The diameter of the drill and the number of apertures drilled are determined in steps 3 to 9 above.

Well-point installation

A well-point or a number of well-points linked together must be installed as deep as possible at a suitable site in the river. The well-point as designed above can be made from a length of steel water pipe or from uPVC pipe closed at one end. Such a well-point can be dug into the sediment late in the dry season when the water-level in the river sediment is low. Alternatively a steel pipe can be driven into the river sand with a heavy hammer, however care must be taken not to damage any exposed threads on the well-point.

A suitable well-point can be made from uPVC pipe and equipped with a steel tip. This well-point can then be driven to the base of the river channel

Example:
Step 1, required yield: 1.5m^3/hr

Step 2, internal diameter of the well-point: selected pipe 50mm O.D. uPVC pipe with 3.00mm wall thickness – internal diameter 44mm

Step 3, diameter of well-point apertures: from a sieve analysis of sediment at the installation site – 3.00mm

Step 4, internal velocity within the well-point: 0.03m/sec is recommended

Step 5, determine the distance between apertures on the circumference of the well-point (twice the diameter of the aperture) – 6.00mm

Step 6, calculate the number of apertures around the well-point, using the formula – 17

Step 7, determine the number of apertures required for the above statistics, using the formula – 1,965

Step 8, calculate the number of rows of apertures required, using the formula – 116.

Increase the number of rows by 10 to 25% to accommodate blockages – 128 (10%)

Adjust the number of apertures, using the formula – 2,169

Step 9, recalculate the velocity through the screen, as a check, using the formula – 0.0272m/sec

Allowing for a 25% blockage of the screen from lodged grains of sediment and incrustation of salts the velocity will be increased to 0.036m/sec, which is still quite adequate.

From other calculations of this example:
Length of screen – 796mm
Surface area of the screen – 12.3%

Photograph A1.1. Use of a jig in the construction of well-points

using a removable steel driving tube and a heavy hammer, which does not come into contact with the uPVC well-point.

An appropriate well-point fabricated from uPVC pipe with a sacrificial steel point to make a driven well-point is shown in Figure A1.2.

Handpump requirements

Direct action suction pumps are suitable handpumps for small-scale sand-abstraction use. A simple and effective pump that has been used successfully by Dabane Trust that is basic in both design and operation and is thus highly suitable for remote area use is the Rower pump. The Rower is a simple open-ended displacement pump which uses standard components and although the pump is available commercially it can also be manufactured locally.

Handpump components

The basic components of a Rower pump with a straightforward connection to a well-point include an inlet pipe, a foot valve, piston and piston rod. The following is a description of the purpose of the components together with the materials from which they can be made:

Inlet pipe – Purpose, a pipe through which water is drawn from a well-point, or from a well to a pump.

Accurate calculations are required to determine the size and class of the pipes that will connect the well-point(s) to a handpump. However, suitable materials for a small-scale single well-point/handpump installation as described above are likely to be 40mm LDPE (Low Density Polyethylene)

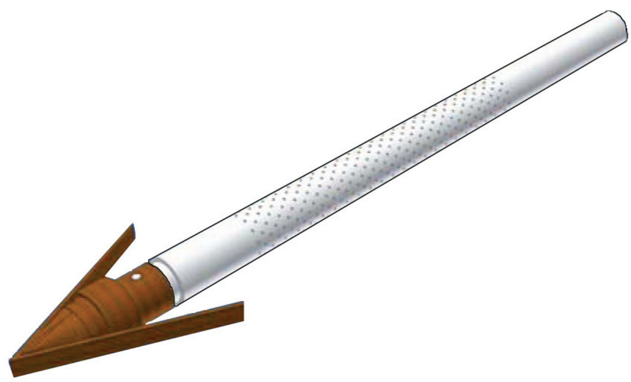

Figure A1.2. Round aperture well-point which will pass through the river sediment and connect to a 50mm uPVC class 10 pipe on the riverbank, which in turn will connect to the handpump. Larger installations will require larger piping and fittings.

Foot valve – Purpose, a check valve in the bottom of the pump to allow water to enter the pump cylinder but not to flow back.

In the systems described foot valves are only located in the pumps. There is no foot valve located in the well-point or the connecting pipe where a grain of sediment lodged under the flap valve might render the system unusable. Suitable materials for simple valves are – uPVC sheet of 10 or 12mm thickness or discs of flattened uPVC pipe built up to 10 or 12mm; rubber flap from a light vehicle inner tube held in place with a 4,00mm × 20mm self-tapping stainless steel domed screw. The uPVC disc is cut to fit inside the pump cylinder and is drilled with 8 holes, 4×6mm and 4×8mm which are clear of the edges of the disc and of the centre. The rubber flap is fitted to the centre of the disc and held in place with the self tapping screw.

