LIFEWATER

DRILLING & WELL CONSTRUCTION

REFERENCE MANUAL

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Lifewater Canada

PO Box 44
Kakabeka Falls, ON
P0T 1W0
E-mail: **gehrelji@yahoo.com**

Lifewater Drilling & Well Construction Manual

Introduction

This manual outlines how to successfully site, drill and construct good water wells. In-depth instructions are provided on using the LS-100 mud rotary drill and Bush handpumps. It is designed to help train people with no well construction experience and to be used as a reference when problems arise later in the field. The manual is most useful when used in conjunction with on-the-job training.

Well drilling is an art, not an exacting science. This manual does not cover all issues which will arise and it does not replace common sense or experience. The best way to learn how to construct good wells is to go and do it with experienced workers. Most importantly, learn from your failures, talk to others and then try again again!

The guiding principle is "**Do the easy ones first"**! There is plenty of water to obtain from shallow depths without taxing the mechanical integrity or engineering design of the LS-100. Hard rock drilling and deep or difficult holes should be left to experienced drillers with more suitable drilling equipment. In general, do not try drilling if there are no existing dug wells within 1 km of the proposed drilling site.

In writing this manual, I have learned much from the many Lifewater volunteers across North America who have selflessly helped people around the world. The collective knowledge and experience that this group has accumulated by drilling hundreds of wells in different circumstances is truly impressive and I thank everyone who shared their successes and failures with me. Finally, I am struck by how God has richly blessed all those who have stepped out in faith and I look forward with excitement to what God will do in the future.

Jim Gehrels, Lifewater Volunteer

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Section 1

Steps to Construct a Well

In order to increase the likelihood of completing a successful and safe drinking water well, follow the steps outlined below:

1. Determine the well location based on community involvement (**Appendix R**) and technical factors (**Section 2**);
2. Drill the borehole (**Section 3**) to the desired depth (30 m (100 ft) or less where there is lots of water (**Section 6**);
3. Install a PVC casing & slotted screen to keep the borehole open and allow clean water to enter the well (**Section 7**);
4. Float-in a filter pack to keep dirt out of the well (**Section 8**);
5. Grout the annular space to keep contaminated surface water out of the well (**Section 9**);
6. Develop the well to remove turbidity from the water (**Section 10**);
7. Construct a concrete pad around the well (keep contaminated surface water away from the well and keep the area around the pump from becoming a mud-hole (**Section 12**);
8. Install a pump (**Section 14**);
9. Disinfect the well to eliminate bacteria introduced during well construction (**Section 15**);
10. Test water quality to make sure it is safe to drink (**Section 16**);
11. Maintain the pump & pad (**Section 17**). You can even make your own cup leathers! (**Appendix L**);

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Section 2

Deciding Where to Drill

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When drilling equipment is available, it is very tempting to get right to work drilling wells. However, wells should be carefully sited (**Appendix D**) so that drilling only occurs where there is a high probability of successfully penetrating into water-bearing formations and the wells can be effectively used, maintained (**Section 17**), and protected from contamination. While every borehole will not result in a good well, advanced planning with the community (**Appendix R**) will maximize the number of successful wells and minimize drilling costs.

In order to successfully site water wells, those involved must know something about the places where underground water occurs and how it got there (see **Appendix C**).

To identify areas where there is a high probability of successfully drilling wells, one must first prepare a site map (Section 2.8). Consideration must be given to each of the following seven factors which are critical in siting new water wells:

- **2.1 - Subsurface conditions,**
- **2.2 - Subsurface soil types,**
- **2.3 - Vegetation,**
- **2.4 - Topography,**
- **2.5 - Surface water,**
- **2.6 - Sources of contamination**
- **2.7 - Accessibility to users.**

Aerial photographs, geologic reports, well logs and topographic maps are useful in studying these factors (see **Section 2.9**). Where available, specialists should be enlisted to use geophysical techniques to define subsurface conditions[1]. This is most important in areas where air photo coverage and hydrogeological information are inadequate, where local rainfall is less than 700 mm/yr (White, 1987) and where adequate water supplies are only available in rock (Dijon, 1981). Usually, however, the best source of well siting information is talking to people who have dug local water wells and personal inspection of water wells in the area. Although this can be time consuming, it is very important and contributes to an understanding of local subsurface conditions and selection of the best place for successful water wells.

2.1 - Groundwater Depth, Quantity & Quality

Where dug wells exist, it is possible to determine the depth to water, geology and expected water quantity and quality. The history of old wells will indicate how far down the water table drops during dry seasons and will indicate how deep new wells must be. **In general, the LS-100 mud rotary drill rig should only be used in areas where people are getting their water from hand dug water wells (less than 40 meters deep)**. Only after numerous water wells are drilled this way should drilling be attempted in areas where little information is available or where subsurface conditions (impermeable clay, hard rock, etc.) have prevented the construction of hand dug water wells.

If existing dug wells will be disinfected (**Section 15**) and continue to be used, the new well should be drilled as far away as possible to ensure that both wells will produce sufficient amounts of drinking water without interfering with one another (drawing water from the same part of the aquifer).

2.2 - Subsurface Soil Types

The amount of water supplied by an aquifer (water bearing formation) is as important as its quality. The only way to know exactly how much water is available is by pumping wells (**Section 10.3**). However, a rough estimate of yield can be made by identifying the soil and rock which comprise the aquifer.

Most sand and gravel deposits contain significant amounts of drinking water. However, the amount of water which can actually be pumped depends on how thick these deposits are and their permeability (how easy it is for water to flow through it). In general, the larger the grain size and the thicker the deposit, the higher the yield of the aquifer.

Unfortunately, the **LS-100** cannot effectively drill past boulders (loose rocks greater than 10 cm in diameter) or through loose gravel greater than 1-2 cm diameter (it is very difficult to keep the borehole from collapsing and it is hard to carry the gravel up and out of the borehole). It is, therefore, important to inspect existing wells and valley sides, cliff faces, quarries, etc. to determine if there are boulders or coarse gravel present.

Try to avoid siting and developing wells in shallow sand and gravel deposits if the water table is less than 3 meters below surface. Under these conditions, waste water can easily infiltrate back down to the water table near the well and contaminate the drinking water supply.

Wells constructed in silt or clay soils will have very low yields regardless of how they are constructed. To compensate for this, large diameter water wells should be carefully dug so that large volumes of water can slowly accumulate in the well casing over time and provide sufficient quantities when required.

Finally, limestone, sandstone or quartzitic rock may also yield adequate quantities of water. Best yields are found where there is a thick zone of weathered rock with many cracks (fractures) (Dijon, 1981). In general, fine grained rocks, such as shale, do not serve as productive aquifers. Also, the LS-100 cannot effectively drill through cemented stone layers or hard rock like granite or gneiss. Therefore, if there are hard rock layers greater than 1 to 2 meters thick in the vicinity of the proposed drilling location, a different drill rig is needed.

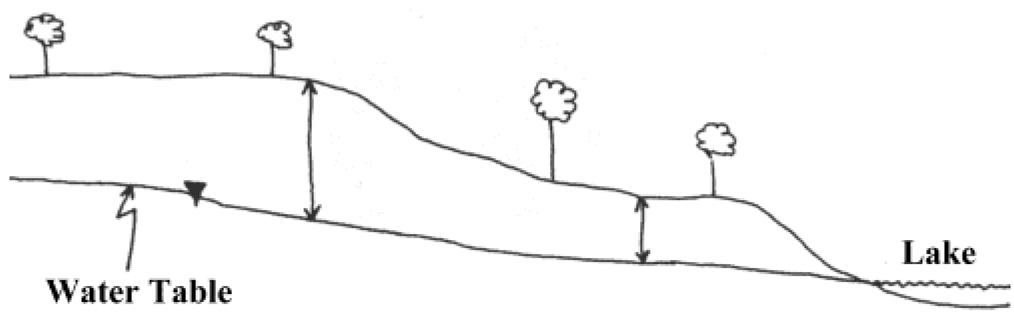
2.3 - Vegetation

During the dry season, survey for indications of groundwater by looking at the alignment of ant mounds and green vegetation in the midst of an arid landscape. Annual plants, such as grasses and ferns, are not good indicators because they come and go with the seasons. However, year-round reeds and broad leaf trees and shrubs like cedar and willow tend to grow where water is close to the surface. Some water indicator trees in West Africa are Daniella (Daniella olivieri), Kapok (Ceiba pentandra) and Baobao (Adansonia digitata).

2.4 - Topography

The water table commonly follows the land surface (see **Figure 1**). While the lowest areas (valley bottoms or depressions where water accumulates after rains) are generally the best places to drill (Dijon, 1981), ensure that the site has good access, is not subject to flooding and is not close to where contaminated surface water ponds. The presence of water bearing fracture zones may be detected by surface features such as shallow linear depressions and abrupt changes in valley alignment. Often these features are difficult to see in the field but become apparent when viewed from the air.

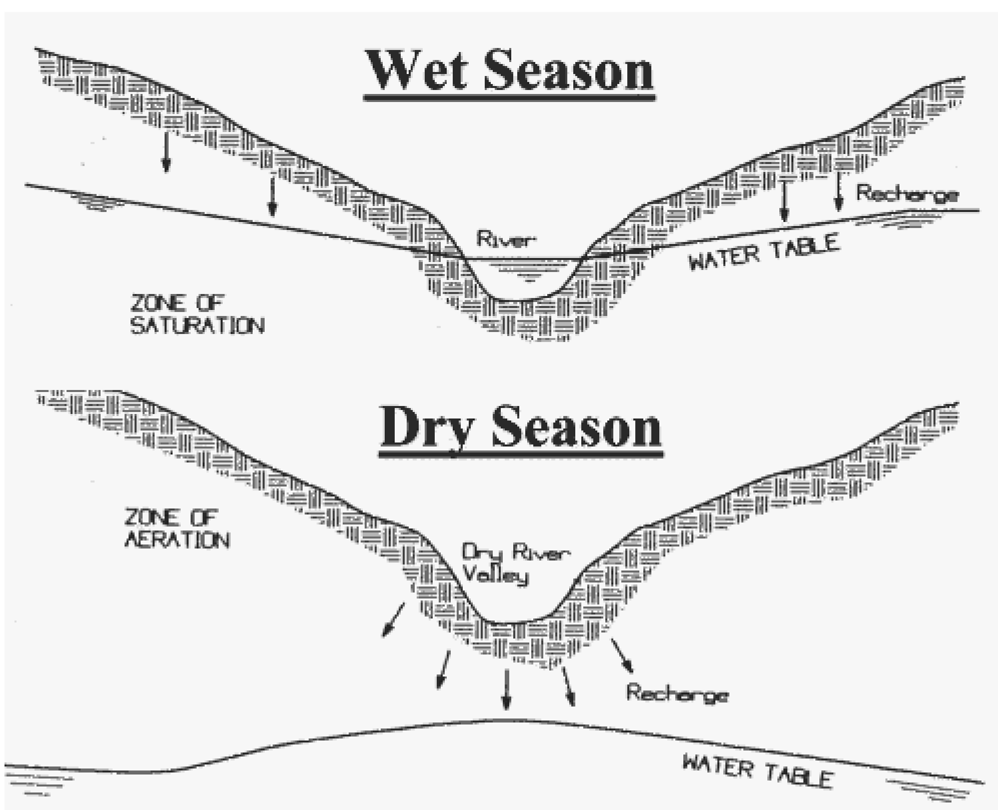
Figure 1: Depth to water



2.5 - Surface Water

Successful wells are often drilled near rivers; groundwater may be available even if the river is temporarily dry **(Figure 2)**. Reliable wells have even been located near broad sandy riverbeds which are active once every 5-10 years (Dijon, 1981). Water taken from wells located at least 15 m from a river is usually cleaner and cooler than water taken from the river. If the well water remains turbid after construction, the soils may be providing inadequate filtration and contaminated river water may be entering the well.

Figure 2: Locating Water Wells Near Rivers

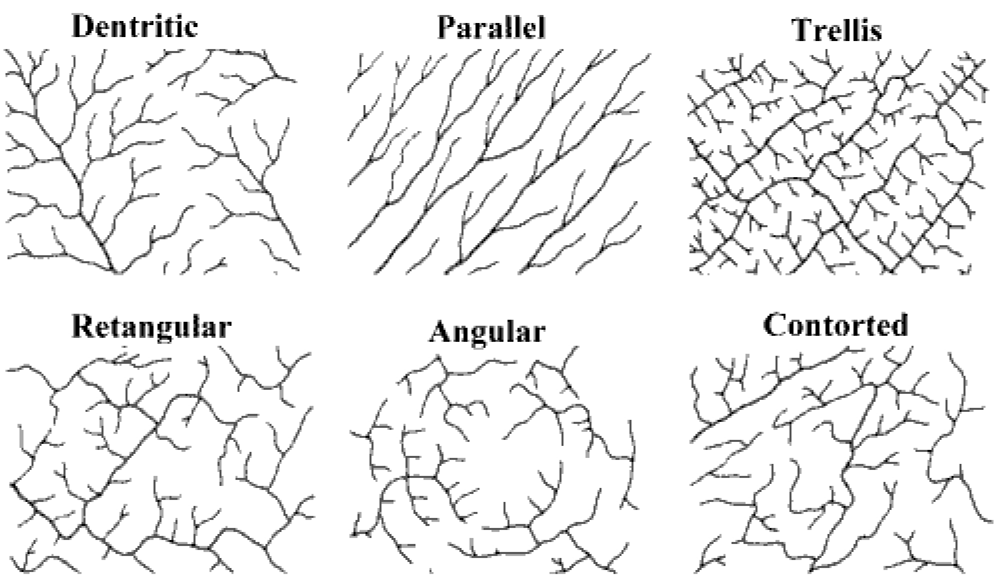


Look for springs since they indicate the presence of a water bearing formation (aquifer). A well can often be successfully drilled just uphill of the spring. Animal trails often lead to seeps and springs.

Finally, surface drainage patterns can be used to determine rock type **(Figure 3)**:

- Trellis and rectangular drainage develops where dipping, fractured sedimentary rocks are present; these are the most favourable areas for high yield aquifers (Selby, 1985);
- Contorted drainage develops over folded rocks. Water bearing tension fractures and gaps between layers of differing hardness sometimes develop near the top of folds;
- Annular drainage typically develops over volcanic or intrusive (granitic) domes, with streams flowing along water bearing fracture zones;
- Dendritic or branching patterns with a large number of tributaries are typical of drainage in areas of impermeable crystalline rock such as gneiss. Parallel drainage patterns may develop in areas with linear water bearing structures such as faults and dikes.

Figure 3: Drainage Patterns



2.6 - Sources of Contamination

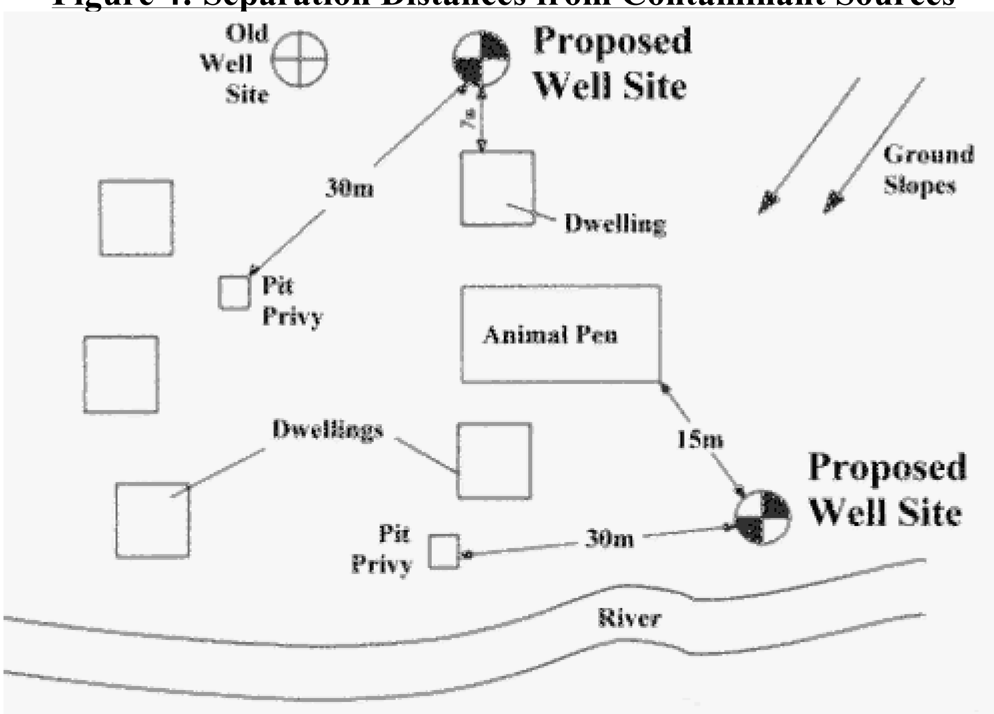
Well water should be tested (**Section 16**) to ensure that it is free from disease-causing organisms. Also, if it is not clear and good tasting, people may revert to traditional unsafe drinking water supplies. Therefore, avoid drilling in areas where unsuitable quality water is known to occur and keep wells as far away as possible from potential sources of pollution (see **Figure 4** and **Table 1**):

Table 1: Minimum Separation Distances from Contaminant Sources

Distance(m)	Possible Source of Contamination
100	Garbage dumps/refuse piles, car repair or fuel (petrol) sales outlets, industrial operations/storage facilities etc.
50	Seepage pit or cesspool
30	Pit toilets, animal pens, barns, fields fertilized with dung
15	Septic tank, surface water body
7	Drain, ditch, house

Locate wells upgradient (uphill) of nearby potential sources of pollution (i.e., the land should NOT slope from pollution sources towards water wells). If this can not be avoided, try to locate wells as far to the side of the slope as possible (i.e., not directly downslope of possible contaminant sources).

Figure 4: Separation Distances from Contaminant Sources



2.7 - Accessibility

Issues of accessibility to well should be clearly addressed in the Community Water Supply Agreement (see **Appendix R**). Wells should be as close as possible to houses because people use a lot less water if wells are located far from their home. Usage drops from 40 litres per day (lpd) per person when water is supplied in the yard down to 15 lpd for sources 200 m away; this rate holds fairly constant for distances up to 1,000 meters (Cairncross, 1987). Only when water wells are located more than 1 km from home does the water consumption rate drop again, often declining to less than 7 lpd[2]. This means that **the most significant benefits (arising from increased water consumption) occur when water wells replace old water sources which were further than one kilometer away** (Cairncross, 1987)[3]!

Another factor in preparing Well Development Plans is to determine how many wells are needed to serve the population. When more than 300 people use one handpump, there will be significant waiting lines to get water.

Ensure that the site is accessible year-round and that the access route to the water well is not susceptible to flooding. Finally, ensure that the site has legal access which is acceptable to users from a societal standpoint. Land ownership law is usually different than what we are used to and requires careful consideration. Having a water well on someone's property enhances its value and therefore a formal arrangement for access needs to be clearly made before the well is drilled.

2.8 Preparation of a Site Map

A map of the village and surrounding area should be prepared. Add to the map all relevant features such as houses, animal pens, pit toilets, rivers, swampy areas, garbage disposal areas and indicate the direction in which the land slopes (see **Figure 4**). Draw all possible well sites on the map and select the best site (try a siting exercise - **Appendix D**).

There is rarely an ideal location and the relative advantages and disadvantages of each site must be weighed. The people that will be using the well and the drillers must together decide which site is best for the community. Since selecting the best site is a matter of judgement and experience, it always helps to seek assistance from hydrogeologists - while their investigation may be time consuming and add some cost to the drilling project, it will help ensure that a site is selected which will provide a safe, abundant supply of drinking water.

2.9 Sources of Groundwater Information

Information which can help effectively site wells includes aerial photographs, geologic reports, well logs, topographic maps, geophysical maps etc. Sources of this information are listed below. It should again be emphasized, however, that the best sources of well siting information are talking to people who have dug wells nearby and visiting these wells yourself. Keep in mind that:

1. Information is often available in-country from government agencies (such as Ministries of Development, Rural Affairs, Geological Survey);
2. In-country information is also often available from libraries and international development/aid agencies;
3. Often excellent information can be obtained by talking to consultants, hydrogeologists and well drillers who have worked in the area of interest;
4. Libraries in most large urban centers in the United States and Canada often contain good information (make use of inter-library loan facilities!). To determine which library is the closest depository for United Nations material, call the UN office at (212) 963-7444;
5. Many high quality maps are available from the U.S. Geological Survey (USGS) in Reston Virginia (703) 648-4380 (Mapping Section) or (703) 648-5727 (Geologic Inquiries) or (703) 648-6047 (International Geology Program). They can search for material by key word. Material takes 2-3 weeks to deliver through their Denver office (303-236-7477). For a slightly higher fee, excellent overnight service is available from "Express Maps" (800-627-0039 or 303-989-0003) or "Powers Elevation Co. Inc" (800-824-2550 or 303- 321-2217);
6. USGS documents which pre-date 1981 can be obtained from the National Technical Information Service (703-487-4600). They require the NTIS number or the complete document title.
7. The United Nations Reference Library (Map Section) in New York is also a good source of information (212-963-0536). Delivery only available through regular mail.
8. The Library of Congress (Mapping Section) in Washington DC has many hydrogeological reports and maps for developing countries (202-707-6277). Requests must be made in person or in writing (response time to written search requests is very slow: 2-3 weeks); additional time is required for delivery.
9. Hydrogeological reports for many countries of the world are available from the National Groundwater Association (NGWA) Information Center at 3675 Riverside Dr, Dublin OH, 43107 (800-332-2104). There is an on-line search facility available for a fee; credit card payment and overnight delivery service are available. There is a minimum $12 base fee for retrieving up to 20 pages (extra fee/page for additional pages).

Footnotes & References

[1] Well siting success improved from 50-60 % (based on site reconnaissance and air photo interpretation) to over 90 percent when

geophysical technology is used (White, 1987). Geophysical surveys employ instruments that quickly and cheaply measure the physical properties of soil and rock (density, magnetism, electrical conductivity, radioactivity etc.). Geophysical surveys can be very useful in locating water-bearing fault zones, in finding an adequate thickness of overburden or weathered bedrock, and in assessing the depth to the water table (see Hazell et al., 1992 and Reynolds, 1987). Success depends on the application of appropriate techniques, having enough time to do the investigation, and having the equipment operated and the results interpreted by trained geologists (Driscoll, 1986). In some countries, the government provides geophysical surveys as a service.

[2] For design purposes, 5 lpd is the minimum consumption level and **25 lpd is an acceptable goal** in places where piped connections to individual houses are not feasible (Brush, 197?). It should be noted that the amount of water needed may be much higher if livestock require water and if well water is to be used for irrigate gardens.

[3] Education is crucial. Unless people understand the benefits clean water can bring, they will not make effective use of a new well and it may have little benefit (Brush, 197?)! Education is also important for on-going well maintenance; if people see clean water as being vital to them, they will be willing to occasionally spend a little time and money to keep their water supply safe and functioning reliably (Brush, 197?).

Cairncross, S. (1987) "The Benefits of Water Supply", Developing World Water, Hong Kong: Grosvenor Press Int'l, pp. 30-34.

Dijon, R. (1981) "Groundwater Exploration in Crystalline Rocks in Africa", Proceedings of the American Society of Civil Engineers, May 11-15, 1981.

Selby, M.J. (1985). Earth's Changing Surface. Clarendon Press, Oxford, 607pp.

White, C. (1987) "Bore Hole Siting Using Geophysics", Developing World Water, Hong Kong: Grosvenor Press Int'l, pp. 107-113.

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Section 3

How to Drill with the LS-100

Experience in developing countries has shown that the construction of drilled wells must be simple and efficient. This keeps projects affordable, maintains a certain momentum and enhances local enthusiasm. This section describes how to set-up and drill with the **LS-100** - a small mud rotary drill rig which has been successfully used in over 20 developing countries around the world with great success.

Drilling With the LS-100 Index

- 3.1 Introduction
- 3.2 Deciding to Drill With the LS-100
- 3.3 Pre-Drilling Preparations
- 3.4 On-Site Set-up
- 3.5 Mud Pit Design/Construction
- 3.6 Drill Rig & Mud Pump Set-up
- 3.7 The Drilling Process
- 3.8 Solutions to Drilling and Well Problems
- 3.9 Footnotes & References

Closely Related Topics Include:

- Section 4 - Drill Bits
- Section 5 - Drilling Fluid ("Mud")
- Section 6 - How to Decide When to Stop Drilling
- Section 11 - Safety on the Job
- Section 18 - Well Record Report

3.1 Introduction

The LS-100 is a small, portable mud rotary drilling machine made by **Lone Star Bit Company** in Houston, Texas. Using this small drill rig, it is possible to rapidly complete safe, reliable water wells. As discussed by Hamann (1992), advantages of the LS-100 include: comparatively low cost, portability, and speed and depth to which the rig can go relative to manual methods (see **Table 2**).

Disadvantages of the LS-100 drill rig are that it is limited to drilling a 6 inch borehole to a depth of 30 m (100 ft) and it cannot effectively penetrate hard rock, loose boulders or coarse gravel (an air-rotary version of the LS-100 is currently being developed to drill in these environments).

Table 2: Comparison of Well Construction Techniques

Comparison Factor	Hand Digging	LS-100 Drilling
Capital Cost	Low	Moderate
Technology	In-Place	New
Method	Established, Familiar	Special training required.
Effort	Effort bonds community.	Onus on few drillers
Time to Complete	Weeks or Months	Days
Safety	Cave-in, falling rock hazards digging in a deep hole.	Nobody in well
Contamination	Poor annular seals; Casing/lid often leak; Shallow water may be contaminated.	Protected by sealed hole & continuous casing. Deep, safe aquifers accessible.
Decontamination	Difficult	Easy
Water Supply	Well depth limited to 1-2 meters into water table.	Well screen 3-10 meters below water table
Water Storage	Large diameter storage augments low yield	Cannot construct useful well in low yield aquifers
Limitations	Caving sand or hard rock.	Cobbles or hard rock
Maintenance	Minimal equipment; readily available.	Spare parts may be difficult to acquire

3.2 Deciding to Drill with the LS-100

A small mud rotary drill rig is only a very small part of a solution to a very large problem. Success in using the drill rig depends on many factors including favourable subsurface geologic conditions, technical aptitude and experience, community support, and a commitment to maintenance, education and communication with others regarding the successes and failures of drilling.

Before you try operating a LS-100 drill rig, it is important that you are familiar with:

- **The equipments design Limitations (see Section 3.8).**
- **The Name and Function of each Major Part.**
- **What must be done to Maintain the Equipment.**
- **How to operate the equipment SAFELY (Section 11).**

In addition, before deciding whether or not to use the LS-100, the following factors should be seriously considered because they have a very strong bearing on the success or failure of a drilling project:

- Are there people in place who are already drilling using mud rotary techniques? If not, are there people with a mechanical aptitude who are willing to learn how to drill and service the machinery?
- Are there local people who will be willing and able to maintain the well once it is installed?
- Are basic supplies (piping, petrol, chlorine) readily available?
- Is there sufficient technical support available to assist if problems are encountered?
- Are there adequate communication and transportation options available for the team to function and effectively communicate with you?
- What equipment, if any (engine spares, well screens, hand pumps, etc) will need to be imported into the country? How reliable is the supply?
- Is the process of drilling and taking water from a handpump accepted by the prospective users?
- Do the local people understand the associated costs (time, money and effort)?
- Are the people committed to actively participate in and complete the project?

3.3 Pre-Drilling Preparations

Prior to traveling to a drilling site, there are a number of tasks which should be done. While it may be sometimes necessary to embark on a drilling project without all these tasks completed, projects will have a higher success rate and a lower level of frustration if they can be done ahead of time. Ideally, **people have been trained**, an Action Agency and Village Water Committee(s) established, and a Drill Team Selected (see **Appendix S**).

Maximizing drilling efficiency: Before you leave ensure that:

1. **suitable drilling sites have been selected. Each site should be:**
   - **in needy areas;**
   - **located where the LS-100 has a high potential for success;**
   - **located where drilling has been approved by the required government authorities.**
2. **the drill rig, mud pump, pump cylinders and other equipment (such as extra seals for the pump and drill) has cleared customs, is in good repair, is stored in a secure room;**
3. **a truck is available to transport the drill machine, handpumps, drilling supplies and drillers to the drilling site each day;**
4. **Village Water Committees have been established in each prospective drilling site and that the committee and potential users are supportive of a well being constructed and are willing to take ownership of the project. Before you commit to the job, sign a "Community Water Supply Agreement" (see Appendix R).**
5. **Drill crews have the required basic tools and equipment and that all necessary material has been purchased locally or will be brought with the crew to the drill site (see Table 3).**

Table 3: Essential Tools and Supplies (pre-drilling shopping list)

Drill crews should have the following basic tools and equipment available prior to heading out to drill a well (these items are normally used to complete the construction of multiple wells):

1. Thread die & wrench to fit diameter of local hand pump rod.
2. Four 200-litre (55 gal) drums with tight fitting lids for hauling water to the drill site (water can be used up very fast during drilling and is the main cause of avoidable drilling delays).
3. Three 19 L (5 gal) pails (buckets).
4. Two 130x15 cm (2x6) boards to support and level drill rig legs.
5. Six 1.8m (6ft) long 2x6 or 2x8 boards to build a form for the handpump pad (these can be re-used for future wells).
6. Six 30-36 cm (12-14 in) lengths of rebar bent at one end to stake down the drill rig legs and guy lines.
7. 30 m (100 ft) nylon rope to secure casing and pump during installation.
8. Carpenter's bubble level
9. 6.4 - 7.6 cm (2.5 - 3 in) diameter bailer, 1.2 m (4 ft) long to develop well.
10. Socket wrench set with metric and English sockets.
11. Hack saw blades (high quality).
12. Wheelbarrow.
13. Many cloth rags.
14. 2 shovels, 2 pick-axes.

15. 3x4 m (8x12 ft) MINIMUM sized heavy gauge plastic sheet to line the mud pits (to prevent water loss) and to put on the ground to keep equipment clean.
16. First aid box (with basic medical supplies).

The following material should be purchased and stored for Each well that is to be drilled:

1. 4 sacks bentonite clay or a half a sack of commercial drilling polymer;
2. 5 lengths of PVC pipe, schedule 40, 10 cm (4 in) dia. 7 m (20 ft) long;
3. 1 7m (20 ft) length of manufactured wire wrap of PVC screen (or make a screen by slotting a length of casing with a hach saw);
4. 8 PVC couplings for 10.16 cm (4 in) pipe;
5. One 10 cm (4 in) dia PVC end cap or make 1 wooden point/end plug;
6. 1 litre each of PVC cement and primer;
7. 5 litres (1.3 gallons) liquid bleach to disinfect the well;
8. 8 sacks of sand for concrete mix (1 sack=50 Kg, 96 lbs or 1.1 cubic ft)
9. 4 sacks of cement for annual grout seal and handpump pad;
10. 36 concrete blocks for forming pad edge;
11. 10 sacks of gravel for concrete mix;
12. 3 sacks of washed, sieved coarse river gravel (2-6mm dia) for filter pack;
13. 15m (50 ft) of 1 cm (0.4") diameter reinforced rod or heavy guage wire mesh for the handpump pad base;
14. 40 litres (10 gallons) gasoline ("petrol") for the drill rig and mud pump engines;
15. 4 litres (1 gallon) SAE 30 engine oil;
16. 1 Kg (2 pounds) heavy duty grease for drill pipe joints;

The following material should be purchased and stored for Each handpump that is to be installed:

1. 5 lengths of 3.18 cm PVC pipe, schedule 40, 7 m (20 ft) long;
2. 12 PVC couplers (3.18 cm, male-thread with female-glue adapter);
3. 12 PVC adapters (3.18 cm, female-thread with male-glue adapters);
4. 10 lengths steel pump rod (1.11 cm dia 3.05 m long 1.11 cm NC threaded ends or 7/16 inch dia, 10 ft long, 7/16 NC threaded ends) *Stainless steel preferred where water is corrosive;
5. 12 steel couplings for the pump rod (matching thread).

Well construction in many countries has been complicated by lack of locally available:

1. **Drilling Mud (see Section 5).**
2. **PVC Screen and Casing (see Section 7).**
3. **Filter Pack Material (see Section 8).**

3.4 On-Site Set-up

Unload all tools and equipment on dry ground near the selected drilling location. If possible, orient the drill rig so that it will be shaded during the afternoon. It is very hard to clean sand from greased threads, so keep pipes off the ground by placing them on boards (or tree branches).

Fill four 200 litre (55 gallon) drums with water and ensure that villagers are ready to keep these drums full during the drilling process. Arrange the water drums next to the area where the pits are to be dug. Add 1 cup of chlorine to each drum of water to ensure that bacteria are not injected into the groundwater during drilling - unless you are using polymer to thicken your drilling fluid (see **Section 5 - Footnote #1**).

Fence off an area behind which all observers must stand during the drilling process. Designate one of the local leaders to ensure that this safety rule is observed at all times. Have one of the drillers frequently explain what is happening while the well is being drilled.

Hand dig a 10 cm (4 in) diameter "well guide hole" about 15 cm (6 in) deep where the well is to be drilled.

3.5 Mud Pit Design/Construction

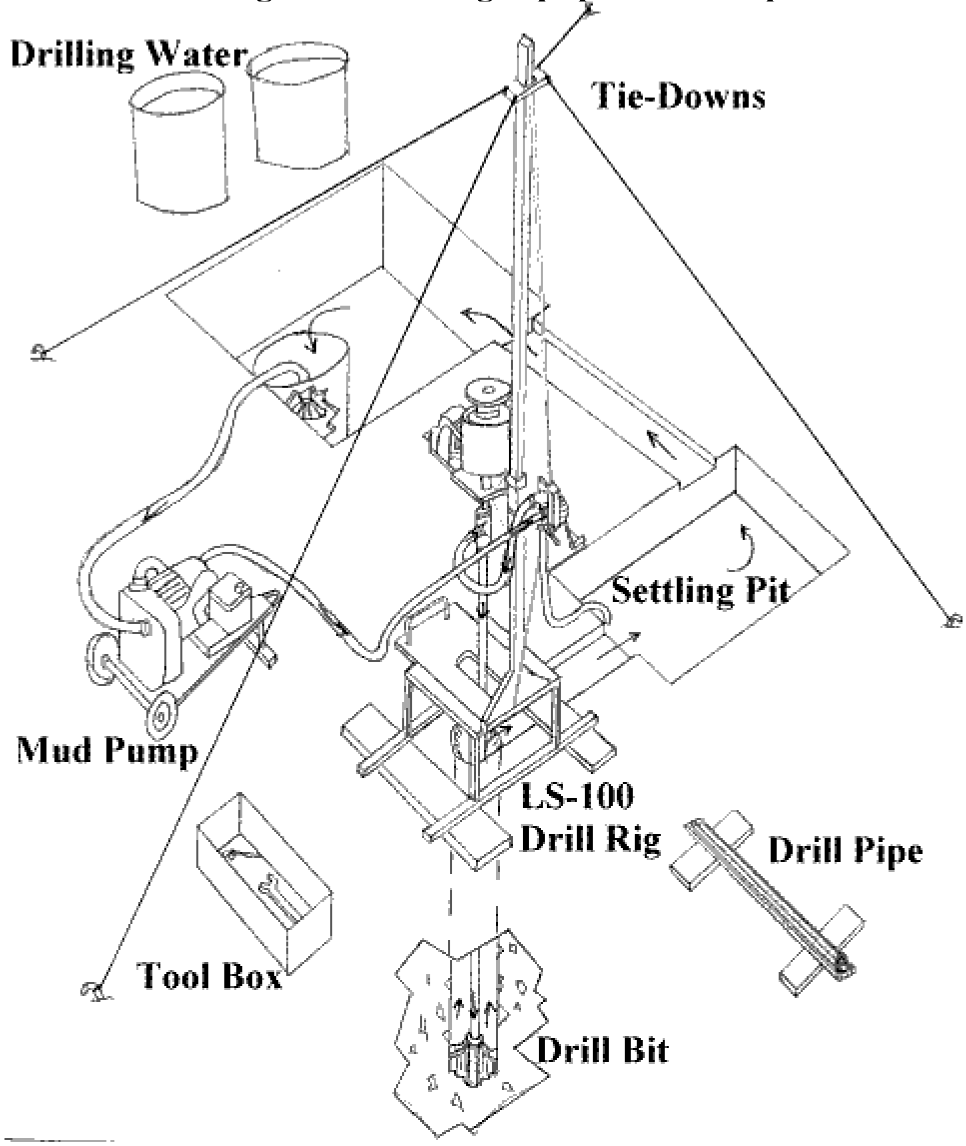
Dig two pits (settling pit and suction pit) - see **Figure 5**. **Keep these pits 1.5 metres away from the well guide hole so that, when the well is finished, the pump pad does not need to be built on the unstable filled-in mud pits.**

Together, the 2 pits should have at least three times the volume of the hole being drilled[(1)] (Driscoll, 1986). It is usually good if each pit is approximately 60 cm deep, 60 cm wide and 90-120 cm long (2 ft deep, 2 ft wide and 3-4 ft long) (with the long axis parallel to the direction of flow).

If the soil in the pit is sandy or water scarce, line the pits with un-punctured plastic. Wrap the edge of the plastic over and bury it a foot or more into the ground along the flow channels to prevent drilling fluids from flowing beneath the plastic.

Dig a 6 inch deep channel between the well guide hole and the first mud pit. Put the mud pump between the drill rig and the suction mud pit (see **Figure 5**).

Figure 5: Drilling Equipment Set-up



3.6 Drill Rig & Mud Pump Set-up

Set-up the LS-100 and mud pump following the steps outlined below (see Figure 6):

- Erect the drill rig over the guide hole. **Orientate it so that the hoses are over the mud pits, out of the way of the operator, and that the drill table legs are parallel to the channel going from the guide hole to the mud pits.** Level the ground around it and install the front and back 2 x 6 boards (see Figure 5).
- Attach the 3 guy ropes to the drill mast and firmly secure in the ground in a triangular fashion (see Figure 5)). Tighten the ropes to adjust the drill tower for vertical form (use a small carpenters level held against the Mast on two adjacent surfaces).

Connect hoses as follows **(see Figure)**:

- one hose to the middle port of the 3 way Valve, and the other end to the Mud Pump discharge port (top side);
- one end of Suction Hose Assembly to suction port of mud pump and lower the foot valve (strainer) into a 18.93 L (5 gal) pail placed in the suction pit **(Figure 5)**. The pail is required to avoid re-circulating cuttings back down the hole;
- the 1.5 m (5 ft) hose (with both ends fitted) from the top port of the 3-way valve to the side port of the swivel on the drill rig;
- the fitting end of the by-pass hose that has only one fitting (see **Figure 5** and **Figure 6**) to the bottom port of the 3 way Valve. Allow other end to hang in the settling pit or in the return ditch between borehole and settling pit.

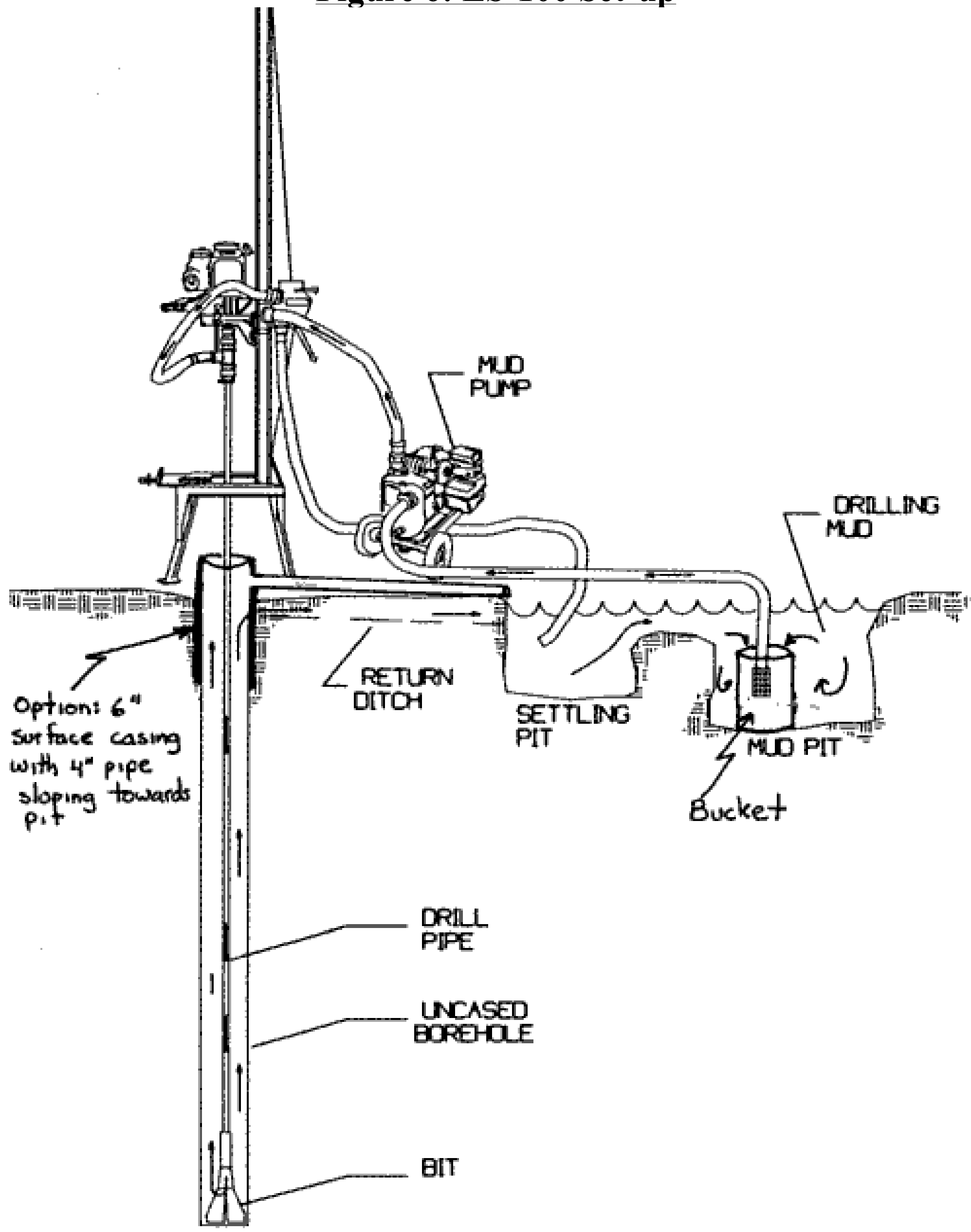
Make sure the crankcases on the drill rig and mud pump engines and transmissions are filled with SAE 30 oil up to the filler hole before you start them! *CAUTION: change the oil after the first 5 hours operation for new machines*!

The only part of the LS-100 that uses grease is the swivel. Loosen the upper and lower compression nuts of the water entry swivel, remove the 95 mm (3/8 in) bolt from the shaft, and pull out the quill. Apply grease liberally to the inside surfaces of the seals (not the outside of the seals or to the swivel housing). Reinstall the quill, insert the bolt and tighten the lock nut. Tighten the upper compression nut until it is snug. Engage the rotary and, circulating clean water, tighten the compression nut until the quill starts to bind. Then loosen slightly and lock in place using the Allan screw. Repeat tightening procedure for the lower compression nut. Then pump grease into the top and bottom fittings until it is no longer easy to inject grease. Stop if you see grease at the top or bottom of the fittings! If any leaks are observed during rig operation, loosen the set screws and tighten the compression nuts immediately (see Appendix Q to learn more about maintainance).

To prevent the LS-100 engine from stalling when it is idling, adjust the choke as follows prior to initial starting:

- Remove air filter from carburettor;
- Pull throttle control cable all the way out;
- Keeping the throttle in the full open position, move the cable in the direction which will completely close the choke valve in the carburettor. Re-tighten the cable clamp.
- Raise the drill head (engine/clutch assembly) to a convenient level to pull the starting rope (**it is always easiest to start the engine prior to raising the drill head**).

Figure 6: LS-100 Set-up



To keep the LS-100 drive shaft from rotating when the throttle is in the idle position, check and adjust it as follows:

- With the engine running, turn the throttle control against the stop to the idle position (opposite direction to the choke position);
- If the output shaft is turning, adjust the idle set screw on the carburettor throttle governor linkage to reduce the RPM to a point where the output shaft stops turning;
- If necessary, adjust the length of the spring on the governor linkage by either stretching it or bending the ends to shorten it.

Secure a 10 cm (4 in) drill bit on the end of the drill pipe with a pipe wrench after cleaning and lubricating the threads of both the drill pipe and drill bit (see **Section 4**).

3.7 The Drilling Process

A borehole is drilled by rotating a bit at the end of drill pipe. Borehole cuttings are removed by continuous circulation of a drilling fluid as the bit penetrates the formation. The drill pipe is connected to the drill engine. Drilling fluid is pumped down through the hollow drill pipe using a centrifugal pump (mud pump) to a drill bit. The fluid flows upward in the annular space between the drill pipe and the borehole to the surface where it is channeled into a settling pit and most of the cuttings drop out. Fluid from the settling pit overflows into a second pit (suction pit). Relatively clean fluid from the second pit is then pumped back through the drill pipe and the cycle repeats.

Using water from the 208 litre (55 gallon) drums, fill the mud pits to the very top. Make sure that one person is responsible for keeping the pits full of water during the entire drilling process. This must be done to ensure that the cuttings will settle-out.

Fill the fuel tank of the drill engine and start it. With engine running in idle, raise the drill head to a sufficient height to allow the installation of a drill pipe section with the drill bit. Turn pipe by hand to thread it onto the swivel thread until it is all the way on.

Lower the drill bit into the prepared hand dug guide hole. Allow the drill pipe to rotate above the bottom of the guide hole.

Fill the fuel tank of the mud pump and start it using the following process:

- Prime the pump before starting the engine by removing the discharge hose or the plug on top of the pump housing and pouring water into this opening until full. It will take a good amount of water since the Suction Hose will also be filled up.
- Set the choke and run levers to the CHOKE and RUN positions respectively. These control are located on the side of the fuel tank opposite the pump side of the engine.
- Pull the starting rope (several times may be necessary), and when engine starts to run, immediately return the choke lever to the OFF position. Leave the run lever in the RUN position. Note that it will take a few minutes for the pump to prime.

Increase the engine RPM until the clutch engages and the pipe starts turning. Turn the 3 way Valve so that the water will circulate from the Mud Pump through the bottom by-pass hose back to the pit. **Add water as required to top-up the pits.**

Then turn the valve so that water flows into the drill swivel. Make sure no water is leaking from the swivel seals. If it is, re-direct the water through the by-pass hole or stop the mud pump. Loosen set screws and tighten gland nuts quite snug and until leaking stops. Re-tighten set screws. It may be necessary to repeat this process during the drilling operation. Pump grease into the top & bottom gland nuts before tightening.

When the water begins pumping through the drill pipe, it will make a lot of splashing so make sure the drill operator is ready to lower the drill pipe into the hole fairly rapidly. After the drill has penetrated 30 cm (1 ft) or so, there will be a smooth flow of water.