Pump cylinder – Purpose, a pipe or cylinder in the base of which the foot valve fits and through which the piston moves up and down.

Suitable materials for the system described - 63mm class 16 uPVC pipe

Piston – Purpose, moving check valve within the pump cylinder. It allows water which is held by the foot valve to flow through it as it is pushed downward and lifts water as it is pulled up.

There must be an airtight seal between the piston body and the cylinder so that air can be evacuated from the system in order for the pump to draw water. Suitable materials for fabrication of a piston are – layers of 10 or 12mm uPVC sheet or flattened uPVC pipe built up to a total thickness of 30mm, a rubber valve flap, rubber cup seals. Similar to the fixed foot valve the piston is also drilled with 4×6mm and 4×8mm holes.

Piston rod – Purpose, a shaft and tee bar which raises and lowers the piston within the pump cylinder. The rod passes through the centre of the piston and holds the rubber valve in place on top of the piston.

Suitable materials – 10mm bright steel rod, 2×10mm hex nuts, 1×10mm nyloc nut, 20mm black steel pipe.

A sketch of a Rower pump foot valve and piston fabricated from the materials listed above is shown in Figure A1.3.

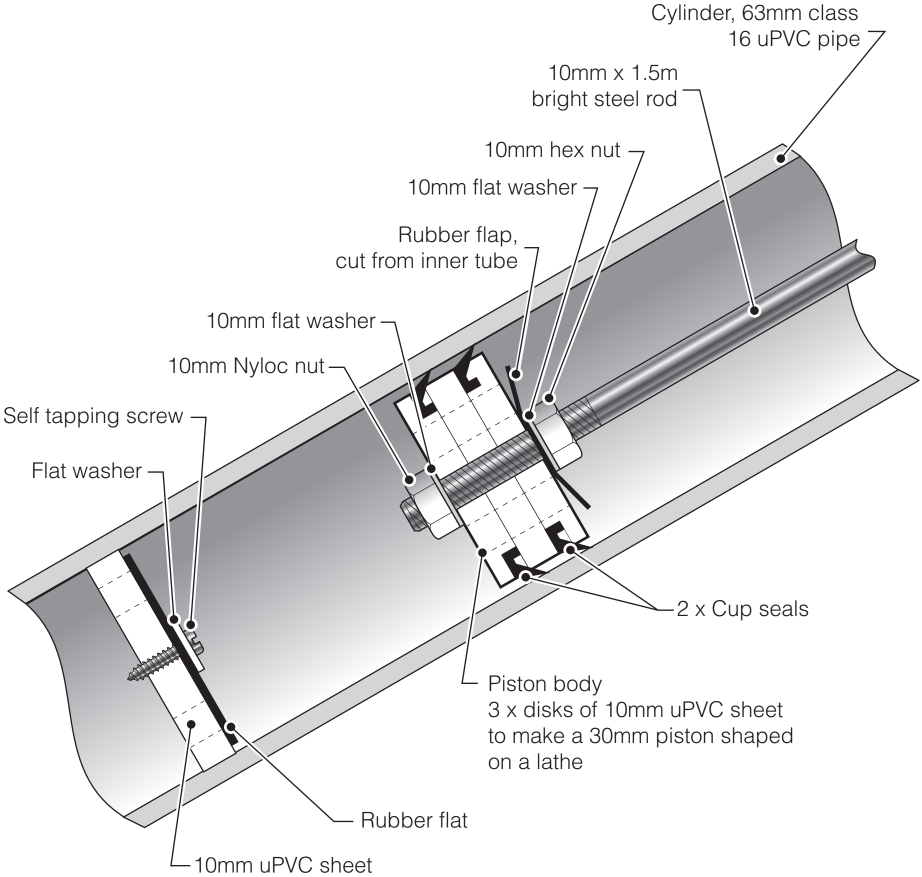

Figure A1.3. Components of a Rower pump

Pump and well-point installation calculations

The height from the water-level to the pump site must be calculated. At sea level where there is maximum atmospheric pressure this could theoretically be as much as 9.8 metres, however the actual lift will be determined by the efficiency of the pump to create a vacuum and will reduce by some 300mm for every 1,000 metres of altitude. In reality a lift of some 4 to 5 metres at an altitude of ±1,500 metres is quite acceptable. Consideration must also be given to the weight of water raised. Although it would be quite possible to construct a pump with an internal cylinder diameter of 63 or 75mm to raise a large volume of water over say 5 metres, the operation of the pump would most likely be beyond the capability of most handpump users.