Maintain a slight back pressure on the winch handle; at an easy drilling speed, the winch handle should make a full circle every 20 seconds or so. **Do not exceed this speed or the water will not be able to circulate the cuttings out of the hole fast enough (causing the bit to seize) and/or the borehole walls will not be coated with enough fines to resist caving** ! In harder formations it should make a full circle every 40 seconds. In very hard rock, a drilling rate of 30-150 cm/hr (1 - 5 ft/hr) is to be expected.

In hard rock, insufficient pressure on the drill pipes may result in an extremely low drilling speed. Caution should be used to avoid excessive pull-down pressure (weight) exerted on the drill string because this may result in crooked holes, bent drill rods and jammed drill bits (see **Appendix G-3**). Rotation speed should be slowed as the pull-down pressure increases.

Watch that the water is circulating continuously when the drill is rotating.

As soon as the drill has penetrated 60 cm (2 ft) or so, take sample cuttings from the first small pit and place them on the appropriate record location.

Continue the drilling process until all 1.5 m (5 ft) of the drill pipe has penetrated the hole.

Leave the drill string turning at the bottom of the hole and continue circulating drill mud until all cuttings are removed from the borehole (even if it takes 5 minutes or longer). **This cleaning process is increasingly important as the hole is deepened**: if not fully done in the manner described, cuttings may settle to the bottom of the borehole and make it impossible to add another length of drill pipe, cause the hole to cave-in or plug-up (see **Appendix G-2**) or the drill bit to jamb (see **Appendix G-3**). Note that the deeper you drill, the longer it takes the cuttings to be removed from the hole.

Switch the 3-way valve so that the drilling fluid circulates back into the mud pits rather than down the drill pipe. Clamp off the drill pipe and unscrew the drill head.

Raise the drill head to the full mast height (be careful not to allow the cable buckle to enter the top hole in the drill mast head and get jammed). If the drill engine is stopped, start it when it is at an easy operating level as the drill head is being raised. **Work rapidly to prevent problems caused by cuttings settling in the borehole.**

Lubricate the threads of the next drill pipe and screw it into the one clamped at the well head. Screw the other end onto the output shaft. Tighten the joints with wrenches.

Switch the 3-way valve so that the drilling fluid starts to circulate back down the drill pipe. **Do not lower the drill head until there is clear evidence that the mud is circulating through the pits again.**

Once drilling, it is important to:

- monitor the drill cuttings to help determine what type of material is being drilled. Take samples of the cuttings every metre or so (at least 1 per drill pipe);
- clean mud pits frequently to ensure cuttings are not re-circulated;
- be sure a continuous supply of water is being provided to the 200L (55 gal) drums. Keep water drums replenished.

Special measures must be taken if you drill into:

- a formation which is very hard to drill (see **Appendix G-6**).
- contaminated soil and/or groundwater (see **Appendix G-7**
- a confined aquifer which causes water to flow out of the borehole under pressure (see **Appendix G-8**).

After the 10 cm (4 in) "pilot" borehole is completed to the desired depth, allow the drilling fluid to circulate for 10 minutes to remove as much cuttings as possible from the well.

After 10 minutes, raise the drill head until the slip clamp on the drill table can be engaged at the coupling of the next length of drill pipe. Turn-off the mud pump.

Remove the upper length of drill pipe and lower the drill head to engage the socket in the next length of drill pipe.

Continue to carefully remove the drill pipe from the well. **BE SURE THE SLIP CLAMP IS FULLY ENGAGED EACH TIME AND THAT EVERYTHING IS SECURED** because it is very easy to drop drill pipe and tools into the borehole! If this happens to you... pray.... and read **Appendix G-5**!

Be sure to keep the mud pits and borehole full of water during this process.

When all the drill pipe is removed, the crew must now decide if subsurface conditions warrant completing a well. Careful action should be taken if the aquifer is marginal (see **Appendix G-9**);

If it appears that the borehole has only penetrated a marginal aquifer see section on "When to Stop Drilling" (**Section 6**), set a 5 cm (2 in) PVC casing with 3 mm (1/8 in) slots in the aquifer area. Then rapidly bail-out the casing, pump it using Waterra tubing or blow-out water using an air compressor (see **Section 10.3**). If the casing can be easily pumped dry, it may be worthwhile to abandon the well and drill elsewhere.

If there is a good flow from the aquifer, add a 6 inch reamer bit behind the 4 inch bit (see **Section 4**). Then re-drill the hole to widen it to the required 6 inches. While this is being done, the screen interval, length of casing, volume of gravel pack, grout etc can be planned, materials cut to size etc. This is very helpful to do since time is always of the essence when the drill pipe and bit are pulled from the completed borehole and the screen and casing installed.

If there is much sticky clay, the water-bearing portion of the 10 cm (4 in) hole may be filled with clean sand prior to reaming. This keeps clay from dropping into the borehole and smearing onto the borehole walls (causing severe well development problems).

Replace the drilling fluid with clean water or drilling mud prior to drilling into the aquifer (see "**Section 5**"). **If not done, the well may never reach its full yield!**

If in doubt, keep drilling until you are sure that you have found enough water. For tips on "How to Decide When to Stop Drilling", see **Section 6**.

After you have decided to stop drilling, allow the drilling fluid to circulate for 10 minutes to remove as much cuttings as possible from the well. Then circulate the "mud" out of the borehole by replacing it with fresh (clean) water.

When removing the drill pipe from the well, keep the bit rotating and water circulating. This leaves a nice smooth borehole wall behind the bit as it is coming out of the hole[2].

The casing, gravel pack, annular seal, cement pad and hand pump can then be installed.

3.8 Solutions to Drilling and Well Problems

There are many problems that you will encounter when drilling wells. Learn from the problems and try not to repeat them too often!

You will have more success if you keep in mind the following 5 common problems which lead to unsuccessful well completion:

1. **Drilling in conditions beyond equipment capability (Section 3.1);**
2. **Unsuitable Drilling Mud and Borehole Caving (see Appendix G-2);**
3. **Failure to get casing to bottom of borehole (see Appendix G-10));**
4. **Poor gravel pack (see Section 8);**
5. **Inadequate well development (see Section 10);**

In addition, the following problems have also been encountered:

- Excessive Fluid Loss (see **Appendix G-1**);
- Drill Bit Jamming (see **Appendix G-3**);
- Objects Dropped Into Well (see **Appendix G-5**);
- Resistant Beds Encountered (see **Appendix G-6**);
- Contaminated Soil/Water-Bearing Zones (see **Appendix G-7**);
- Flowing Wells (see **Appendix G-8**);
- Marginal Aquifer Encountered (see **Appendix G-9**);
- Well Stops Producing Water (see **Appendix G-11**);

Footnotes

[1] Ideally, for a 30 m (100 ft) deep borehole drilled with the LS-100, the settling pit should be 60 cm (2 ft) deep, 75 cm (2.5 ft) wide and 2 m (6 ft) long; the suction pit should be 60 cm (2 ft) deep, 75 cm (2.5 ft) wide and 1 m (3 ft) long. However, while these pits provide optimum settling capability, they require large quantities of water to be brought to the site.

[2] If this is not done, the fins of the blade bit may disturb the borehole wall and cause silt/clay cuttings to "ball-up" or bridge within the borehole. In addition, drilling fluid may cause silts and clays (especially above the water table) to swell and bulge into the borehole. Getting the screen past these blockages can be very difficult and it is almost impossible to avoid severely plugging the screen.

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Section 4

Choosing the right Drill Bits

When drilling with the LS-100, there are two basic sizes of drill bits: 10 cm (4 in) and 15 cm (6 in). Usually a 10 cm drill bit is used to drill a pilot hole (especially in hard formations). This maximizes drilling speed and gives the drilling crew a "preview" of subsurface conditions. Given the limited power of the LS-100, wells are commonly extended into rock using a 10 cm hole which is left uncased (a 15 cm hole should be drilled several feet into the rock to firmly seat the surficial casing). In overburden and soft rock formations, 15 cm bits are used to ream the pilot hole open wider so that the casing (Section 7), filter pack (Section 8), and grout annual seal (Section 9) can be placed. A 15 cm bit can be used without first drilling a pilot hole where drilling is easy, the water table close to surface or subsurface conditions are well known.

Three general types of bits are used when drilling with the LS-100: the drag (blade or fishtail) bit, the roller (or tricone) bit and reamer bits (see Figure 7).

Drag bits have short blades, each forged to a cutting edge and faced with tungsten carbide tips. Short nozzles direct jets of drilling fluid down the faces of the blades to clean and cool them (Driscoll, 1986). A blade bit is a drag bit in which the blades can be replaced. Drag bits have a shearing action and cut rapidly in sands, clays and some soft rock formations. Most drilling is done using the Drag bit (especially in clay and sands). However, it does not work well in coarse gravel or hard-rock formations. Whenever possible, drag bits should be used to drill pilot holes because they produce cuttings which are easiest to log.

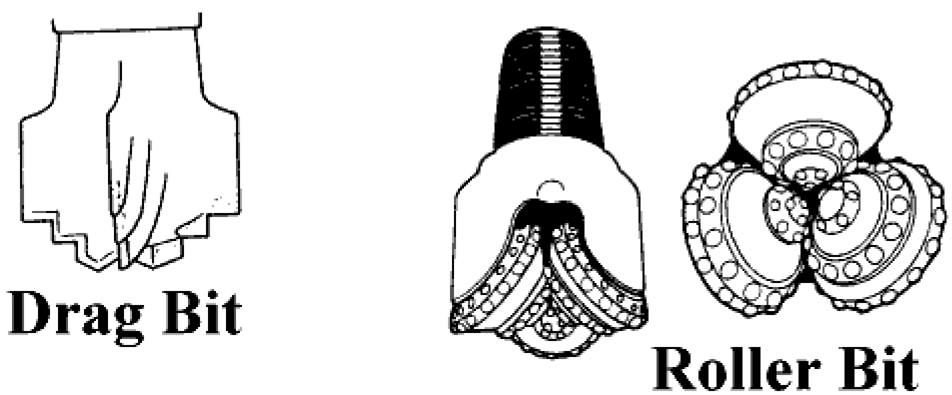
Roller bits have three or more cones ("rollers" or "cutters") made with hardened steel teeth or tungsten carbide inserts of varied shape, length and spacing. They are designed so that each tooth applies pressure at a different point on the bottom of the hole as the cones rotate. The teeth of adjacent cones intermesh so that self-cleaning occurs. The cutting surfaces of all roller bits are flushed by jets of drilling fluid directed from the inside (centre) of the bit. Roller bits exert a crushing and chipping action, making it possible to cut hard rock formations (Driscoll, 1986). If possible, use roller bits for reaming the 10 cm pilot hole open to 15 cm because they produce minimal amounts of clay smearing etc on borehole walls.

The three roller **Tricone** bit is the most common roller bit. It has conically shaped rollers on spindles and bearings set at an angle to the axis of the bit. It is used as an all-purpose bit in every type of formation.

As a general rule, hard rock roller bits should be used at much slower speeds and higher bit weight than blade bits used for drilling soft formations.

A REAMER BIT is later used to widen the hole to 15.24 cm (6 in). A reamer bit consists of hardened cutting surfaces attached to drill pipe; it is screwed just above the drill bit. A reamer bit is used in sandy soils or in clay if the roller bit becomes too gummed-up with clay and/or there are problems keeping the hole straight. A 10.16 cm (4 in) roller or blade bit is fitted ahead of the reamer bit and runs in the existing 10.16 cm pilot hole. This makes it easy to keep the borehole very straight during the reaming process.

Figure 7: Types of Drill Bits



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Section 5

Mixing and Using Drill Mud

Drilling fluid (often called "mud") is used to:

- **lift soil/rock cuttings from the bottom of the borehole and carry them to a settling pit;**
- **allow cuttings to drop out in the mud pit so that they are not re-circulated (influenced by mud thickness, flow rate in the settling pits and shape/size of the pits);**
- **prevent cuttings from rapidly settling while another length of drill pipe is being added (if cuttings drop too fast, they can build-up on top of the bit and seize it in the hole);**
- **create a film of small particles on the borehole wall to prevent caving and to ensure that the upward-flowing stream of drilling fluid does not erode the adjacent formation;**
- **seal the borehole wall to reduce fluid loss (minimizing volumes of drilling fluid is especially important in dry areas where water must be carried from far away);**
- **cool and clean the drill bit; and**
- **lubricate the bit, bearings, mud pump and drill pipe (Driscoll, 1986).**

Always start drilling with clean water as the drilling fluid; keep it as clean as possible during drilling to minimize subsequent well development problems. In clay-rich formations, the water will quickly mix with natural clays in the borehole to form a thin clay slurry (Driscoll, 1986). **While this "natural mud" can be used for drilling the 10 cm (4 in) pilot hole, it should be replaced with clean water or a drilling mud prior to the water bearing zones being reamed-out to 15 cm (6 in). If this is not done, the natural clays will be pushed into the aquifer and will not break-down with development, thus seriously restricting well yield.**

In sandy soils, bentonite clay (sodium montmorillonite) must be mixed with the drilling water to increase its viscosity and keep the borehole from collapsing (just a small amount of bentonite is required).

While better than natural clays, bentonite does not readily break down its cohesive structure and it can be difficult to remove from the borehole and aquifer. Since this can keep boreholes from reaching their potential yield (Moffat, 198?), it can be adventageous to use synthetic muds (polymers) such as Revert when drilling into marginal aquifers (see Footnote #1). Because it is very concentrated, powdered polymer can be shipped at relatively low cost into countries where bentonite is not available.

Whenever using synthetic drilling polymers, however, it is extremely important to flush all the polymer out of the borehole as soon as possible. Some polymers have an organic base which can act as a bacterial food source. If left in the borehole, nuisance and health-related bacterial populations can grow rapidly and permamently affect the taste, odour and safety of the well water. To avoid these problems, flush as much polymer out of the borehole as possible before floating in the gravel pack (Section 8). Break-down can be enhanced by adding 500 to 1,000 ppm chlorine to the drilling fluid during the flushing process.

If bentonite or polymer is not available, it is best to determine (from the government or other knowledgeable organization)where there is a good supply of clay suitable for drilling (one that is relatively pure and has little or no sand). Make sure that you evaluate the suitability of local clays prior to drilling (see **Appendix H**).

Drilling mud is created by thoroughly mixing water with clay to a desired consistency. Pumping water through the by-pass hose on the 3-way valve and recirculating water back through the pits will help ensure that the clay and water are thoroughly mixed.

After the fluid is mixed, sufficient time must be allowed to elapse to insure complete hydration of the clay prior to it being circulated into the hole (Driscoll, 1986). If this is not done, the clays may swell in the hole or in the aquifer itself. **If this happens, it may be impossible to remove them after the casing is installed and the well may never reach its potential yield.**

Drilling fluids must be mixed thick (viscous) enough to bring soil cuttings up from the bottom of the hole to the surface, yet not so viscous as to prevent their settling out in the mud pits. It is, therefore, very important to understand the properties of drilling muds and their proper use:

The ability of a fluid to lift cuttings increases rapidly as viscosity (the degree to which a fluid resists flow under an applied force) and up-hole velocity are increased. After cuttings are brought to the surface, however, it is essential that they drop out as the fluid flows through the settling pit. The desired results are obtained by properly designing the mud pits, controlling the viscosity and weight of the drilling fluid and adjusting the pump speed (Driscoll, 1986).

During the drilling process, solids accumulate in the drilling fluid - especially when drilling silt, clay or weakly consolidated shale (Driscoll, 1986). The thickness of the drilling fluid often needs to be adjusted during drilling by adding more water and/or removing some of the accumulated cuttings from the settling pit.

Fluid which is too thick will be difficult to pump and will cause unnecessary wear of the mud pump since cuttings will not have settled out of the mud before the mud is pumped back down the borehole. **It will also make it difficult to remove the mud from the borehole walls and adjacent aquifer during well development**. The rate of penetration is also potentially reduced (Driscoll, 1986).

If the mud is too thin, cuttings will not be brought to the surface and the drill bit and drill pipe may get stuck in the borehole by settling cuttings. In addition, thin mud can result in excessive migration of mud into the formation, thus decreasing the potential yield of the well.

Once the well is started and the fluid is being pumped, it is important to keep the well and mud pits full of water and complete the drilling and installation of the casing before the well is allowed to run out of water from the drilling process. If return circulation of drilling fluid out of the borehole is suddenly lost, ensure that you take immediate action (see **Appendix G-1**).

If drilling stops for more than a few minutes and the water recedes down the hole, the well may cave-in! (see **Appendix G-2**). To minimize caving risk, keep the drill pipe in the well (several metres off the bottom) and re-fill the well through the drill pipe. Do NOT pour water down the open hole since this may actually cause a cave-in! If the drilling stoppage lasts long, pull the drill pipe out of the borehole to ensure it is not jammed and lost (the drill string can even be pulled-out by hand using pipe wrenches).

References and Footnotes

[1] Drilling polymer's (such as "Revert" made by Johnson & Johnson 612-636-3900), are organic drilling fluid additives which take the place of native clay or bentonite. When Revert is mixed with water in a ratio of about 7.1 Kg per 1000 litres (6 lb per 100 gal), a bright blue viscous fluid forms. Revert prevents caving, drops cuttings in the mud pit better than bentonite mixtures. Biological breakdown causes it to change ("revert") to a fluid as thin as water after several days (the fluid

becomes light grey when reversion to a water-like fluid is imminent). After the fluid has reverted, it can be thoroughly flushed from the well and the well can be developed as easily as if only clear water had been used in drilling. Dry Revert powder can be put in a coffee can and slowly sprinkled into a barrel of water which is agitated using a paddle mixer (such as a paint mixer attached to an electric drill). If fed too fast it will tend to form lumps. If more than 3 ppm iron is present, pre-treat the water with about .75 lb calcium hypochlorite per 1,000 gals of water (50 ppm chlorine) to oxidize any dissolved iron.

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Section 6

Deciding When to Stop Drilling

A reliable method for determining when appreciable volumes of groundwater are encountered is by conducting a preliminary assessment of wells or water sources in the area and having a good understanding of where groundwater occurs. It is generally good practice to inspect as many wells in the vicinity of interest as possible. If the inspected wells encounter groundwater at approximately the same elevation and groundwater does not occur in discontinuous lenses, groundwater should be present in the subsurface at roughly the same elevation as in the inspected wells.

Sometimes, however, there are no nearby boreholes to guide the drilling. In these cases it is often very difficult to know when the borehole has intercepted the water table due to the drilling mud sealing-up the borehole as the drill bit advances.

Careful observation to the drilling sometimes reveals one or more of the following signs indicating that a good water-bearing layer has been reached:

- **the cuttings may indicate that the drill bit has hit a zone of sand and/or gravel (formations which usually produce abundant volumes of water if they are saturated). This is the most widely useful indicator and requires continuous, careful sampling of drill cuttings;**
- **there is often a significant increase in the speed with which the hole is being drilled when a permeable sand aquifer is reached;**
- **when drilling into a gravel aquifer, the gravel will often cause the bit to bounce;**
- **sometimes the drilling fluid (drilling mud) suddenly starts to thin appreciably;**
- **there may be a noticeable drop in the level of drilling fluid (Brush, 197?). If a formation is permeable enough to take water, it may also yield enough water for a well!**
- **the water temperature may drop when groundwater is encountered.**

In general, boreholes should be completed as far as possible into aquifers because:

- more of the aquifer can supply the intake portion of the well, resulting in a higher yielding well (increased specific capacity);
- sufficient saturated thickness is available to maintain well yield even during periods of severe drought or heavy pumping;
- Where clay soils are found, it is often important to drill down and slightly into underlying rock to find significant quantities of water. To learn more about "tropical hydrogeology", see **Appendix C-5**.

As mentioned earlier, after you stop drilling, ensure that the borehole is kept full of drilling fluid until the casing and screen (**Section 7**) have been inserted into the well, gravel packed (**Section 8**) and the sanitary grout seal placed (**Section 9**).

Footnotes

Brush, R. (197?) "Wells Construction: Hand Dug and Hand Drilled", US Peace Corps, Washington DC.

Driscoll, F. (1986) Groundwater and Wells, St. Paul: Johnson Division

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Section 7

Well Casing and Screen

To keep loose sand and gravel from collapsing into the borehole, it is necessary to use well casing and screen. The screen supports the borehole walls while allowing water to enter the well; unslotted casing is placed above the screen to keep the rest of the borehole open and serve as a housing for pumping equipment. Since the well screen is the most important single factor affecting the efficiency of a well, it is sometimes called the "**heart of the well**"!

7.1 Screen Design
7.2 Screening Wells Drilled Into Rock
7.3 Screen Centralizers
7.4 Casing and Screen Installation
7.5 Solvent Welding (Gluing PVC)
7.6 Footnotes & references

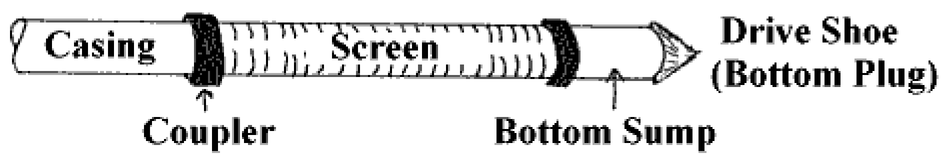
7.1 Screen Design

Well screens should have as large a percentage of non-clogging slots as possible, be resistant to corrosion, have sufficient strength to resist collapse, be easily developed and prevent sand pumping (Driscoll, 1986). These characteristics are best met in commercial continuous-slot (wire wrap) screens consisting of a triangular-shaped wire wrapped around an array of rods (see Footnote #1). If these screens are available, conduct a sieve analysis on samples on the water-bearing formation and select a slot size which will retain 40-60 percent of the material.

While wire wrap screen should be used whenever possible, it may be exorbitantly expensive and/or not available. Most Lifewater wells are constructed using PVC casing and screen (Footnote #2) - see **(Figure 9)**. Grey PVC pipe, which is available in most countries, is relatively cheap, corrosion resistant, lightweight, easy to work with and chemically inert.

Slot Design: Using a hack saw, cut slots in the plastic casing which are as long and close together as possible. Slots should be spaced as close together as possible vertically and should extend about 1/5th the circumference of the pipe; there should be 3 even rows of slots extending up the pipe separated by 3 narrower rows of solid, uncut pipe (for strength).

Figure 9: PVC Cut-Slotted Screen



Screen/Casing Diameter: Three inch diameter casing and screen can be easy inserted into the 15 cm (6 in) LS-100 borehole and allows creation of an effective 3 cm (1.25 in) thick filter pack (this is especially important where the aquifer is composed of very fine materials). However, since 7.6 cm (3 in) screen is often not available and has low total open area, carefully centered and filter packed 10 cm (4 in) screen is most frequently used. Larger diameter screens make the filter pack ineffective and do NOT significantly increase well yield. For example, moving from a 10 - 12.7 cm (4 - 5 in) screen will increase yield by 3 percent or less! Besides, a good filter pack expands the effective radius of the well to the full 15 cm (6 in) diameter of the borehole.

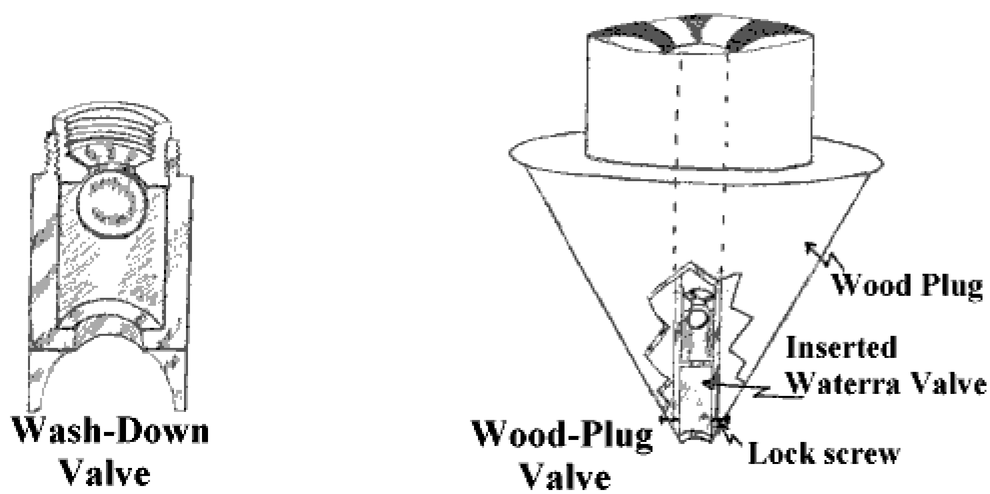
Screen Length: For confined aquifers, 80-90 percent of the thickness of the water-bearing zone should be screened (Driscoll, 1986). Best results are obtained by centring the screen section in the aquifer. For unconfined aquifers, maximum specific capacity is obtained by using the longest screen possible but more available drawdown results from using the shortest screen possible! These factors are optimized by screening the bottom 30-50 percent of the aquifer (Driscoll, 1986). One 7m (20ft) length of screen is often adequate. Screening 6-7 meters beneath the water table generally assures adequate year-round yield (Brush, 198?). *In many tropical areas, successful wells can be constructed by drilling 5 feet into underlying rock and placing a 10 foot screen which straddles the bedrock/overburden interface* (see Appendix G-5)

Bottom Casing: Significant quantities of fine materials are often present in the extreme upper and lower parts of an aquifer. Therefore, unless the aquifer is less than 7 m thick, extend the casing **at least** 1-2 m into the top of the aquifer before starting the screen. Similarly, unless the aquifer is very thin, ensure that **at least** the bottom 1-2 meters of the aquifer is completed with a piece of solid casing pipe. This casing (known as a "sump" or "rat hole") provides a place for solids to settle as they are drawn into the well, thus minimizing screen blockage and minimizing the amount of fines drawn into the well (see **Figure 9** and **Section 9 - Figure 15)**.

Bottom Plug: A plug ("drive shoe") should always be installed to help the casing slip down the borehole and prevent unfiltered fines from entering the well. A cap or pointed wooden plug are the most common plugs. If "belled" casing (with a built-in socket on one end) is used, the non-belled end can be shaped into a point. Finally, a wash-down valve can be used or a one-way valve (allowing water to flow out of the casing) can be installed in a wooden plug which has a beveled inner surface **(Figure 10)**. This valve allows the well to be effectively rinsed-out and ensures that the filter pack is effectively placed.

If any type of wooden plug is used, it is good practice to **place a cement plug** at the bottom of the well to ensure that sediment can not enter the well when the plug rots out.

Figure 10: Wash-down Bottom Plugs



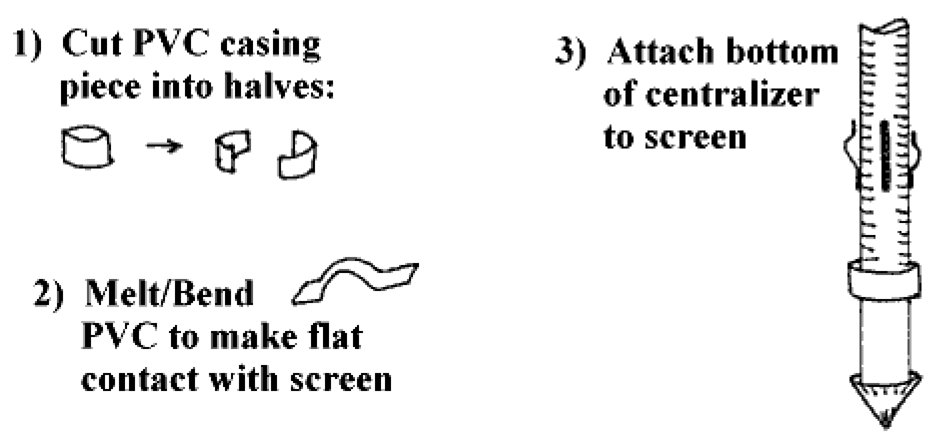
7.2 Screening Wells Drilled Into Rock

No casing or screen is generally required in the portion of boreholes drilled into rock. The first 2 - 3 m of the rock borehole should be 15 cm (6 in) in diameter; the borehole can then be extended using a 10 cm (4 in) bit (this maximizes the drilling speed which can be very slow in rock). The 11.4 cm (4.5 in) OD casing should be placed into the 15 cm (6 in) hole and carefully aligned with the (10 cm (4 in) hole. Fill the rock annular space with 40 cm coarse gravel followed by 60 cm coarse sand/fine gravel with 100 cm medium sand on top (this prevents fine sands and silts often found at the overburden-bedrock contact from moving into the well). Since the main water-bearing zone may be within the upper few inches of bedrock, only seal the casing into rock with cement where contamination is major concern.

7.3 Centralizers: Whenever possible, centralizers should be used on the outside of the rising main ("drop pipe") and on the pump rods. Adding centralizers minimizes the chance of pump rods banging against the rising main during operation of the handpump. This can be a serious problem in wells over 12.19 m (40 ft) deep since it eventually leads to early wearing-out of the rods and/or holes being rubbed in the rising main... leading to pump failure! Centralizers are also very important when installing casing since slots in the well screen may become severely blocked with clay if the screen rubs hard against the borehole wall while it is being inserted into the borehole. Centralizers also ensure that there is even distribution of cement grout and filter pack. This is really important since if the screen is placed against the borehole wall, the well may always produce turbid water! Poor grout placement can result in contaminated surface water entering the well and making the water unsafe to drink!

These problems can be avoided by attaching (gluing, screwing, tying-on with wire) 3 centralizer strips to the top and bottom ends of the screen. Centralizers can be made from PVC casing, flexible green wood or 1.2 cm (0.5 in) wide iron straps (see Figure 11). Only fasten the lower end of each centralizer (so that it can "flex") and do not put any on the casing or the screen/casing may jamb during placement. Centralizers work best with 7.6 cm (3 in) casing; jamming may occur when installing 10 cm (4 in) casing in the 15 cm (6 in) borehole (the outside diameter of schedule 40 PVC pipe is 11.4 cm (4.5 in) and the diameter of couplings is 13.2 cm (5.2 in)! If this is a concern, just make the bottom plug the same diameter as the couplings.

Figure 11: Casing Centralizers



7.4 Casing and Screen Installation

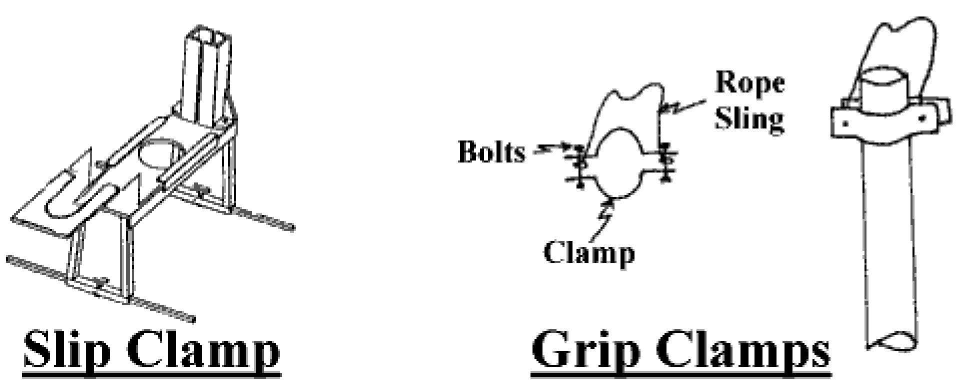
Make sure you know the distance from the ground level to the bottom of the borehole and ensure that the required lengths of well casing and screen are prepared, clean, close at hand and ready to install when the drilling is completed. Attach the casing sump with the drive shoe to the bottom of well screen. For more information on solvent welding, see **section 7.5**. If bell and spigot pipe is not used, pre-glue a joining coupler (collar) to one end of each length of casing **(see Figure 12)**.

Figure 12: Preparing Pipe for Installation

Once the borehole is completed to the desired depth, continue to circulate drilling fluid through the drill pipe at the bottom of the borehole until the returning fluids are clear of cuttings, sand, and clay balls. The fluid in the mud pits may need to be replaced several times before the water exiting the borehole is clean. When it is, keep the fluid circulating and the bit rotating and slowly remove the drill pipe from the borehole.

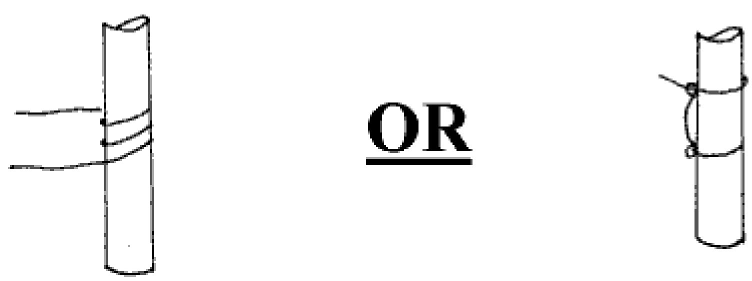
When the drill pipe is removed, swing the engine/drive assembly to the side. Prepare to clamp the casing using 2 grip clamps formed from iron or wood: 1 clamp should be on the casing suspended in the hole and the other on the length of casing to be joined **(Figure 13)**. Alternatively, use a casing slip clamp made from 1/2 or 3/8 inch steel plate by cutting a slot slightly larger than the casing and welding on a handle **(Figure 13)**.

Figure 13: Casing Clamps



Keeping the borehole full of water, carefully lower the screen assembly into the borehole. Ensure that a grip clamp is attached or use a slip clamp to catch the casing should it slip while being lowered. One at a time, wipe clean, add and glue 6 metre (full 20 foot) lengths of casing (see **Section 7.5**). If a slip clamp is used, wrap a 1 cm thick hemp rope 3-4 times around the upper length of casing **(Figure 14)** and keep it tight when pulling the clamp back to ensure that the casing can not slip. After the slip clamp is back in place, lessen the tension on the rope and allow the casing to slowly slip into the well until it is again resting on the clamp. Continue to add and lower casing until the well screen reaches the bottom of the borehole. Then raise it slightly and suspend it using grip clamps or by tying a rope to the drill table (this ensures that the casing is placed straight). Work quickly to minimize the chance that the borehole may start to collapse.

Figure 14: Rope Wrap Around Casing During Installation



Keep track of the length of screen and casing that is installed to ensure that the well has not partially caved-in (see **Appendix G-2**) and to ensure that the casing reaches the bottom of the borehole and is not stuck part way down the borehole (see **Appendix G-10**. Keeping the casing suspended 10 cm above the borehole bottom, cut the top off the casing so that only about 50 cm sticks-up above ground level (see **Section 9 - Figure 15** and **Section 14 - Figure 17**).

After the casing is securely suspended, thoroughly flush the borehole again with clean water (this greatly reduces well development time (**Section 10**). If a one-way valve was installed at the bottom of the casing, run drill pipe down inside the casing until it is engaged in the top of the valve. If there is no valve, place a tight fitting surge block or securely wrapped rag on the end of the drill pipe. Then set the end of the drill pipe down to the bottom of the screen and pump clean water down the drill pipe so that it is forced out through the bottom section of screen. If these flushing processes are not possible, rinse-out the casing by connecting the mud pump outlet hose to the top of the casing by means of a well cap and appropriate fittings.

Finally, bail or pump out the casing. If it can be bailed practically dry, develop the full length of the screen several times (**Section 10**). Continue until no further improvement in yield is noticed. If there is not enough water (**Section 10.3**), remove the casing and abandon the well.

7.5 Solvent Welding

Solvent weld the pipe segments using the following procedure (NWWA, 1981):

1. Clean the contact surfaces of the pipe end with a clean, dry cotton cloth or paper towel.
2. Roughening contact surfaces with abrasive paper ("sandpaper") helps develop a better bond. Sand the pipe by holding the paper around the pipe and turning the pipe around and around. This is better than sanding up and down lengthwise along the pipe;
3. Check the fit of the sections to be cemented. A good "dry fit" should show the spigot end entering the socket to about one-half to two-thirds of its depth. Incorrectly dimensioned pipe or sockets **should not be used**!
4. Apply primer to the outside of the casing end and to the inside surfaces of the socket to prepare them for joining (the primer may require more time to soften the belled end casing sockets than is necessary to prepare the sockets of separate moulded couplings);
5. Apply a thin, uniform coat of solvent cement to the interior surface of the socket and to the exterior spigot end of the casing (too much solvent could weaken the casing);
6. Insert the spigot end of the casing section forcefully into the socket to the entire depth of the socket while both the inside socket surface and outside surface of the casing are completely coated with wet cement. **Give the casing a half turn when pushing together**;
7. Hold the socket and casing sections together for at least 15 to 20 seconds or until an initial set takes place. Then wipe the excess cement from the socket. A properly cemented joint should show a bead of solvent cement around the entire circumference of the casing/socket joint;
8. To insure a strong bond, a joint should be allowed to set for at least 5 minutes. If less time is desired, drive three or four 95 mm (3/8 in) self-taping screws through each joint to ensure that the pipe can not separate during installation. Fully penetrating screws should not be used because their corrosion over time may leave a hole in the casing through which contaminants or bacteria may enter the well (Driscoll, 1986).

7.6 Footnotes & References

[1] They are strong, allow maximum flow rates and the small slot size screens-out fines. In addition, the screen is unlikely to plug-up over time since sand grains cannot plug slots which are V-shaped and widen inward and sand particles can only make contact at two points (Driscoll, 1986). Finally, the closely pitched, continuous slot facilitates uniform well development (Schreurs, 198?).

[2] The disadvantages of using a locally manufactured screen when compared with commercial continuous wrap wire screens are:

- since strength cannot be maintained if openings are closely spaced, the percentage of open area is lower (4-12% open area compared to 30-50% for wire wrap screens) thus restricting the entry of water into the well;
- the size of the slots varies significantly and slots cannot be made small enough to screen out fine sand;
- the screen tends to clog during the development process if the aquifer is composed of fine sand. Sand grains can lodge solidly in a round or square opening and greatly limit the effectiveness of the screen (Schreurs, 198?); and
- The blank areas between slots prevents all portions of the aquifer around the screen to be effectively developed.

Brush, R. (197?) "Wells Construction: Hand Dug and Hand Drilled", US Peace Corps, Washington DC.

Driscoll, F. (1986) Groundwater and Wells, St. Paul: Johnson Division

National Water Well Association and Plastics Pipe Institute (1981) Manual on the Selection and Installation of Thermoplastic Water Well Casing, Worthington, OH, 64pp.

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Section 8

Gravel Filter Pack

A filter pack is coarse sand or fine gravel (2-6 mm diameter) that is placed between the borehole wall and screen (see Section 9 - Figure 15). Filter packs are used to settle-out fine grained particles that may otherwise enter the well and to increase the effective hydraulic diameter of the well. A filter pack is like a wells "lungs" passing water to the "heart of the well" (the screen). A filter pack should be installed in all wells except those completed in rock, coarse sand or gravel.

Filter Material: Ideally, the filter media should consist of silica-based material since it will not dissolve over time; this ensures that the integrity of the filter pack is maintained and that harmful or unpleasant substances are not leached into the water (Ives and Coad, 1987).

Material Cleanliness: Filter material must be clean to minimize filter pack collapse and reduce well development time (Driscoll, 1986). Treat all filter material with 50 mg/L chlorine solution prior to placement to ensure it doesn't contaminate the well.

Grain Size/Uniformity: The sand or gravel should be of a uniform size which is just slightly larger than the size of the slots in the well screen. **This is the main factor controlling the possibility of sand pumping**! Desert sand, for example, should be avoided because it is too fine and will block the screen or wash into the well causing turbid water and rapid pump cylinder wear. If there is a wide range of particle sizes, the filter pack can become severely blocked (Ives and Coad, 1987). Alternatively, the coarse material may separate as it is poured into the well resulting in possible continued sand pumping (Driscoll, 1986).

Grain Shape: Well-rounded and sorted grains from river or ocean deposits should be used since they will reduce drawdown, increase yield and allow for more effective development (Driscoll, 1986). Even if rounded gravel must be transported from far away, local angular rock should not be used since it will compact when the well is pumped and can severely restrict the flow of water (Moffat, 198?). Finally, flake-like grains are unacceptable because they settle to form a filter media with a low permeability (Ives and Coad, 1987).

Finding Material: ***The best material is coarse silica sand and fine gravel material which is usually found in river-beds or ocean beaches.*** **Separate the desired size fraction by using two screens which have slot sizes of 3 and 6 mm (1/8 and 1/4 in). Put the screens on the top and bottom of a strong wooden frame with the coarse slot screen on top. Suspend the frame in the water and scoop sand and gravel onto the top screen. After rinsing, suitable material will be trapped between the two screens. Suitably sized, strong window screen may not be readily available overseas, but can be easily flattened and brought with you in your suitcase.**

Filter Volume: Calculate the volume of filter material (see **Appendix B**) necessary to fill the well annulus to 2 metres above the top of the well screen - this allows for areas of borehole washout to be filled without exposing the upper screen to formation stabilizer or borehole fines. Whenever possible, however, do not place gravel within 3-6 m (10-20 ft) of ground surface.

Installation: After the casing and screen have been installed, continue to rinse the borehole by circulating clean water through the bottom of the casing (see Section 7). Slowly pour the filter media into the annular space and let it settle into the upward flowing water (0.19 - 0.25 L/s or 3 - 4 gpm). This process, called "floating in the gravel pack" helps prevent the filter material from bridging and keeps the fines from settling. A feeler line or weighted measuring tape should be used to confirm where the top of the filter pack is.

After the filter pack is installed, place a cap over the casing so that nothing can fall in the well during grouting and cement pad construction. The **LS-100** can now be removed.

References

Driscoll, F. (1986) Groundwater and Wells, St. Paul: Johnson Division

Ives, K and A. Coad (1987) "Selecting Filter Media", Developing World Water, Hong Kong: Grosvenor Press Int'l, pp. 202-203.

Moffat, B. (198?) "Efficient Water Wells", Developing World Water", Hong Kong: Grosvenor Press Int'l, pp. 36-37.

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Section 9

Sanitary Grout Seal

After the filter pack is placed, there is still an irregularly shaped annular space around the casing. In caving material such as sand or sand and gravel, the annular space is often quickly filled by caving material. However, where the material overlying the water-bearing formation is firm sand, clay, shale etc. and the borehole does not cave-in, the annular space must be filled.

A formation seal (cement grout) is placed into the annular space to prevent the seepage of contaminated surface water down along the outside of the casing into the well. General instructions on how to place grout seals are provided below and more detailed directions are available (see Appendix [).

If cement is scarce or extremely expensive, the annular space above the filter pack can be filled to within 3 - 6 metres (10 - 20 feet) of surface with a formation stabilizer consisting of clean, washed sand or drill cuttings **(see Figure 15)**. **Wherever possible, it is best to avoid using a formation stabilizer and place a formation seal directly above the filter pack**. Formation stabilizer should not be used in wells constructed in rock that is overlain by relatively thin, loosely consolidated sediment; they should be grouted from the ground surface to the rock.

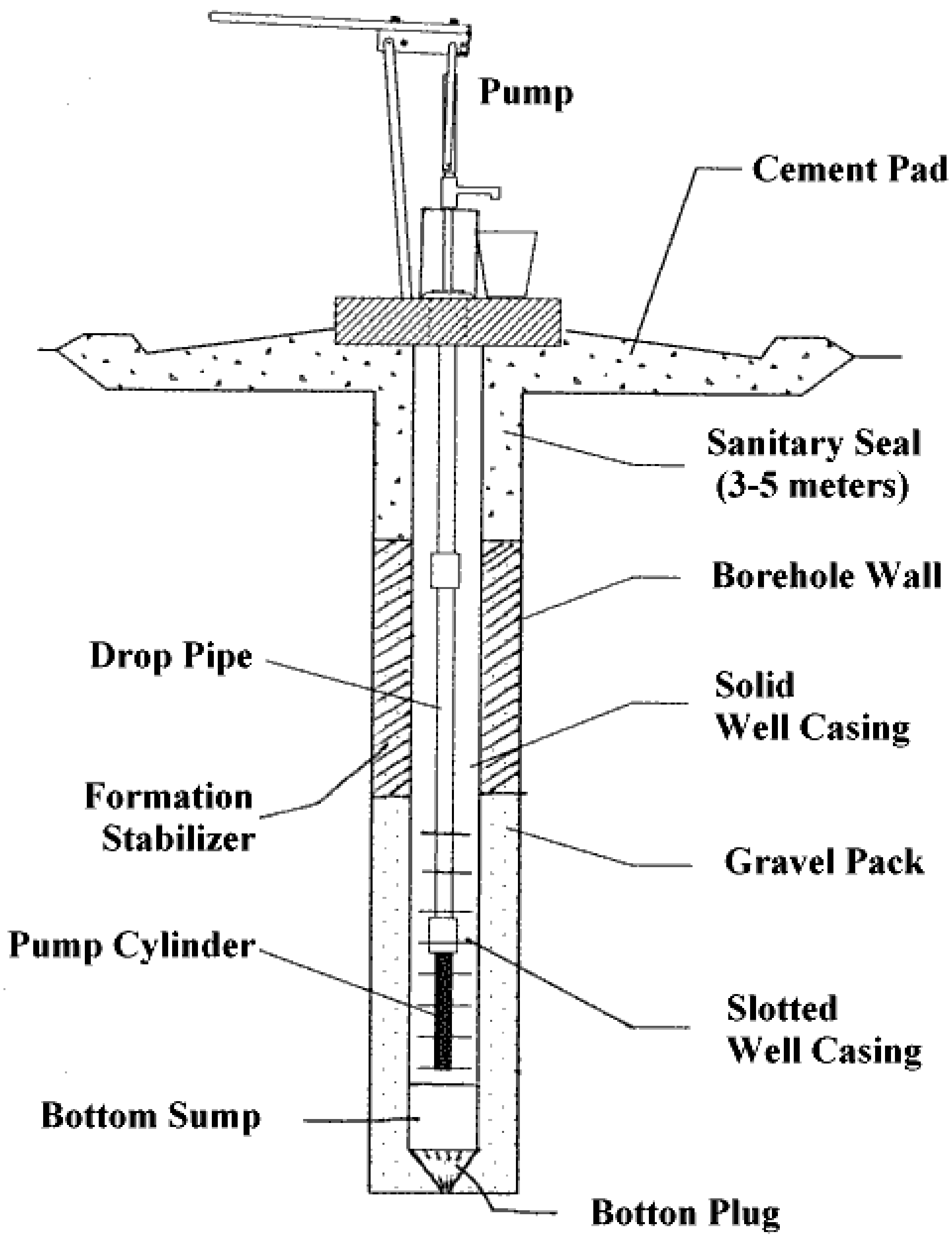
Fill the top 3 - 6 m (10 - 20 ft) of annular space with a formation seal that extends up to ground level **(see Figure 15)**. The sealant may be cement grout, bentonite (clay) or concrete. Comonly used converstion tables are available to help you calculate the required volume (see **Appendix B**). **The formation seal must be effectively placed to prevent contaminated surface run-off from infiltrating into the well.**

Concrete is normally used as the formation seal; mix it using a ratio of 2:3:0 - 2 parts cement: 3 parts sand: 0 parts gravel. If grout is to be poured into the hole through a small grout (tremie) line (Appendix I), mix the grout to the consistency of a thick cream (4 volumes cement powder + 3 volumes water = 5 volumes grout slurry (Australian, 1992).