Construction of pump head works

Head works for the pump system must be fully suited to the proposed use of the water. However as the intended purpose may change and as invariably it is clean, safe water that is drawn from river alluvium a general purpose style head work that enables easy collection of water for household use is probably best considered from the outset.

Photograph A1.2 shows a livestock drinking trough beside the Manzamnyama River, Bulilima District, Matabeleland South, Zimbabwe. The trough is filled by a Rower pump that is direct coupled to a well-point. At one end of the trough and directly under the pump is a bucket stand for immediate collection of water before any contamination can occur. If there is no bucket in place water flows directly into the trough. The scheme is community owned and managed. The pump operators are protected from the cattle by a stout fence and in order to further safeguard the infrastructure from possible damage by pushing cattle the owners are always in attendance when the cattle are drinking. In the base of each trough a connection is fitted for a pump to draw water a further distance to a small irrigated garden.

Photograph A1.2. Makhulela community sand-abstraction water supply

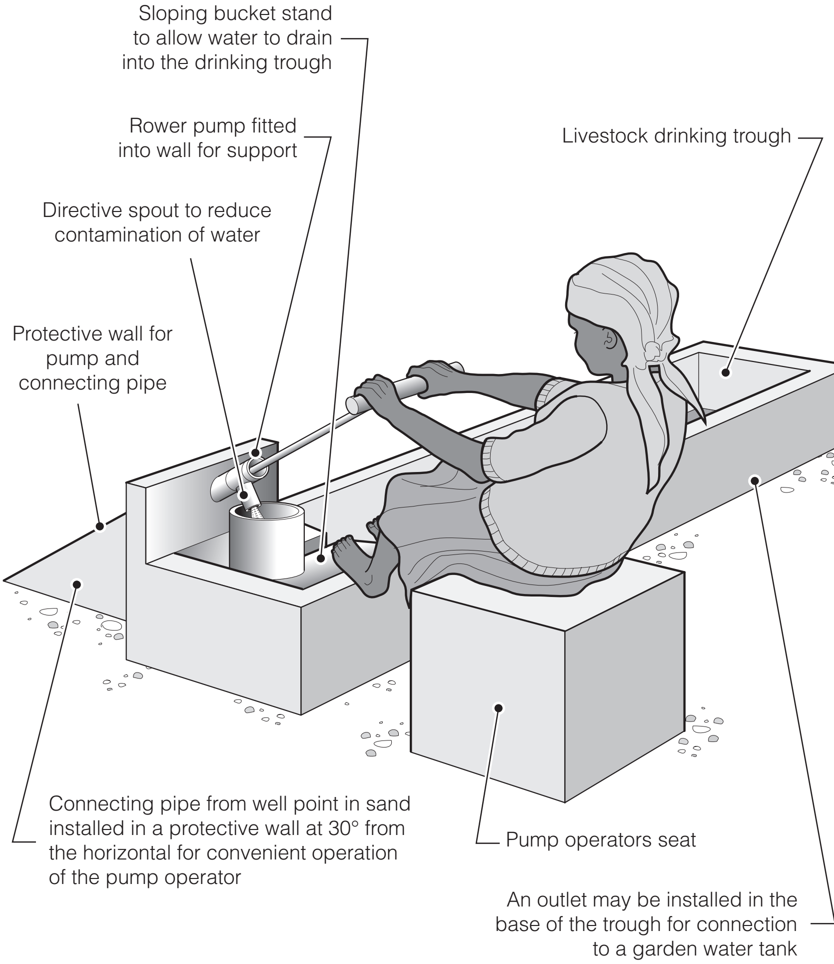

Figure A1.4. Household water supply point with livestock drinking trough

The design of a domestic water/livestock water supply point is shown in Figure A1.4.

An alternative system designed primarily for garden water supplies is shown in Photograph A1.3. In this design a bucket for clean water can be fitted under the Rower pump or without a bucket in place water discharges directly into a sub-surface sump. As there is no rise between the sump and the garden at this particular installation, a second Rower pump which is mounted beside the water storage tank is used to draw water for irrigation.

Photograph A1.3. Clean water/garden water supply

Another alternative arrangement is shown in Photograph A1.4 with a Rower and Joma pump combination to deliver water to a garden more than 10 metres above the Mtshelele River, Gwanda District, Matabeleland South, Zimbabwe. A diagram of this set up is shown in Figure A1.1.

Photograph A1.4. Rower and Joma Pump combination