While gravel is normally used in making concrete, the annular space (between the casing the and borehole wall) is so small that just getting a thin grout down the hole is hard; adding gravel to the mix would make it much more difficult.

Keep the concrete mix as dry as possible since increasing the amount of water will increase the amount of subsequent shrinkage and increase the chance of contaminants entering the well!

Figure 15: Completed Well Details



There is no significant penetration by cement into uniform sand with grain size finer than 0.6 mm (0.025 in). Therefore, if grouting on top of a filter pack, ensure that 1 metre (3 feet) of fine sand is first placed on the filter pack to avoid plugging it with grout. **If available, it is even better to pour 0.3 - 1.0 metres of bentonite on top of the filter pack before the cement seal is poured.** If this is done, the bentonite will swell and force it and the cement into the formation creating one of the best seals you can have in a well.

If cement is unavailable, the casing be sealed by pouring just bentonite down the hole. The bentonite should be mixed at concentrations of 0.7 kg (1.5 lb) bentonite per 3.8 l (1 gal) of water (Driscoll, 1986). Pour it soon after mixing so that it hydrates (absorbs water and swells) in the ground, thus creating a tight seal. Although this concentration it too thick to be pumped, it will not shrink provided the ground around the grout remains somewhat moist.

When heavily contaminated soil or a severely polluted surficial aquifer are encountered, well casing should be securely grouted into an underlying rock or clay layer. This can be done using the "Modified Halliburton Wiper Plug Method", a technique which can also be used to seal casing into rock when switching from mud rotary to air hammer drilling (see **Appendix I**). If you need to backfill part of the borehole prior to setting a casing, consider using the Cement "Plastic Bag Plug" Method (**Appendix I**).

Finally, once casing is grouted in-place, mound soil around the well and grade it away from the well. This will prevent poor quality surface water from ponding near the well and entering the well through the annulus (between the well casing and the borehole) if the grout seal is not perfect. **References**

Australian Drilling Industry Training Committee Ltd (1992) Australian Drilling Manual 3rd edition", Macquarie Centre: Australian Drilling Industry Training Committee Ltd, ISBN 0-949279-20X.

Driscoll, F. (1986) Groundwater and Wells, St. Paul: Johnson Division

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Section 10

Well Development

The well screen **(section 7)** is the "**heart of a well**" and the filter pack **(section 8)** acts as the "**lungs**" passing water to the screen! However, after drilling a borehole and installing a casing and filter pack, it is necessary to get the "**heart pumping**" and the "**lungs breathing**" since the drilling fluid forms a thin layer of mud on the sand grains of the borehole wall and is forced into the pore spaces and cracks in the aquifer. This plugging effect decreases the flow of water into the well.

Section 10.1: Well Development Basics

The act of cleaning out the clay and silt introduced during the drilling process as well as the finer part of the aquifer directly around the well screen prior to putting the well into service is called "well development"[(1)]. Effective well development:

- **increases the rate of water movement from the aquifer into the well;**
- **stabilizes the aquifer to prevent sand pumping, thereby producing better quality water and increasing the service life of the pump cylinder and well (Schreurs, 198?);**
- **removes organic and inorganic material which may inhibit effective well disinfection.**

By ensuring that wells are developed to the best possible technical standards, fewer boreholes will be required to meet the total demand and the wells will be less likely to fail within a few years (Moffat, 198?).

Development should continue until the discharge water is clear and all fine material from the well and adjacent aquifer have been removed. The time required for development depends on the nature of the water bearing layer, the thickness of screen slots relative to aquifer particle size, the amount of material rinsed from the well prior to placing the filter pack, and the type of equipment and degree of development desired. Large amounts of development energy are required to remove drilling fluid containing clay additives (Driscoll, 1986); **well development may be completed in 1 hour, but up to 10 hours may be required** (Brush, 197?).

Section 10.2 - Well Development Techniques

Well development methods are all based on establishing velocities of flow greater than those produced by the expected rate of pumping from the completed well. Ideally, this is combined with vigorous reversal of flow (surging) to prevent sand grains from bridging against each other (Schreurs, 198?). Movement in only one direction, as when pumping from the well, does not produce the proper development effect - sand grains can "bridge" voids around the screen. Agitation from pumping during normal pump use may cause these bridges to break down over time and sand to be pumped. This sand will act like sandpaper in the pump cylinder and will cause the cup leather to wear-out and the pump to fail within a few days or weeks!

As discussed below, there are a number of techniques which can be used to develop newly constructed wells. Although hydraulic jetting and hydraulic fracturing are effective well development techniques, they are not covered in this manual since they require more sophisticated commercial equipment and specialized training and are usually used in developing large capacity wells.

Overpumping:

The simplest but least effective development method is pumping a well at 2-3 times the designed discharge rate for a prolonged period. This does not really agitate the soil enough to create a real filter around the screen and it tends to develop only a short section of the length of screen (Anderson, 1993)[(2)]. However, it is useful because if the well can be pumped sand free at a high rate, it can be pumped sand free at a lower rate (Driscoll, 1986).

If the water level is within 3.05 to 4.57 m (10 to 15 ft) of ground surface, it is sometimes possible to use the mud pump as a suction pump to pump water from the well for 2 to 3 hours. If this can be done, do not pump continuously: start-stop cycle pumping is best for developing a well.

If this is not possible, install the bush pump and use a separate cylinder for the development process since particulate matter removed during development can cause an abnormally high rate of wear on the pump resulting in early pump failure. Using a larger pump cylinder than planned for the final installation will enhance the effectiveness of the well development.

The effectiveness of overpumping can also be enhanced by attaching a rubber gasket around the top of the pump cylinder and lowering it into the well until it is adjacent to the top of the well screen. Start developing the well **at the top** of the screen so that fine material around the screen can gradually loosen and be pumped out of the well without jamming the pump! When pumping no longer produces sediment, the pump can be lowered several feet using specially made half length connecting rod and quarter length sections of rising main (also know as "drop pipe", "draw pipe" or "pump column"). The cycle of pumping until the water clears and lowering the pump further into the screened interval should continue until the entire screen has been developed. Attaching a second gasket 0.5 - 1 metres below the bottom of the pump cylinder would greatly increase the suction effect on the isolated sections of screen.

Backwashing: This too is a relatively simple method of development which requires a water lifting device and a container in which water can be stored and then from which it will be allowed to flow easily back into the well. Water is pumped to the surface until the container is full; it is then rapidly dumped back into the well. Repeating this motion many times can provide some development of the surrounding water bearing formation.

It is crucial that the water which is pumped to surface be allowed to sit until the suspended material has settled. The clear water should then be decanted into a second container and from there dumped back into the well. This will ensure that fine particulate is not inadvertently re-introduced into the well.

If a gasket has not been attached to the top of the pump cylinder, it may be possible to combine overpumping with backwashing by collecting water from the overpumping process, allowing it to settle and then rapidly pouring the decanted water back into the well.

Surging: Surging is the most common method of well development. It involves forcefully moving water into and out of the well screen using one of the following techniques:

Compressed Air: Compressed air can be injected into the well to lift the water; As it reaches the top of the casing, the air supply is shut off, allowing the aerated water column to fall (process called "rawhiding"). The air supply should be periodically run without stopping to pump sediment from the well[(3)]. This equipment is usually not available in remote areas and often only opens a small portion of the screen.

Bailer: A bailer is like a length of pipe with a one-way valve in the bottom. The bailer is lowered into the well until it fills with water and sediment; it is then pulled to the surface and emptied. Water from the aquifer will then flow towards the well and bring in more drilling fluid.

A bailors up-and-down motion causes a surging action which will develop the area around the screen. The heavier and wider the bailor is, the better it will function because it will have more force to push water through the screen (Brush, 197?). Be prepared to bail and bail and bail and bail ... it is hard work and can take all day!

Surge Block: A surge block is a flat seal that closely fits the casing interior and is operated like a plunger beneath the water level. Because it seals closely to the casing, it has a very direct positive action on the movement in the well (Brush, 197?).

Placing a surge block on the end of Waterra tubing equipped with a one way valve has the advantage of the down stroke being milder than the upstroke because some water passes up the tubing. This is advantageous because it ensures that fines are not driven further into the formation and it helps to remove sediment which is loosened by the surging action. This prevents the screen from becoming totally blocked with accumulated fines.

To effectively surge a well, apply an up and down motion, repeatedly raising and dropping the plunger 2 to 3 feet. The plunger should drop rapidly on the downstroke in order that turbid water will be lifted out of the connecting tubing. While the plunger can be forced down on each stroke, adding weight just above the surge block will make it easier to work for a longer period of time.

Surging should start above the screen to reduce the possibility of "sand-locking" the surge block (Anderson, 1993). Initial surging should be with a long stroke and at a slow rate (20 to 25 strokes per minute); after surging above the screen, the hole should be cleaned and surging started at the lower end of the screen - gradually working upward until the entire screen has been developed (Anderson, 1993).

When the amount of fine material drawn into the well begins to decrease, the process should be repeated, beginning at the bottom of the screen, but with a faster stroke (30 to 35 strokes per minute). The final surging should be as rapid as possible for as long as possible.

10.3 - Testing Well Yield

Well yield is the volume of water that can be pumped during a specific period of time (it is expressed as litres or gallons per minute). Sometimes the yield of existing wells will be tested to determine if it is worthwhile to drill in the same area. If a submersible pump is installed, a full pump test can be done[(4)]. If a handpump is installed, try to measure the water level before and after pumping. Pump at a steady rate for as long as possible (1-4 hours if new wells will be heavily used). This pumping rate is sustainable if the water level returns to pre-pumping levels within 6-12 hours. The shorter the time, the better the aquifer. Section 10.4 - Capacity

If the yield of a newly drilled well is questionable, it is often a good idea to test it to determine whether or not it is worthwhile to pour a concrete pad and install a bush pump. In general, a well which is capable of reliably supporting a heavily used bush pump should be able to yield at least 0.2 L/s (3 gpm) and have a specific capacity of at least 0.01 L/s for every meter of drawdown[(5)]. Rough estimates of the yield of new Lifewater wells can be obtained using an air compressor, Waterra tubing equipped with a foot valve or a bailer.

If available, use an air compressor to inject large volumes of air into the well. This will cause the water to spill over the top of the well casing. A trench should be prepared ahead of time to carry this water away so that it does not pond around the well. After 30 minutes, the amount of water still flowing over the top of the well casing will provide a rough estimate of how much water the well can produce. This should be confirmed by turning off the pump and measuring how long it takes for the water in the well to return to the pre-pumping level. Measure the water level every minute for 10 minutes, then every 5 minutes for half an hour, then every 15 minutes for an hour and then every half hour until recovery is complete. These readings can be used by hydrogeologists to analyze the aquifer.

Finally, an inertia-lift system (Waterra) or a bailer can be used to test the yield of a newly constructed well. If the well can be pumped dry using these devices and the yield does not improve with development, the well will not have sufficient yield to support a hand pump.

If the well yield is too low to support a hand pump, the well should be abandoned by removing as much casing as possible and filling the well with clay or silty sand and filling the top 2 meters with concrete. **If this is not done, future well supplies may be jeopardized since the well may allow contaminants to pass into groundwater.**

Footnotes & References

[1] In sands and gravels, filter packs are often created by developing the well so that 30 to 60 percent of the aquifer material adjacent to the screen passes into the well leaving a hydraulically graded filter of coarse sand and gravel around the screen (Anderson, 1993).

[2] For a given pumping rate, the longer the screen, the less development will take place in the lower part of the screen. After fine material has been removed from the permeable zones near the top of the screen, water entering the screen moves preferentially through these developed zones, leaving the rest of the well poorly developed and contributing little to well yield (Driscoll, 1986).

[3] If limited volumes of air are available, put a small diameter air hose down a larger pipe (such as the rising main, Waterra tubing or drill pipe); blowing air through the small air hose will cause water to lift out through the larger pipe (Anderson, 1993). A useful rule of thumb for determining the proper compressor capacity for air-lift pumping is to provide about 0.35 L/s (3/4 cfm) of air for each 0.06 L/s (1 gpm) of water at the anticipated pumping rate (Driscoll, 1986). In general, a compressor producing 861.8 kPa (125 psi) and 94.4 L/s (200 cfm) is required. Submerse the air line about 60 percent of its length during pumping.

[4] Using a submersible pump, a pump test can be done as follows:

- Measure the distance to the water level in the well;
- Then turn on and operate the pump at about one-third its capacity for 1 to 4 hours;
- During the pumping, measure the yield of the pump by filling a container of known volume and recording the length of time it takes to fill it. For small containers, the flow rate (gpm) = (Volume in gallons x 60) / Time (seconds) to fill. For filling the typical 208.2 L (55-gal) oil drum, the pumping rate in L/s is 208.2 L/Time (seconds).
- At the end of the pumping period, measure the water level as soon as the pump is turned off.
- Calculate the drawdown by subtracting the original depth of the static level from the new depth.
- Calculate the **"specific capacity"** of this one-third drawdown point by dividing the yield (how many litres collected in the

barrel in one minute) by the drawdown (see Appendix A)

- Repeat this process pumping at two-thirds of the pumps capacity and then again at full capacity.
- If water level measurements are frequently taken during drawdown and recovery, hydrogeologists can use the information to calculate aquifer characteristics (transmissivity and storativity) which can be used to help develop local groundwater development plans.

[5] Note that if tests are conducted immediately after a well is constructed and before it is put into full use, incomplete development will often cause the calculated yield to be 10-30 percent less than the yield after 2-4 weeks of continuous use.

Anderson, K. (1993) Ground Water Handbook, Dublin Ohio: National Groundwater Assoc.

Brush, R. (197?) "Wells Construction: Hand Dug and Hand Drilled", US Peace Corps, Washington DC.

Driscoll, F. (1986) Groundwater and Wells, St. Paul: Johnson Division

Moffat, B. (198?) "Efficient Water Wells", Developing World Water", Hong Kong: Grosvenor Press Int'l, pp. 36-37.

Schreurs, R. (198?) "Well Development is Critical", Developing World Water, Hong Kong: Grosvenor Press Int'l.

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Section 11

Safety Issues on the Job

When travelling overseas to construct wells, the 5 greatest health and safety risks are:

1. **Heat Stroke;**
2. **Gastro-Intestinal Illness;**
3. **Traffic Accident and/or Transfusion with Tainted Blood;**
4. **Injury on the Job and/or Transfusion with Tainted Blood;**
5. **Mugged (in cities) or Attacked (in remote areas);**

Safe work practices, learned early, help reduce the possibility of accidents occurring causing painful injuries, expensive repairs or irreparable damage to machinery or even the well itself. Good work habits reduce errors that lead to accidents and/or injury. Such errors include:

- positioning the rig on steep slopes that are filled with loose clay or other unstable material, on old rock fills, on surface soils or vegetation overlying sloping rock surfaces, close to traffic hazards and under dangerous banks (Lovett, 1985);
- failing to keep flammables (fuel, chlorine etc) in properly marked, approved containers and stored away from sources of heat. Fire can also result from refilling gas tanks when the engine is running or has not been allowed to cool or failing to immediately clean-up any spilled gasoline (Lovett, 1985);
- starting the drill rig motor when the drill pipe is not secure;
- putting too much down-pressure on the drill bit and having the machine topple over (particularly if the guy ropes are not secure or the weights on the base are too light);
- contacting power transmission lines while raising pipe or the drill mast or drilling during thunder storms (when the elevated drill mast is susceptible to lightning strikes);
- touching the revolving drill pipe;
- employees or spectators positioning themselves where they can be struck or can lose their balance if the drill pipe slips loose or sticks;

- working on machinery that is moving (Lovett, 1985);
- serious burns can occur if people are not careful and touch the hot exhaust mufflers of the mud pump or drill rig engines;
- not covering a borehole after completion and allowing tools or other debris to fall in (this can render a hole unusable!) Similarly, one instant of carelessness can result in drill pipe or bits slipping down the hole when they have been loosened;
- neglecting precautions against slips and falls (particularly where there is wet clay);
- improperly lifting overly heavy or bulky loads of pipe etc causing serious back strain;
- accidents are more prone to happen if spectators are not kept back behind a clearly defined barrier. In addition, a trained driller should also be operating the drill from a position where it is easy to reach all the control levers. Loose clothing should not be worn when drilling because it is more prone to catch on sharp or moving objects and personal protective equipment (such as safety hats, gloves and boots) should always be worn. Finally, it is important to maintain equipment in good working order and to ensure that the area around the drilling rig is kept tidy and in good order (Lovett, 1985).

References

Lovett, W. (1985) "Chapter 2 - Safety on the Job", pp. 9-12 in Water Well Driller's Beginning Training Manual, Worthington, OH: National Water Well Association, ISBN 1-56034-049-5.

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Section 12

Handpump Pad Construction

Click **HERE** if there is no button bar on the left side of your screen!

Handpump Pad Purpose:

The purpose of a handpump cement pad (see Figure 16) is to prevent contaminated surface water from entering the well and to prevent the area around the well from becoming muddy and unsanitary so that water buckets stay clean and users of the pump stay dry.

Design pads to extend 60 cm (2 ft) in all directions past the outer limit of the excavation. Since drilled wells have only a 15 cm (6 inch) annular space, a 60 x 60 cm (2 x 2 ft) pad can provide sufficient sanitary protection. However, many dug wells have annular spaces of 3 m (10 ft) or more. Since it is impractical to fill all the space between the well tiles and the walls of the excavation with cement grout, the concrete pad is essential to ensuring that contaminated water does not enter the well. Therefore, if a 2 m (6 ft) diameter hole is excavated to construct a well, a 3 m (10 ft) diameter pad is required to protect water quality within the well.

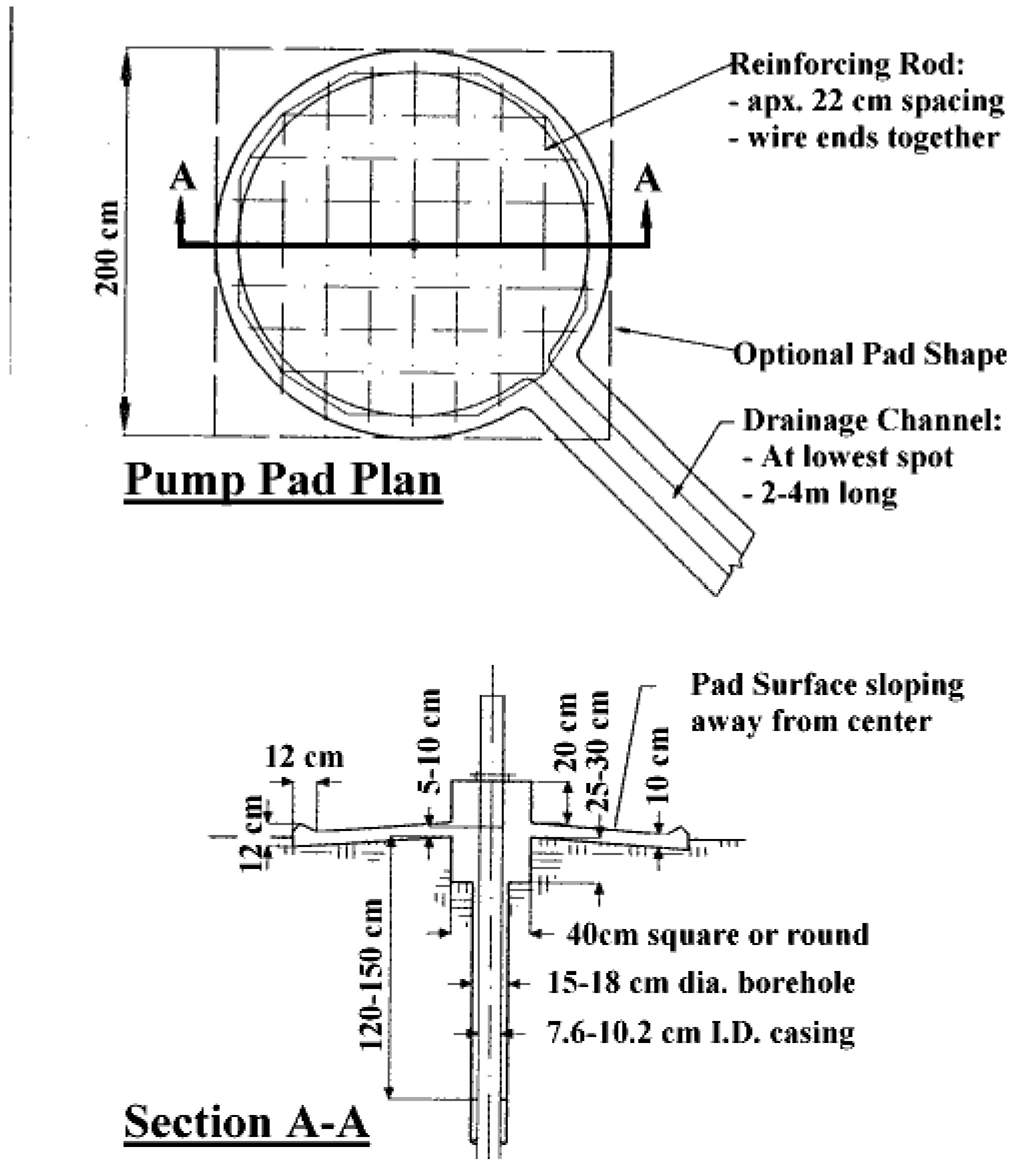
Follow the steps described below to design & build a handpump pad:

1) Decide on the size and shape of your pad. It should be at least 2 meters by 2 meters square and 10 cm thick (see Figure 16). If the pad is to be this small, add a concrete rectangle on the side of the pump handle so that the person pumping will have firm footing.

2) If appropriate, link the pad to a drainage channel that leads to a garden or animal watering area. Locate watering troughs at least 30 meters away and separated from the well by a substantial barrier to keep animals away from the well.

3) Calculate cement volume to make pad (1:2:4 ratio) (Appendix J).

Figure 16: Cement Pad Configuration



4) Ensure that the edge of your pad is excavated to extend down 1 foot into undisturbed soil. This prevents water from eroding underneath the pad over time.

5) Shape pad edges by centering wooden forms around the well casing. Lay out a grid of steel reinforcing bars, tie them together and raise them several centimeters off the ground (see Appendix J). Alternatively, shape pad edges using concrete blocks which are left in-place after concrete is poured. However, concrete blocks are often made with too little cement resulting in the pad edges quickly disintegrating. To minimize these problems, make your own cement-rich blocks and place concrete inside block holes and over the top & sides of the blocks.

6) Pour the concrete into the forms, ensuring that the pad has a slight slope from the centre outward to drain water away.

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Section 13

Bush Handpump Overview

Click **HERE** if there is no button bar on the left side of your screen!

- Make a bush pump (Appendix K)
- Bush Pump Installation (Section 14)
- Bush pump Maintenance (Section 17)
- More Bush pump info. (HTN Network)

Advantages of using the Bush Pump

Over the past decade or two, the bush pump has become the world's most robust and widely used locally made handpump. Benefits of this hand pump include:

- **create desperately needed local jobs;**
- **low cost;**
- **maintenance - what's locally built can be locally repaired;**
- **removable parts have minimal resale value (an important consideration where expensive imported pumps are looted).**

Because the Bush pump is locally made, it has also picked-up many different names. Besides being called a modified Guinea-Bissau Pump, it is also called:

- **POV-RO 2000 Pump** (Nepal)
- **Zimbabwe hand pump** (Zimbabwe)
- **Simple hand pump** (Kenya)
- **Bush Pump** (Liberia)

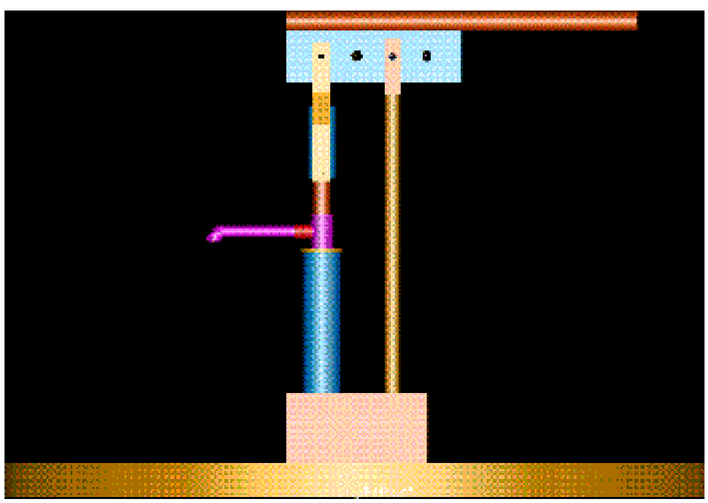
These pumps have several key common **Design Specifications**:

- **Wood Block Bearing:** Usually three pieces of 5.08 x 15.24 cm (2 x 6 in) wood are laminated together to form the pivot bearing. An extra set of 2 holes is drilled in the block so that when the holes wear significantly over time, the block can be quickly rotated and the bolts inserted into the new holes.
- **Pump or Pivot Support:** A single strong pipe or a frame made of angle iron is embedded into concrete and used as the pivot support for the wood bearing.
- **Outlet Pipe Assembly:** An outlet pipe assembly made from local plumbing supplies rests on-top of the well casing cap or protective casing cover.

Deciding to use the Bush pump

When deciding whether or not to use a bush pump in a particular community, it is important to consider the following factors:

- **What is the projected use? In general, the bush pump is suitable for use in communities of up to 500 people. Where there are significantly more people, either a second well should be drilled or another handpump chosen (such as the Afridev hand pump, India Mark II, Kardia hand pump or Vergnet hand pump);**
- **What is the availability and cost of other hand pumps? In some countries, handpump use has been standardized to one or two types which are widely available at low cost. If this is the case and parts and trained repair people are locally available, the advantages of using these hand pumps will normally outweigh the benefits of introducing the bush pump.**
- **What is the pumping level? Bush pumps can be used for depths up to 100 metres. Pumping ease is maintained by counter-balancing the weight of the water column by putting concrete or sand inside the hollow pump handle.**



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Section 14

Bush Handpump Installation

This section describes how to install Zimbabwe Bush handpumps and pour a cement pump pad. Also, see instructions on how to manufacture Zimbabwe handpumps **(Appendix K)** and detailed guidelines for working with concrete **(Appendix J)**.

Table 4: Zimbabwe Bush handpump installation Tools

The following tools are needed to install fully manufactured Bush pumps:

- **Thread Cutter**
- **Hack Saw**
- **Two Adjustable Wrenches or a set of Open-end Wrenches**
- **Cement working tools (trowels, shovels etc)**
- **Carpenters level**
- **Measuring Tape**

Cutting the Well Casing: After the casing has been installed (Section 7), gravel packed (Section 8), and grouted (Section 9), it is typically cut-off 16 inches above the finished pad surface. This distance is much less critical if a casing reinforcement base is used (see Appendix K - Figure 27).

After cutting the casing, test the well yield to confirm that there is enough water to support a handpump. If there is not, develop the well some more or abandon it. If there is enough water, install the Zimbabwe Bush pump as follows:

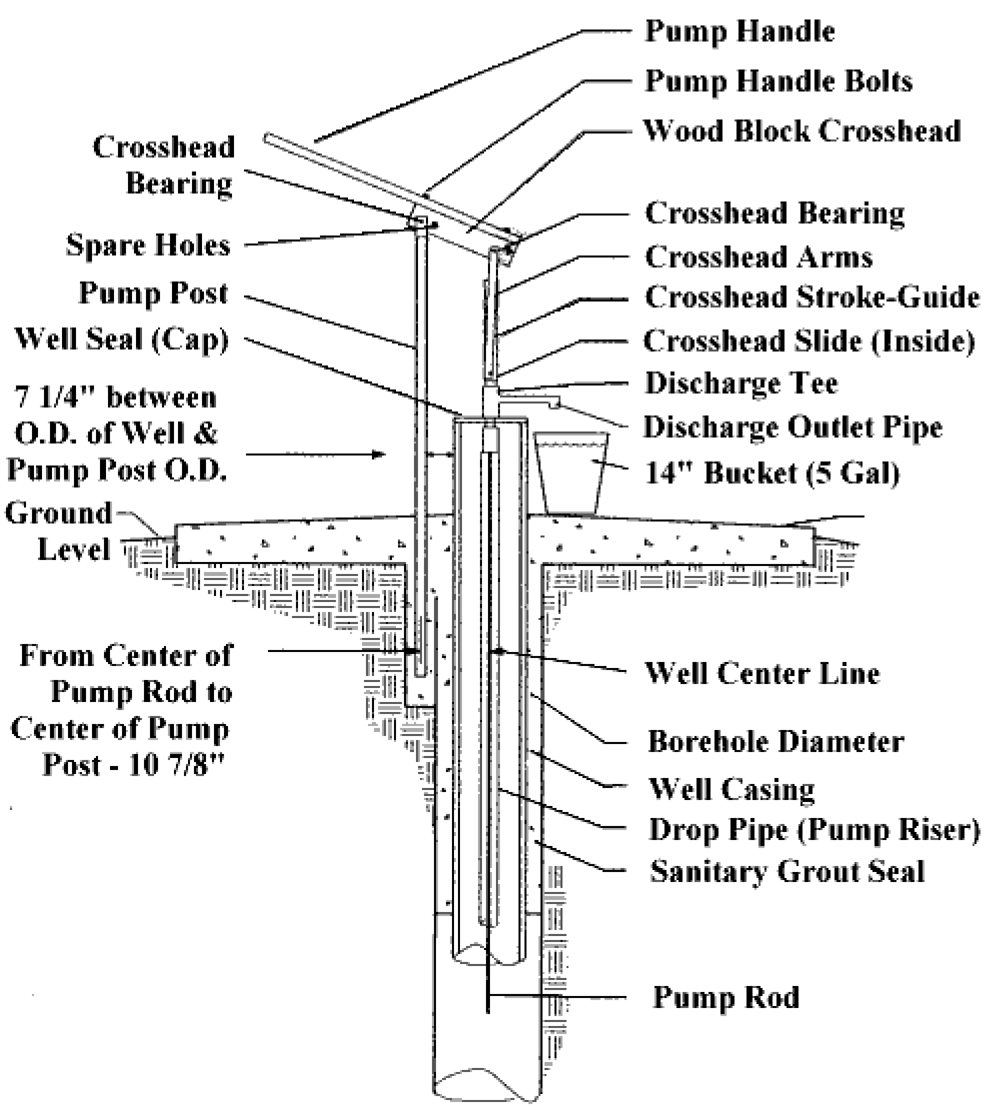
Pump Post Installation: ***Installing the pump post and the casing reinforcement base is the hardest part of installing Bush pumps because these two parts must be precisely aligned to each other.*** **To install the pump post:**

1. **dig a hole (90 cm deep and 25 cm diameter) centered 30 cm from the middle of the casing reinforcement base (see Figure 16).**
2. **position pump post in hole (using braces & rocks) so that:**
    - **the bottom end is 85 cm (2.79 ft) below the projected surface of the finished pump pad, AND**

- **the distance of the center of the fulcrum holes to the center of the casing is 30 - 31 cm, AND**
- **the horizontal reinforcement angles face 90 degrees away from the casing, AND**
- **the post is vertical in two directions 90 degrees from each other. Tolerance: leveling bubble not more than 1/8 bubble outside the markings.**

3. Dig around the casing so that the pump base (Figure 27) will fit over the casing. Rest the base anchors on small rocks of that concrete can flow underneath them. The top of the base should be 16 inches above the finished pad surface (ensure that commonly used containers will clear the spout.
4. Pour concrete in the hole around the post and the pump base, leaving sufficient room at top to allow for the thickness of the pad. For details on mixing concrete, see Appendix J.

Figure 17: Zimbabwe Handpumps Configuration



Dug Well Installation: It is much more complicated to install Bush / Zimbabwe handpumps on a dug well. One option is to bolt the steel pump post to the outside of the casing and then support it by pouring concrete around it. Make a hole near the edge of the concrete well lid so that the cylinder and rising main (sometimes called "drop pipe", "draw pipe" or "pump column") can be lowered into the well right beside the well tiles. Bolt the casing reinforcement base (Appendix K, Figure 27) to the well lid and then pour concrete around it. Alternatively, the pump could be modified by welding the pump post and casing reinforcement cover onto two horizontal steel bars. The two bars can be bolted to the well lid and then covered in concrete. Installation of the pump cylinder, pump rod and rising main would then be completed as described below.

Design and Pour the Concrete Pad. After the concrete around the pump post and base has cured for a day, pour the cement pad **(see Section 12)**. While the concrete pad is curing, disinfect the well **(see Section 15)**.

Installation of Pump Cylinder, Pump Rod, and Rising Main: After the pad is cured (7 days and keeping it wet), install the cylinder. Wipe the pump cylinder and rising main with the disinfectant solution prior to installation. Lay-out enough rising main and pump rod (also known as "sucker rod") so that the pump cylinder will be positioned at or above the middle of the screen **(see Figure 15 - Section 9)**. Note, however, the following special cases:

If very fine sand is present in the water, the cylinder should be positioned 1-2 meters above the screen to minimize sand pumping;

If the only available water bearing formation is a shallow unconfined aquifer or if the well has a low yield, the pump may produce water for a little while before sputtering dry only to work again an hour later. If this is the case, ensure that the pump cylinder is placed as close to the bottom of the well as possible (within 61 cm). Alternatively, a 10 m length of one-inch diameter PVC pipe could be attached to the pump cylinder and a one-way valve added to the bottom end. The pump cylinder should then be installed above the screen with the suction line dropping into the casing below the screen. Since the suction limit is 8.5 m, this will limit the maximum pumping rate and will prevent the well from being rapidly pumped dry. If an existing well starts sputtering dry, there are a few other things you can try (see Appendix G).

Glue one male and one female threaded coupler to the ends of each length of rising main. Ensure that you follow proper proceedures for joining PVC pipe to prevent pipe from separating once it is in the well **(see Section 7)**.

Take apart the pump cylinder and make sure the piston rod is tightly connected to the piston. This is done by tightening one nut. Also make sure that all fittings on the piston are secure... *THEY ARE OFTEN NOT TIGHTENED AT THE FACTORY!*. If you ever come upon a pump where there is water in the well and the handle moves very easily up and down but no water comes out the spout, the fittings inside the cylinder and/or the pump rod connections have come undone!

Put one length of steel rod inside one length of plastic drop tube. The steel rod should be threaded on both ends. The drop tube should have threaded fittings so that it can be taken apart when the cylinder has to be removed for maintenance.

If you ever come upon a pump where the handle is very hard to push down and it "snaps" back up without producing water, the threaded fittings have come unscrewed or the glue holding the fitting onto the rising main has let go. If the rising main separates, the water-filled rising main and the attached cylinder will slide down inside the well until they are stopped by the piston striking the top of the cylinder. Each time you push the pump handle down, the pump rod will lift the cylinder and the water-filled rising main. It doesn't take long before the pumphead breaks or the pump rod separates and the rising main and cylinder drop to the bottom of the well!!!

Connect the steel rod to the piston rod of the cylinder using a threaded steel coupling. **TIGHTEN FIRMLY**!

Disinfect a long nylon rope with a mild chlorine solution and attach one end to the rising main several feet above the pump cylinder. Connect the other end to the inside of the well casing just below the top of the well. This safety rope will ensure that the cylinder and the rising main can be retrieved if accidently dropped during removal **(see Section 17: Bush / Zimbabwe Handpumps Maintenance)**.

Connect the rising main to the pump cylinder. Make sure the rising main section joints are at the same location as the pump rod joints. If possible, make rubber or metal centralizers and install them every 6.10 - 12.19 m (20 - 40 ft) to keep the rising main centered within the casing (this minimizes the amount of wear caused by pump rod rubbing against the rising main).

Lower the cylinder with attached rope, rising main and pump rod into the well. Be sure to grip the pipe with a pre-made slip clamp so that it can not fall down the well. Ensure the clamp is larger than the diameter of the well casing so that it can not fall into the well.

Place the next length of pump rod into the next length of rising main and raise them up vertically. Have a helper hold the rising main several feet in the air and firmly connect the pump rod to the rod already in the well. Then connect the rising main.

Carefully lower the pipe until it can be clamped at the coupling for the next pipe and pump rod. Continue the process until all the pipe and rods are installed and the cylinder is at the correct depth.

Cut the rising main level with the casing and glue on a male threaded glue-screw fitting. Put the threaded fitting through the hole in the base plate and screw the pump spout on to it. Ensure that you follow proper proceedures for joining PVC pipe **(see Section 7.5)**. Mount the spout and the expansion pipe assembly to the base plate, install it on the pump base and secure it with four 1/2 inch bolts.

After you have inserted the pump rod through the hole at the top of the pump sleeve (see Appendix K - Figure 26), adjust the length of pump rod as follows:

1. **Lower the pump handle until the handle screw rests against the travel stop bar on the pump post (Appendix K - Figure 25).**
2. **Pull the pump rod until the piston hits the top of the cylinder, then lower it 20-25 mm. While holding it in this position, mark the rod about 25 to 30 mm above the pump sleeve.**
3. **Remove this section of rod and cut it off at the mark. Cut a thread on this end about 25 to 35 mm long.**
4. **Re-install the rod and secure with two wide area washers (to seal the hole in the top of the slide tube) and a nut and a jam nut.**
5. **Now raise the pump handle until the pump sleeve rests against the "Tee" joint (Appendix K - Figure 26) on the top of the pump outlet assembly. If the end of the pump rod is still hanging on the nut then the adjustment is correct. If the nut is pushed away from the washers the it means that the piston is bottoming on the cylinder. Pull the pump rod up by about 15 mm and bring the nut all the way down to the washers. Check that the piston does not hit the top of the cylinder when the handle is pushed all the way down. Re-adjust if necessary.**
6. **Move the handle through its full range of travel and make sure that the handle hits the stops before the piston hits the top or bottom end of the cylinder. (When the user-end of the handle is all the way down, the wooden block should hit the angle piece that is was welded across the posts. When the handle is moved completely in the opposite direction, the slide tube hits the "T" of the spout assembly). It may be necessary to cut off some more of the pump rod so that it will not interfere with the wooden block when the handle is moved through its full range of travel. Install a jam nut to secure the first nut in place.**

The pump is now fully installed and may be pumped until the water comes to the surface. Continue to pump until the water clears up. The well should then be chlorinated prior to use. While the well is being chlorinated, the entire pump assembly can be painted. Test the water for bacteria **(Section 16)** and repeat the disinfecting procedure if necessary.

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Section 15

Well Disinfection

After constructing or repairing a well or pump, the entire well and pumping system must be disinfected in order to kill harmful microorganisms (germs and bacteria) that may be on the well casing, gravel, soil, rising main, pumping rod or in the water from the digging operation. If you think you know how to do this, try this chlorination exercise (Appendix E)!

Chlorine is normally used as the disinfecting agent since it destroys bacteria by neutralising the enzymes that are essential for their survival (Richard, 1987). Chlorine is usually sold in 2 forms: sodium hypochlorite (liquid bleach) and calcium hypochlorite (powder or pellets).

Sodium hypochlorite is the main ingredient in liquid bleaches which initially contain about 5% available chlorine; it gradually loses its strength over time, especially in hot climates. While substantial quantities are required to effectively disinfect large diameter wells, it can be easily mixed with the water and it is relatively safe to handle and use.

Calcium hypochlorite comes in strengths ranging from 30-75 percent available chlorine (70 percent is most common). Like sodium hypochlorite, it slowly loses its strength with exposure to air and should be stored in sealed containers in a cool dark place to retain its strength. Much less quantity of this agent is required to effectively chlorinate wells and special, slow-dissolving pellets can be purchased to provide longer-lasting chlorine residuals. However, calcium hypochlorite becomes unstable and may spontaneously combust if it becomes warm and moist and it can even explode & burn if dropped.

Care must be taken when mixing and adding chlorine to a well since exposure to it can result in severe skin/eye irritations and blisters. It is also poisonous; inhaling concentrations of 30 ppm can lead to harsh coughing and concentrations of 1,000 ppm can be fatal in few breaths!

Chlorine is a very reactive substance. When added to a well, it first combines with inorganic compounds (hydrogen sulphide, ferrous iron, manganese); there is no disinfection at this stage. After these compounds have been reduced, remaining chlorine then reacts with organic matter (algae, phenols & slime growth). While some bad tastes and odours may be eliminated, there is only a slight disinfection action and trihalomethanes (carcinogenic, chlorinated organics) may be formed.

After the demand exerted by inorganic and organic compounds has been met, chlorine will combine with nitrogen compounds (primarily ammonia) to form chloramines. This combined chlorine form results in long lasting disinfection, produces minimal chlorine taste/odour and controls organic growths. However, it is slow acting and long contact times are required.

Finally, once even more chlorine is added to the water, the chloramines are destroyed and excessive chlorine, known as the free residual, forms Hypochlorous Acid (HOCL). HOCL is a potent, fast reacting disinfectant which is desirable when contact times are kept as short as possible and/or if there are high concentrations of iron, manganese, colour or bacteria. The amount of chlorine (dose) required to create sufficient quantities of HOCL depends on:

1. Bacterial numbers: If there are large numbers of aerobic or anaerobic bacteria in the water, a high chlorine dosage is required to ensure that all disease causing organisms have been destroyed;
2. pH: Hypochlorous acid (HOCL) will form in waters ranging from pH 6.5-7.5. As the pH increases above pH 7.5, HOCL increasingly dissociates to the hypochlorite ion, which is up to 250 times less effective as a disinfectant that HOCl (in terms of concentration). Under pH 6.5, the concentration of HOCL is reduced and hydrochloric acid (HCl), a very weak disinfectant, is formed. Generally HCl doesn't become a problem in the desired pH range of drinking water.
3. TEMPERATURE: Affects disinfection speed (high temperature = fast disinfection);
4. TURBIDITY: Effective microorganism destruction will only begin after the chlorine demand exerted by turbidity (inorganic and organic compounds) is met. In addition, chlorine is a surface-active agent and, since it can not effectively penetrate solids to kill concealed bacteria, disinfection of turbid water will be incomplete.

In established municipal water treatment/distribution systems, water is filtered to remove solids and excessive concentrations of chemicals prior to chlorination. In these systems, where chlorine and water are brought into active contact by pumping into mixers, holding tanks and/or through long distribution lines, initial chlorine dosages are often 1 ppm or less.

However, new wells often have turbid water, elevated concentrations of iron and/or organic slimes and few many existing wells were not thoroughly disinfected following construction and pump installation. Finally, it is difficult to achieve even mixing of chlorine and water in large diameter wells, chlorine tends to settle to the bottom of wells and high chlorine concentrations must reach the outside of the well tiles and the surrounding gravel pack.

As a result, much higher chlorine doses are required for shock chlorination of wells than are used in operating treatment systems. All newly constructed wells should be chlorinated so that a minimal chlorine dosage of 250 ppm is maintained for at least 12 hours (MOEE, 1987). Once wells have been effectively developed and chlorinated, they can be treated by maintaining a chlorine dosage of at least 50 ppm over a contact time of 12 hours. The higher the amount of organics and inorganics in the water, the higher the initial dose must be to ensure that at least 50 ppm chlorine is present in the well 12 hours after it was added.

Wells must be effectively developed prior to disinfection since the presence of organics (including residual drilling fluid) and fine particulate matter can make disinfection incomplete and can result in the formation of compounds that have unacceptable health and/or aesthetic characteristics.

Table 5: Well Shock Chlorination Procedure

1. **Calculate the volume of water to be treated. To do this, measure the number of metres of water in the well. For wells completed with 10.16 cm (4 in) diameter schedule 40 PVC pipe, the volume of water (l) to be treated is the depth of water in the well in metres times 10.5 l/m (or depth in feet times 0.85 US gallons/foot)[(1)]. If a 7.62 cm (3 in) diameter schedule 40 PVC pipe is used, multiply the depth of water (m) x 8.7 l/m.**
2. **Determine how much chlorine needs to be added to effectively disinfect the calculated volume of water. Newly constructed wells should be chlorinated with 250 milligrams per litre available chlorine.**
3. **For wells completed with 10.16 cm (4 in) diameter schedule 40 PVC pipe, for every m of water in a LS-100 well add: 3.8 grams of 70% strength calcium hypochlorite (TIP: there is about 10 grams in a level tablespoon); OR 8.8 grams of 25-35% strength bleaching powder or chlorinated lime; OR 53 millilitres of 5%**

strength sodium hypochlorite (liquid bleach).

4. **If a 7.62 cm (3 in) diameter schedule 40 PVC pipe is installed in a 15.24 cm (6 in) diameter borehole, for every m of water add: 3.1 grams of 70% strength calcium hypochlorite; OR 7.2 grams of 25-35% strength bleaching powder or chlorinated lime; OR 44 millilitres of 5% strength sodium hypochlorite (liquid bleach).**
5. **If sodium hypochlorite is used, just pour the chlorine into the well. If calcium hypochlorite is used, dissolve the chlorine powder or tablets in a 20 litre (5 gallon) bucket of water before adding it to the well. Add no more than 100 g of calcium hypochlorite to each bucket. When mixed with water, an insoluble residue will likely be formed. This residue should be allowed to settle and the clear supernatant containing the chlorine should be decanted (Richard, 1987). Pour the clear solution into the well.**
6. **If possible, agitate the water to evenly mix the chlorine. If the pump is already in-place, it should be operated until a distinctive chlorine smell is detectable in the treated water. If it isn't, place the required quantity of chlorine powder or tablets into a weighted porous container and surge it up and down in the well until the contents are dissolved.**
7. **Leave the chlorine solution in the well for at least 12 hours and preferably for 24.**
8. **After 12-24 hours, the strongly chlorinated water should be pumped from the well. If the pumping equipment has not yet been installed for some reason, do it now: it will be disinfected by using it to remove the excess chlorine. Choose a disposal place for the chlorine solution where it will have minimal contact with plant and animal life.**
9. **If a chlorine smell is not present in the discharge water after this contact time, the chlorination procedure should be repeated.**
10. **Discharge the water in the system to waste until the smell of chlorine disappears. The amount of chlorine remaining in the water will not be harmful.**
11. **In about a week, collect a water sample for bacteriological examination (see Section 16: "Water Quality Testing"). To be totally safe, boil or chlorinate all drinking water until the bacteriological results are returned (see Appendix T). Two consecutive "safe" tests will probably indicate that the treatment has been effective[(2)].**

Footnotes & References

[1] This assumes a 4 inch dia. ID and a 4.5 inch OD well casing, a 6 inch dia. borehole and a 30% porosity of the gravel pack and/or formation stabilizer in the annular space. The volume of water, therefore, = volume in casing + 0.3 x annulus volume (see Appendix A for volumes). Note that the amount of water within the well casing alone is

8.11 litres per metre of casing below the water table since volume (litres) = depth of water in the well (metres) x (casing diameter in metres/2) x (casing diameter in metres/2) x 1,000 l/m^3 x 3.14.

[2] If tests show continuing bacteriological contamination, a second chlorination is needed. Following the second treatment additional tests should be conducted. After repeated positive bacteriological tests, a well contractor should be contacted to surge the well and the surrounding formation with a strong chlorine solution. Chlorination will sterilize a well and water system; however, unless the source of the bacterial contamination is found and corrected the problem will continue to reoccur and chlorination will not solve the problem. In some cases, a new well may have to be constructed to correct the problem.

Ministry of Environment (1987) Water Wells & Ground Water Supplies in Ontario, ISBN 0-7729-1010-3 WRB

Richard, Y. (1987) "Disinfection in the Treatment of Drinking Water", pp.215-217 in Developing World Water, Hong Kong: Grosvenor Press International.

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Section 16

Water Quality Testing

There is no single measure that constitutes good water quality ... it depends on its use. Also, keep in mind that some water quality problems (iron, manganese and turbidity) can be treated (**see Appendix M**). Water quality is defined by analyzing it in terms of its:

1. **Chemical Content**: Hardness (calcium + magnesium), Metals (iron etc), nutrients (nitrogen and phosphorus), chloride, sodium, organic compounds, etc.
2. **Physical Content**: Turbidity, colour, odour, etc.
3. **Biological Content**: Fecal coliform, total coliform, viruses, etc[1].

Good quality (potable) drinking water is free from disease-causing organisms, harmful chemical substances and radioactive matter, tastes good, is aesthetically appealing and is free from objectionable colour or odour. It should be emphasized that there is a difference between "pure water" and "safe drinking water". Pure water, often defined as water containing no minerals or chemicals, does not exist naturally in the environment. Safe drinking water, on the other hand, may retain naturally occurring minerals and chemicals such as calcium, potassium, sodium or fluoride which are actually beneficial to human health. These will impart a taste to the water that may take some getting used to.

In some cases, however, groundwater can be contaminated with chemicals or bacteria. For example, a recent study has found that the health of many people has been put at risk due to the presence of **naturally occurring arsenic** in drinking water wells!

Recommended Sampling Program

***After a new water well is completed or when the quality of a water supply is suspect (because of turbid water, unusual colour, taste or smell), water samples should be collected and analyzed chemically and bacterially*. If possible, local health officials should check the water for purity and contamination. When the proper authority has pronounced it safe to drink, it may be used by the community.**

Often, however, many communities with Lifewater wells do not have reasonable access to commercial laboratories. In these cases, it is still desirable to sample but it must be done at the well site for minimum cost.

Tests for nitrate-nitrogen (NO3-N), pH, turbidity, total dissolved solids (TDS), odours, total coliform (the most important test), aerobic and sulphate reducing bacteria can be performed with minimal equipment and cost and provide accurate information on the state of the well water. Ideally, these tests should be done every 6-12 months to ensure that the water is still safe to drink. The tests will indicate if the well water quality is staying the same or will give an early indication that some activity is impacting it. Any indication of quality deterioration can then be corrected at an early stage.

Recommended Test Methods

Water samples should be taken in the following manner:

1. Pump water from the well for about three minutes. While the water is still flowing, immerse a **nitrate** test strip in the stream for one second and withdraw the strip and allow the colour to develop for 60 seconds. Compare the colour against the enclosed colour strip and record the result. Do the same with a **pH** strip.
2. Collect a sample in a clean clear glass vial or bottle; and
   - make visual observations concerning the **turbidity**.
   - make statements about any **odours** observed in the water.
3. With the sample in the clear glass, measure the **TDS** with a TDS pocket meter (if available). Record the number in ppm using the appropriate multiplier.
4. Bacteria tests must be carefully performed to obtain meaningful results. The pipe from the pump should be briefly scorched with a match to insure that any detected bacteria are from the water itself and not the pump surfaces. Then the water should flow for 2-3 minutes before a sample is obtained. Fill the sterile plastic sample bag; take care that the inner surface of the bag is not touched by anything (including hands).

   For **total coliform,** carefully pour water into the sample vials until the liquid level reaches the fill-line (the LaMonte test requires 5 vials; the COLI-MOR test uses 1 jar with a red liquid media). Ensuring that the lip of the vials and the inner surface of the cap do not touch anything, place the cap back on. Place the vials upright in the provided box and set aside for 24-36 hours. Record colour changes, gas formation and position of the thimble in the vials. After the test, carefully remove the lids, rinse the vials with bleach and then crush and bury them 2 feet in the ground where children cannot find them and play with (they contain potentially dangerous bacteria).

Aerobic and sulphate-reducing bacteria tests[2] indicate if bacteria are present which can cause problems ranging from slime formation, turbidity, taste, odour and corrosion through to greater hygiene risks (hydrogen sulphide-producing bacteria have been shown to be associated with the presence of fecal contamination). Although these tests serve as simple indicators, it is recommended that, where a problem is found, further tests be conducted to more precisely determine the nature of the microbial problem.

Test Result Interpretation/Response

If the water is turbid or cloudy, contaminated surface run-off may be entering the aquifer through cracks in the casing or the cement pump pad or through surrounding soil which is very permeable. While turbidity is not dangerous, it reduces the effectiveness of disinfection and indicates the presence of other conditions that need to be further investigated.

Odours should not be present in the drinking water. If present, potentially harmful substances may be entering the water from households (washing activities), agricultural sources (animal fecal matter), or natural sources (sulphates from springs or aquifers).

If total dissolved solids (TDS) exceed 500 mg/l, objectionable taste may drive people to use unsanitary water supplies. Increasing TDS concentrations over time indicates that the well is drawing groundwater from deeper in the earth or that contaminants (such as salt water if the well is near the ocean) are leaching into the aquifer. Serious TDS changes over time will require reducing pumping volumes and/or drilling a new well (likely at a higher elevation).

Readings of pH should be in the range of 5.5 to 8.5 for well waters. If readings are outside this range, the source and corrections may be difficult. The worse effect may be premature corrosion of metal surfaces contacting the water.

Nitrate concentrations above 10 mg/L can cause blood disorders in infants (blue baby disease). Elevated levels indicate that manure, sewage, or nitrogen fertilizers are reaching the water source. One elevated test reading (greater than 50 mg/l nitrate) must be followed up with more frequent testing (weekly). If nitrate levels above 45 mg/l (10 mg/l nitrate as nitrogen) persist, the source of the nitrate (animal confinement areas, privies etc) should be determined and relocated.

Nitrite readings (can be measured with the same test strip) should always be less than 1 mg/l. If nitrite concentrations are above 1 mg/l, the water must not be given to infants and a different source (boiled for disinfection) must be used.

Specific disease-producing organisms are difficult to identify in water. Therefore, while total coliform and aerobic/anaerobic bacteria are themselves not harmful, their presence signals that bacterial contamination from either human or animal fecal sources may be present. If total coliform and/or active aerobic or anaerobic bacteria are found, the water supply should be re-tested with extra careful attention given to all the sampling details.

If bacteria problems are still found, try to get local health professionals to conduct more thorough testing of the water supply. In addition, the well and surrounding area should be carefully examined to determine possible entry points for contaminated water. Note that the same sources that cause nitrate problems are probably responsible for bacterial contamination (see **Section 2.6**). However, bacterial contamination can also indicate a cracked well casing. Each circumstance will require its unique solution to improve the water quality. If problems persist and cannot be corrected, each individual user should disinfect the water they need for drinking, cooking, brushing teeth (**see Appendix T: Learn how to make water safe to drink!**).

Footnotes & References

[1] Coliform bacteria detect both non-pathogenic and disease-producing bacteria. Since the identification of specific disease-producing micro-organisms is difficult, total coliform is often used as an indicator of the water possibly containing disease-producing organisms that normally live in the intestinal tracts of man and warm-blooded animals (Driscoll, 1986). The four major types of pathogenic organisms that can affect the safety of drinking water are bacteria, viruses, protozoa and occasionally worm infections. Typhoid, cholera and dysentery are caused by bacteria and protozoa. Diseases caused by viruses include infectious hepatitis and polio.

[2] The Biological Activity Reaction Tests (BART) by Dryocon Bioconcepts inc. include the nutrient media as a sterile dried matrix on

the floor of the tubes (test vials). For the HACH pathoscreen test, the media is contained in small plastic tubes ("pillows") which must be cut and poured into the vial in the field. Only the BART tests do NOT require incubation.

Driscoll, F. (1986) Groundwater and Wells, St. Paul: Johnson Division

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Section 17

Handpump Maintenance

Since a new well is expensive and important to a communities well-being, the well and surroundings should be regularly inspected to ensure that:

- **The well is fully accessible to all users and is fenced off to prevent animal access.**
- **The sanitary well cap is securely in place and watertight.**
- **No openings have developed in the well casing.**
- **The cement pad is not cracked.**
- **The ground surface is sloped so that surface-water drainage is directed away from the well.**
- **Debris is not floating on the surface of the well water.**
- **The well yield is has not declined over time (see Appendix G-11).**
- **The pump is still working efficiently (cup leathers in the pump cylinder need to be changed every 6-24 months. To learn how to make your own cup leathers, see Appendix L.**
- **Ensure that the well is chlorinated (Section 15) *EACH TIME* the well is opened and the rising main pipe is removed! For details on inserting a cylinder back into a well, see Section 14.**
- **That all screws and connecting bolts on the pump are tight.**
- **That the wooden bearings and steel on steel contact points are lubricated and, if worn, replaced.**
- **That any broken or worn parts or supports are promptly re-fastened or replaced.**
- **The area around the well is being kept free of animal and human waste and garbage and that people are not doing dishes beside the well or mixing or using petrol (fuel), pesticides, or other pollutants near the well.**
- **Make sure that nearby unused wells are propertly abandoned are are not filled with garbage or organic matter.**
- **Test the well once a year for coliform, bacteria, nitrates and any other constituents of concern.**
- **Disinfect drinking water wells at least once per year with bleach or hypochlorite granules.**
- **Keep accurate records of all maintenance work & chlorination**

These ongoing monitoring activities must be performed by villagers and appropriate actions initiated to correct any detected potential problems before the pump breaks down or the water becomes contaminated. About 10 percent of the cost of the pump must be raised every year and local people trained to make/get and install spare parts to ensure a wells continued functioning (UN, 1981). **No project should be implemented if an organizational set-up of financial resources and committed people are not available for operating and maintaining the completed wells**.

> **Foot Valve: Positive displacement pumps have a foot valve on the bottom of the cylinder. The purpose of the valve is to hold the column of water in the rising main while the piston is being pushed down after each upstroke. If you have to pump very fast for a long time before water comes out of the spout, the foot valve is likely not working correctly.**

You can be fairly certain that there is problems with the foot valve if water comes out of the pump spout at a good rate when the pump handle is pumped very rapidly. The condition of the foot valve can be checked by pumping water from the well and then waiting 10-20 minutes. Then open the pump and check the position of the water column within the rising main. If it is high above the water level in the well and is near the pump spout, the foot valve is OK and the problem is more likely to be worn cup leathers (**See Appendix L**).

> **Open Top Cylinder: Foot valves are found in two basic cylinder configurations: "closed top" and "open-top" cylinders. Down-hole cylinders are usually larger diameter than the rising main and they contain the foot valve and the piston. When the piston needs servicing, the rising main must be removed along with the pump rod and the cylinder.**
>
> **Open top cylinders are the same diameter as the rising main. This makes cup leather replacement much easier and quicker and reduces the potential for accidents since the rising main (often called "drop pipe" after hard learned lessons!) and cylinder are left in-place when the piston and pump rod are pulled-out.**

Open top cylinders are, therefore, very beneficial in deeper wells where there are many lengths of rising main pipe. However, special tools are often needed to extract the foot valve and build-up of fine sand can jamb it in place over time. This can be a real problem because the lengths of rising main pipe are usually glue jointed rather than screwed together when working barrel cylinders are used.

Before you begin taking apart a pump that is not producing water, make sure that:

1. **You have ownership permission to work on the well. This is really important since it is possible that you could drop things in the well or break parts of the pump while working on it. You could also be held responsible for future maintenance or bacterial problems. Finally, you could be perceived to be trying to steal the pump or to claim credit for the borehole; issues of organizational integrity and reputation will last long after you have gone!**
2. **Make sure there is water in the well. Use an electric water level tape or a stone on a rope to confirm that there is enough water in the well for the pump to work. If there is no water, assume that the pump is fine and don't take the time, energy and risks associated with taking it apart.**
3. **You understand how the pump works and that you have needed tools and parts. This is important because you will raise people's hopes as soon as you start working on a broken pump.**

References

United Nations (1981) "Rural Water Supply", United Nations Department of Technical Cooperation for Development, Report of a United Nations Interregional Seminar, Uppsala, Swede, 6-17 October, 1980.

Groundwater On-Tap: Consumers Guide to Nation's Drinking Water.

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Section 18

Well Construction Report

A Water Well Record should be prepared for each well that is drilled (**see Appendix F**). The record is used to guide future drilling, to ensure that the well screen extends across the appropriate thickness of the aquifer and that the well casing/screen has been lowered to the bottom of the hole. It is also useful if there is ever a need to conduct repairs on the well in the future.

Well records document details of drilling a borehole and completing a well. Well records should include the driller's description of:

- **the geologic character of each formation;**
- **the depth at which changes were observed;**
- **the thickness of the various formations;**
- **the drilling speed;**
- **the depth to water or where water appears to have been reached;**
- **the depth at which drilling was stopped.**

Drillers should collect representative samples at measured depths and at intervals that will show the complete lithologic character of the borehole. Formation samples should be collected at 1.5 m (5 ft) intervals and at every change in formation materials. Collected samples will consist of muddied cuttings produced by the action of the drill bit.

Awareness of changes in drilling action is vital in compiling an accurate and informative log. Observations made by the driller should be included in the log because the drilling action and penetration rate indicate the character of the formation and especially the depth at which a formation change is encountered (Driscoll, 1986). Therefore, the person making the log must pay close attention changes in drilling fluid level, to the motion of the rig and to the noise made by the rig.

When drilling with the LS-100, the drilling action in clay or shale will be smooth. An occasional "chatter" (drill bit and pipe rapidly shaking/jumping a little) or temporary reduction in penetration rate may indicate scattered gravel in clay and glacial till or concretions in shale. Continuous chatter usually indicates sand and gravel formations or sandstone. Smooth drilling with rapid penetration occurs in layers of fine sand (Driscoll, 1986). Silt and clay is less than 0.08 mm dia, fine sand 0.08-0.43 mm, medium sand 0.43-2.0 mm, coarse sand 2.0-4.8 mm and fine gravel 4.8-19.0 mm (Unified soil classification system).

The value of a systematic record of the drilling time for each drill rod is sometimes overlooked. Each significant change in drilling speed indicates a difference in the material being drilled. The top, bottom, and thickness of each formation can be approximated from drilling speed (Driscoll, 1986); Factors other than formation character also affect the drilling rate. These include weight on the bit, sharpness of the bit, diameter of the hole, type of bit, velocity through the nozzles in the bit and speed of rotation (Driscoll, 1986).

For example, weight on the bit increases as the hole is deepened and additional drill pipe is added, thereby increasing the penetration rate. While interpretation of the time log is a relative matter, the gradual increase in weight on the bit does not seriously affect the usefulness of the results.

References

Driscoll, F. (1986) Groundwater and Wells, St. Paul: Johnson Division

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Appendix A

Handpump/Drilling Glossary

ADSORPTION - The process whereby small particles (e.g. clay) attract and hold ionic constituents.

AESTHETIC - Refers to those aspects of drinking water quality that are perceivable by the senses, namely taste, odour, colour and clarity.

ANCHOR BOLTS - Screws welded into a frame or plate or are grouted directly into the cement pad. They are used to attach the pump to the pad.

ANNULAR SPACE ("annulus") - the space between the well casing and the borehole wall.

ARTESIAN AQUIFER - See Confined Aquifer.

AQUIFER - A saturated geological unit (eg. sands, gravels, fractured rock) which can yield water to wells at a sufficient rate to support a well.

AQUITARD ("aquiclude") - Geological formations or strata that have the ability to store water but can only transmit water in very small quantities (eg. silt, siltstone).

ATTENUATION - The reduction that occurs in contaminant concentrations during transport through soil or rock.

BEARINGS ("fulcrum") - Pivot points used in all lever action handpumps to connect handles to the pump head.

BIODEGRADATION - The breakdown of putrescible (organic) material by biological processes.

BOREHOLE - A hole drilled, bored or dug into the ground into which a well casing is placed.

BOBBINS - Rubber stoper used as a one-way valve in some plunger assemblies and foot valves.

CENTRALIZERS - Devices used to ensure that the pump rod moves straight up and down within the rising main. Can also be installed to ensure the well casing is installed within the center of the borehole

CHEMICAL PRECIPITATION - Contaminant removal from solution through the chemical combining of anion and cations to form solids.

CAPTURE ZONE - The area of water table/piezometric surface drawdown created by pumping a well.

CONE OF DEPRESSION - Cone of depression (or "influence") is the draw-down of the water table or potentiometric surface that happens when a well is pumped. The drawdown cones of two wells close together may overlap so that if the wells are pumped simultaneously they will compete with each other for available groundwater (well interference).

COEFFICIENT OF TRANSMISSIVITY - see Transmissivity.

CONE OF INFLUENCE - The cone of influence is the depression in the water table or potentiometric surface that is produced when a well is pumped. The cones of influence of two wells close together may overlap so that if the wells are pumped simultaneously they will compete with each other for available groundwater (well interference).

CONFINED AQUIFER - A confined aquifer is a fully saturated aquifer whose upper and lower boundaries are impervious geologic units. Water is held under pressure and the water level in wells stands above the top of the aquifer. Completely impervious layers rarely exist in nature and hence truly confined aquifers are relatively rare.

CONSERVATIVE POLLUTANT - A pollutant that is relatively persistent and resistant to degradation, such as PCB and most chlorinated hydrocarbon insecticides.

CONTAMINATION - The introduction of materials which makes otherwise potable water unfit or less acceptable for use.

CUP LEATHERS - Seals used to create suction and pull water up the rising main when the plunger is moved up. Most pumps used curved "cup" leather seals, but some rely on leather or nitrile rubber rings.

CYLINDER - Down hole device used to push water up out of the ground. Key parts are: Cylinder, Plunger Assembly, Cage, Valve, Bobbin, Cup leathers, End Caps & Seals, Foot Valve

CYLINDER BARREL - The cylinder body or housing in which the plunger moves.

DEVELOPMENT - The act of pumping and surging water in a well to remove mud and dirt from within the filter pack, borehole wall and local aquifer. When done completely, pumped water will be free of suspended material. Wells must be developed after drilling to ensure that the cylinder is not prematurely worn-out by the abrasive action of suspended material moving between the plunger and cylinder walls.

DIFFUSION - The spreading of ions into a fluid or porous medium in a direction tending to equalize concentrations in all parts of the system; it is understood to occur in the absence of fluid convection and as a result of the thermal kinetic energy of the particles.

DILUTION - Usually refers to the mixing of contaminated water through mechanical dispersion and molecular diffusion (due to chemical gradients).

DIRECT ACTION - Type of handpump which has non-levered Tee-handles directly connected to the pump rod.

DISCHARGE AREA - The zone in which groundwater leaves the ground either as a spring or into a water body.

DISPERSION - The movement of dissolved solids in the water by chemical forces which results in lower dissolved-solid concentrations.

DRAWDOWN - Drawdown is a measure of the amount of lowering of the water level in a well when pumping is in progress.

DROP PIPE - slang term - see "Rising Main".

EFFECTIVE HYDRAULIC DIAMETER - The area in which water from the aquifer can move freely into a well. If a borehole is completed with a well casing plus surrounded by a filter pack material, the effective hydraulic diameter is equal to the diameter of the borehole.

EVAPOTRANSPIRATION - A combination of evaporation from open bodies of water, evaporation from soil surfaces, and transpiration from the soil by plants.

FILTER PACK - A filter pack is coarse sand or fine gravel (2-6 mm diameter) that is placed between the borehole wall and screen. Filter packs are used to settle-out fine grained particles that may otherwise enter the well.

FISHING - The act of trying to retreive a tool or pump part dropped down into a well. It also is the name for the tool used to extract foot valves from open top cylinders.

FLOWING WELL - A well in which the static water level is above ground level.

FOOT VALVE - Part of the cylinder that holds the column of water in the rising main while the plunger is being pushed down after each up-stroke.

FOUNTAIN - Term used in many French speaking countries to describe the above-ground pump assembly.

FRACTURE - A general term for any break in a rock attributable to tectonic forces, magma movement, thermal processes; glacial or erosional loading or unloading, and earth tides. (Exact causes of fractures are not always known.) They occur in all types of rocks. Incomplete fractures are cracks; a fault is a fracture zone along which movement occurs. Fractured-rock aquifers often have a fast, turbulent flow; are less isotropic and less homogeneous than porous media, and Darcy's law may not apply to them. Hydrogeologic investigations in fractured rock are usually either discrete studies (based on the careful measurement of each fracture) or continuum studies (which investigate the properties of large regions of the fractured material).

GNEISS - A hard, coarse-grained, foliated (banded), metamorphic rock (altered by great temperature and/or pressure) of quartz, feldspar and mica; often has low water yield.

GROUNDWATER - Water that occurs in the subsurface below the water table.

GROUNDWATER FLOW SYSTEM - The total system which describes the movement of water in the subsurface from the point where it enters the ground to where it leaves. Water moves in the direction of decreasing pressure that may be upward in some localities.

GROUNDWATER UNDER THE DIRECT INFLUENCE OF SURFACE WATER (GUDI) - Groundwater having incomplete/undependable natural subsurface filtration of infiltrating surface water. It may contain surficial contaminants like E.coli, giardia and cryptosporidium not found in secure groundwater supplies.

GROUNDWATER VULNERABILITY - The sensitivity of a groundwater system to human and/or natural water quality impacts.

GROUT - A sealing material of cement or bentonite (swelling clay) used to create a sanitary seal in the annular space above the filter pack to prevent surficial contaminants from entering the well.

HANDLE ("lever") - Lever that connects the pump rod to the pump head. Often includes some mechanism to add counterweights to balance the weight of the water being lifted up the rising main.

HANDPUMP - A water pump powered by the movement of people's arms or legs.

HYDRAULIC CONDUCTIVITY -The ability of subsurface materials (sand, rock etc.) to allow a fluid (ie water) to flow through it.

HYDRAULIC GRADIENT - The change in hydraulic head (pressure) per unit distance in a given direction (dimensionless). It is the driving force of fluid flow in a porous medium.

HYDROGEOLOGY - The subject dealing with the occurrence, characterization and movement of water below the earth's surface.

HYDROLOGICAL CYCLE - The continuous circulation of moisture and water on earth. The amount of water never changes but its state and position in the cycle does change.

IMPERMEABLE - Resistant to flow of or penetration by water or other liquids.

ION EXCHANGE - See adsorption.

KARST - A carbonate rock terrain where fractures have been enlarged by chemical solution or physical erosion.

LEACHATE - The liquid that results from the process of water, derived from precipitation, streams and/or groundwater leaching through sanitary landfills or dumps.

MAINTENANCE: Work proactively done to prevent unexpected pump breakdown.

MILLIGRAMS PER LITRE (mg/L) - A unit of measure expressing the concentration of a substance in a solution. Is equivalent to parts per million (ppm).

NON-CONSERVATIVE POLLUTANT - Quickly degrade and lack persistence, such as most organophosphate insecticides.

NON-POINT SOURCE - An area from which pollutants are exported in a manner not compatible with practical means of pollutant removal (e.g. crop lands.)

OBSERVATION WELL - A well drilled solely for the purpose of monitoring a potential or an existing source of contamination.

OPEN TOP CYLINDER - Cylinder has no constricted top cap. When installed with a large diameter rising main, the pump rod and plunger assembly can be pulled-out without removing the rising main. The foot valve is designed to be pulled up through the cylinder body rather than being removed through the bottom of the cylinder.

OUTLET - The term used to describe the spout assembly of some pumps.

OVERBURDEN - Unconsolidated (loose) soil overlying rock.

PERMEABILITY - The ability of an aquifer or water-bearing formation to allow water to pass through it. Permeability is also known as effective porosity because it is a function of interconnected saturated pore spaces.

PERMEABLE - Permitting the flow of water or other liquids.

PHREATIC ZONE - See saturated zone.

PIEZOMETER - A device for measuring pore water pressure (i.e. measuring the location of the water table). Some types of piezometers can also be used for collecting water samples. As a result, wells designed specifically for collecting water samples are often referred to, incorrectly, as piezometers.

PIEZOMETRIC SURFACE - The water level surface that can be defined from the mapping of water level elevations in wells tapping into a confined aquifer.

PISTON - Slang term - see "plunger".

PLUNGER ASSEMBLY ("piston")- The part of the cylinder that is connected to the pump rod and which forces water up the rising main.

POROSITY - The ratio of the volume of voids to the total volume of a rock or unconsolidated material. It is a measure of the amount of empty 'space' in a material. See permeability.

POSITIVE DISPLACEMENT - Downhole cylinders pushing (displacing) water up the rising main.

POTABLE WATER - Water fit for human consumption.

PUMP HEAD - Pump assembly attached to the stand. Contains the following parts: Surge chamber, Handle, Bearings, Outlet Assembly.

PUMP ROD ("plunger rod", "sucker rod", "connector rod") - Steel rod that connects the pump handle to the plunger assembly within the cylinder. It is usually threaded and coupled to allow it to be easily taken apart when extracting the plunder assembly to change the cup leathers.

PUMPING LEVEL - The level at which water stands in a well when pumping is in progress.

PUMPING LIFT - The maximum height of the water column that can be pushed up the rising main.

PUMP STAND ("pump base" or "pedestal") - A base that attaches the handpump to the ground and connects to the rising main.

RAW WATER - Surface or groundwater that is available as a source of drinking water but has not received any treatment.

RECHARGE AREA - The part of a flow system where precipitation percolates downward.

RINGS - Some pump cylinders rely on leather or nitrile rubber rings instead of cup leathers to create suction within the cylinder when the plunger is moved up.

RISING MAIN("drop pipe", "draw pipe", "pump column") - The pipe connecting the pump cylinder to the pump body. Water moves up this pipe and out the pump spout during pumping when the plunger is moved up and down within the cylinder.

SATURATED ZONE - The zone below and including the water table in which all pore spaces or fissures are totally filled with water. Also referred to as the phreatic zone.

SEMI-CONFINED AQUIFER - A semi-confined (leaky) aquifer is a completely saturated aquifer overlain by a semi-impervious layer and underlain by a impervious layer. Lowering of the potentiometric head in a leaky aquifer by pumping will generate a vertical flow of water from the semi-pervious layer into the pumped aquifer.

SORPTION - The attachment of dissolved ions to rock minerals, generally by electromagnetic bonding forces.

SPECIFIC CAPACITY - A measure of pumping rate per unit drawdown. If you know a wells specific capacity, you can estimate drawdown at different pumping rates. For example, the specific capacity of a well that delivers 20 gpm with 40 ft of drawdown would be 0.5 gpm/ft. At 30 gpm the drawdown would be 30/.5 = 60 ft.

STAND PIPE - A device that measures the height of the water table in an unconfined aquifer.

STATIC WATER LEVEL - Static water level is the level at which water stands in a well when the water level is at equilibrium with atmospheric pressures). It is a measure of the depth from the ground surface or from a known measuring point to the water level.

STORAGE COEFFICIENT - see storativity.

STORATIVITY - The volume of water released from storage per unit surface area of aquifer per unit decline in hydraulic head (dimensionless).

STRATA - Layers of deposited rock, soil etc which are distinguishable from each other.

STROKE - The maximum distance that the plunger moves when the handle is moved.

SUBMERGENCE - Vertical distance between pumping level and pump intake.

SUCKER ROD - Slang term - see "pump rod"

SUCTION - Pumps without down-hole cylinders rely on suction generated by above-ground cylinders to lift water up the rising main.

SURFACE WATER - Water bodies (lakes, wetlands, ponds - including dugouts), water courses (rivers, streams, drainage ditches), infiltration trenches and areas of temporary precipitation ponding.

SURGE CHAMBER ("water tank" or "delivery cup") - Connects the rising main to the outlet assembly. It usually has a larger diameter than the rising main. The water level in surge chambers rises and falls with each pump stroke, but the spout inlet stays submerged. This evens the flow of water between pump strokes.

TAIL PIPE - Extension pipe screwed into the bottom of a cylinder to increase submergence.

TRANSMISSIVITY - The rate at which groundwater can flow through an aquifer section of unit width under a unit hydraulic gradient. It is the average permeability of a section of the entire aquifer at a given location multiplied by the thickness of the formation.

UNCONFINED AQUIFER - An aquifer whose upper boundary is defined by the water table (water is at atmospheric pressure). Water usually saturates only part of the geologic unit and there is no upper confining layer. Also called a "water table aquifer".

UNSATURATED ZONE - The zone above the water table in which soil pores or fissures are less than totally saturated. It is also called the vadose zone or the zone or aeration.

VADOSE ZONE - See unsaturated zone.

VALVE - A device that allows water to move in only one direction. A valve at the bottom of each cylinder holds the column of water in the rising main while the plunger is being pushed down after each up-stroke. A one-way valve in the plunger allows water to flow through the plunger while it is being pushed down.

VENT HOLE ("weeping hole") - A small hole drilled in the rising main below the depthof frost penetration during winter. It is used to prevent frost burst in cold climates.

WATER - A compound of oxygen and hydrogen. Water is commonly found in liquif form, but below freezing (0 degrees C) it forms a solid and above 100 degrees C it forms a vapour (steam). In pure form it is colourless, odourless and tasteless, but usually contains disolved compounds that give drinking water sources their unique taste, appearance and odour.

WATER TABLE - The top of the zone in which all pore spaces or fissures are totally filled with water.

WATER TABLE AQUIFER - See Unconfined Aquifer.

WELL - A hole drilled or dug into the ground to extract liquid. Drinking water wells must be deep enough to reach far below the water table or they may have no water during the dry season when the large of recharge causes the water table to fall.

WELLHEAD PROTECTION - The pro-active management of land to assess and mitigate potential risks posed to well water quality.

WORKING BARREL - Slang term - see "open top cylinder".

YIELD - The amount of water that is produced when a pump is operated for a fixed number of full strokes.

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Appendix B

Useful Conversion Tables

- Length Conversions
- Area Conversions
- Volume Conversions
- Borehole, Well Casing & Annular Space Volumes
- Flow Rate Conversions
- Weight Conversions & Water Density
- Miscellaneous

Table 6: Length Conversions

	cm	m	in	ft
1 centimetre (cm) =	1	.01	.3937	.0328
1 metre (m) =	100	1	39.37	3.281
1 inch (in) =	2.54	.0254	1	.0833
1 foot (ft) =	30.48	.3048	12	1
1 mile = 5280 ft = 1760 yards = 1.609 km = 1609.3 m				

Table 7: Area Conversions

	cm^2	m^2	in^2	ft^2
1 square centimetre (cm^2) =	1	.0001	.155	.00108
1 square metre (m^2) =	10,000	1	1,550	10.76
1 square inch (in^2) =	6.452	.000645	1	.00694
1 square foot (ft^2) =	929	.0929	144	1
1 hectare = 2.471 acres = 10,000 m^2 = .01 Km^2 = .00386 $mile^2$				

Table 8: Volume Conversions

	cm^3	m^3	l	U.S.gal	ft^3
1 cm^3	1	.000001	.001	.000264	.000035
1 m^3	1,000,000	1	1000	264.17	35.314
1 Litre	1,000	.001	1	.2642	.0353
1 US Gallon	3,785.4	.003785	3.785	1	.1337
1 $foot^3$	28,317	.028317	28.317	7.481	1

1 US Gal = 4 qts = 8 pints = 16 cups = **128 fl oz** = .83269 Imp. Gal
1 Imp Gal = 4 qts = 20 cups = **160 fl oz** = 4.546 l = 1.2009 US Gal
1 cup = 8 fl oz (**1 US fl oz = 29.574 ml; 1 Imp. fl oz = 28.413 ml**)
1 cup (US) = 236.592 ml = 16 tablespoons (tbsp);
1 level tbsp = 0.5 US fl.oz = 14.79 ml = 240 drops

Table 9: Borehole, Well Casing & Annular Space Volumes

	6" Borehole	3" Schedule 40		4" Schedule 40	
	Volume	Casing	Annulus	Casing	Annulus
US Gallons/foot	1.5	0.41	0.97	0.65	0.64
Cubic Feet/foot	0.2	0.06	0.13	0.09	0.09
Litres/metre	18.2	5.08	12.0	8.11	7.98

Table 10: Flow Rate Conversions

	GPM	l/s	cfs	m^3/day
US gallons per minute (GPM) =	1	.0631	.00223	5.42
litres per second (l/s) =	15.85	1	.03531	86.4
cubic feet per second (cfs) =	448.8	28.32	1	2,447
cubic metres per day (m^3/day)	.183	.0116	.000409	1

Table 11: Weight Conversions and Water Density

	gm	kg	oz	lb
1 gram (gm) =	1	.001	.03527	.002205
1 kilogram (kg) =	1000	1	35.27	2.205
1 ounce (oz) =	28.35	.02835	1	.0625
1 pound (lb) =	453.6	.4536	16	1

1 ft^3 water weighs 62.4 lbs; 1 m^3 water = 2204.5 lbs; 1 litre water weighs 1 Kg; 1 cm^3 = 1 gram; 1 IMP Gal = 10 lbs; 1 US gal = 8.3 lbs = 133.5 oz = 3.78 Kg

Miscellaneous:
1 milligram/litre (mg/L) = 1 part/million (ppm)
1% = 10,000 ppm.
Degrees Fahrenheit = (9/5 * Degrees Celcius) + 32
Degrees Celsius = (Degrees Fahrenheit - 32) * 5/9

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Appendix C

Finding Underground Water

- **C-1: Hydrological cycle**
- **C-2: Groundwater**
- **C-3: Groundwater movement**
- **C-4: Tropical hydrogeology**
- **C-5: References**

People can not exist without good water. Drinking water is obtained from two main sources: surface water and **groundwater**. These sources are connected by the **hydrological cycle**.

C-1: Hydrological Cycle

The water (hydrological) cycle is the continuous circulation of water between land, air and ocean **(see Figure 18)**. The cycle has no beginning or end. Radiation from the sun evaporates water from rivers, lakes and oceans. The water vapour rises, collects to form clouds and then falls back to earth as precipitation (rain, hail, sleet or snow).

When precipitation falls on land, some of the water runs off into the lakes and rivers, some is evaporated back into the atmosphere, some is adsorbed by plant roots and re-enters the atmosphere by a process known as transpiration **(evapotranspiration)**, and some of the water infiltrates into the soil. This **recharge** water is known as **groundwater**. Groundwater moves slowly through the subsurface into rivers and oceans where it is evaporated to complete the hydrological cycle. Groundwater makes up 97% of the world's freshwater available for human use, is found almost everywhere and it is of relatively good quality in most areas **(see Table 12)**.

C-2: Groundwater

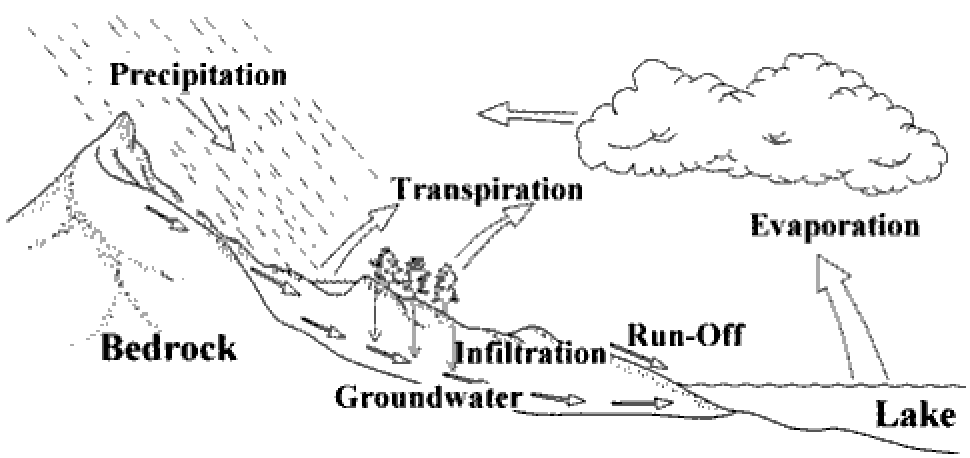
Water infiltrates downward until it reaches a depth where water fills all of the openings in soil and cracks in rock. This is called the **saturated zone**. The top of the saturated zone is called the **water table** **(see Figure 18)**. The depth to the water table depends on the nature of the geological materials and the slope of the land surface. During rainy seasons the water table rises; during the dry season it falls.

Water occurs in all geologic materials; if enough openings are interconnected, water can move in appreciable quantities and the deposit is called an **aquifer**. Aquifers may be found in the bedrock and in the **overburden** overlying the bedrock.

Bedrock aquifers derive their **permeability** from joints, bedding planes, fractures and solution channels. The yield of bedrock aquifers is highly variable, depending on the width and interconnectedness of fractures. While water can usually be found within rocks, it is hard to predict the depth of yield of this water. Many Lifewater wells have been sucessfully drilled in limestone or andstone.

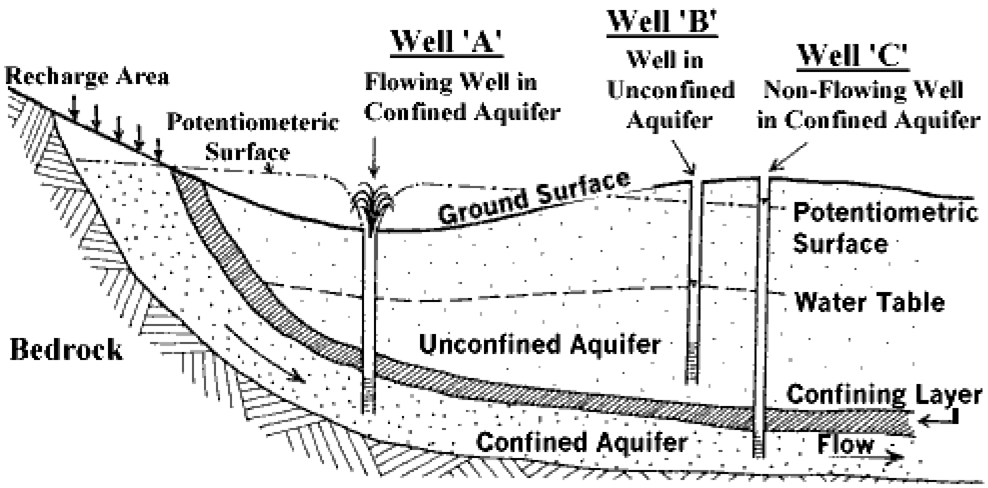
Overburden aquifers are deposits of sand or gravel which are of sufficient extent and permeability to store and transmit water and are readily recharged by percolating water from the surface **(see Figure 19)**. Saturated sand and gravel yields lots of water; fine sand or silt formations yield water more slowly. When the upper limit of an aquifer is the top of the saturated zone (water table), the aquifer is called a water-table or **unconfined aquifer** **(see Figure 19)**. **Even where surficial soils are low yielding clays (aquitards), good water bearing aquifers are often found at the overburden/ bedrock interface.**

Figure 18: The Hydrologic Cycle



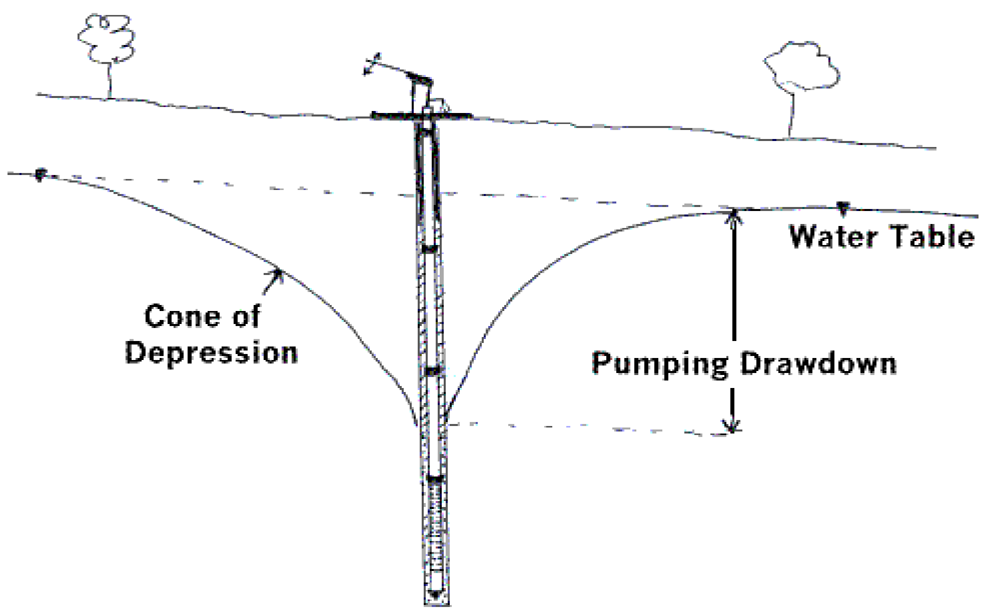
An aquifer that is overlain by material through which water cannot easily pass (aquiclude) is called an **unconfined aquifer** **(see Figure 19)**. Water in confined aquifers is under pressure caused by the weight of the confining materials, the elevation differences in the aquifer, and the restriction in movement of water in the aquifer. When a well is drilled into a confined aquifer, water rises in the well to a point somewhere above the top of the aquifer **(piezometric surface)**. Sometimes the pressure is so high that water rises to ground surface and wells overflow.

Figure 19: Unconfined and Confined Aquifers



When a well is pumped, the water table is lowered forming a **cone of depression (see Figure 20)**. The shape of the cone is determined by the pumping rate of the well and the permeability of the rocks surrounding the well.

Figure 20: Cone of Depression



As water is withdrawn, the aquifer must eventually be replenished to keep producing. Water table aquifers are usually recharged from local sources of precipitation. **Confined aquifers**, however, frequently receive recharge many miles from the well.

The **residence time** of groundwater (the amount of time water spends underground), varies from a few days to thousands of years.

Groundwater moves at a very slow rate, usually much less than 1 metre per day **(see Table 12)**.

Table 12: Surface Water vs. Groundwater Characteristics

	Surface Water	Groundwater
Understanding	Easily seen & observed	Invisible, mysterious, complex.
Where Found	Streams, rivers, lakes etc.	Everywhere beneath the surface in layers of sand, gravel, clay or cracked rock. Rarely forms underground "streams" or "lakes"
Availability	The amount of water stored underground is more than 85 times the amount found in streams, rivers and lakes!	
Uses	**Drinking water**, food (fish, trapping, rice etc), transportation, bird/animal habitat, power, aesthetics and spiritual health.	Drinking water, energy, maintaining flow in surface water courses.
Flow Direction	Downhill	Usually from high to low elevations.
Flow Rate	Fast (metres/second)	Slow (metres per year)
Quantity (yield)	Easy to assess. Supply problems rare.	Drilling and pumping. Lots of water in sand and gravel or heavily fractured rock. Low yields in silt and clay or unfractured rock.
Quality	Low dissolved (soft, low iron) High organics Temperature changes Mud, clay, algae	High dissolved (hard, high iron) Low organics Constant, cool temp No suspended solids
Consistency	Changes with seasons	Constant over time
Safety	Variable bacteria/virus counts	Safe because of filtration and natural purification processes
Treatment	Continuous chlorination	Initial chlorination
Cost	High	Low
Contamination Risk	Easily contaminated	Not easily contaminated.
Contamination Remediation	Natural breakdown by sun, air, mixing etc.	Clean-up difficult or impossible; May take many decades.

The earth filters and purifies water moving through it. Since groundwater is protected by earth, it is far less vulnerable to contamination than the water in rivers and lakes **(see Table 12)**.

As water moves through the ground, it dissolves minerals from soil and rock. In general, groundwater from deep sand or rock layers contains more minerals than water from shallow deposits. Because the water has travelled a greater distance underground, it has had more time to slowly dissolve minerals. Sometimes leached iron gives groundwater a strong red colour and bitter "mineral" taste **(see Table 12)**. Although this may be unpleasant, the water is **potable** (safe to drink). Sometimes, however, safe water supplies are not used because the water is "cold" or has "no taste" or a "bad taste" (UN, 1981).

C-3: Groundwater Movement

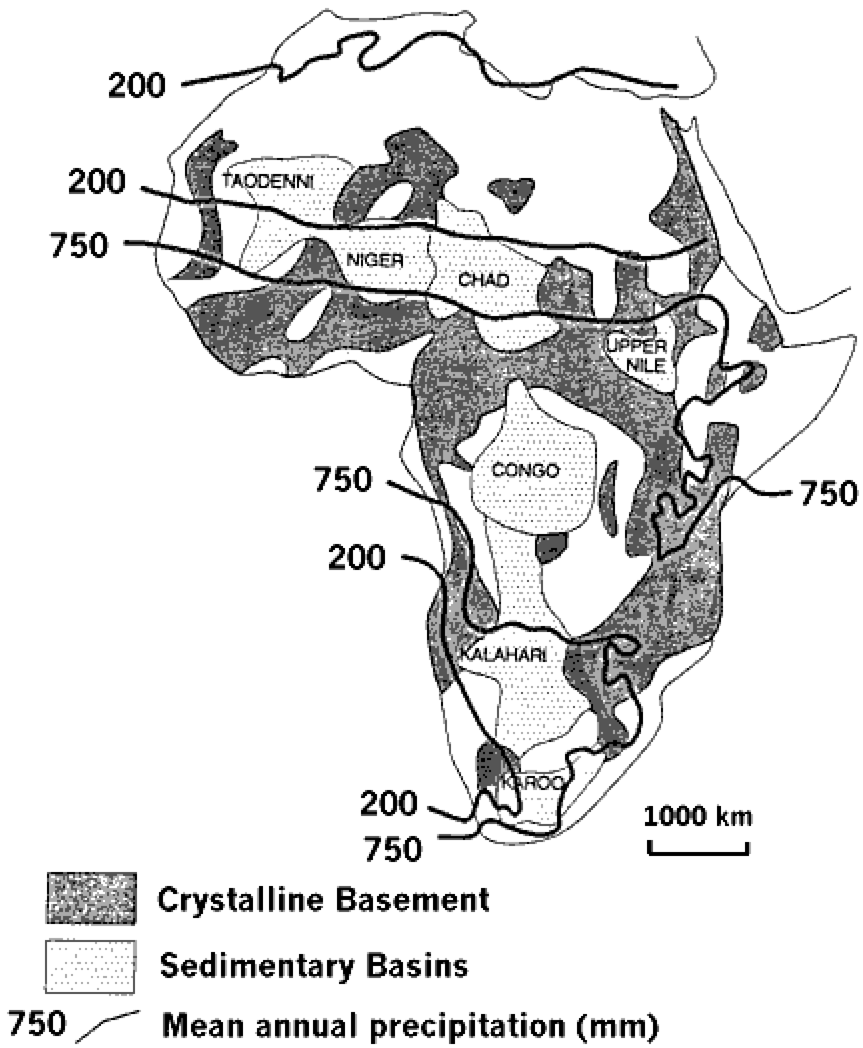
There are two fundamental components to groundwater movement:

1. water flows downhill **(hydraulic gradient)**: Water always moves downward due to the potential energy from gravity. Just like a stream can not flow up a hill, groundwater only flows from areas of high groundwater levels to areas of low groundwater levels.
2. Water flows through open spaces **(hydraulic conductivity)**: groundwater can only move through interconnected spaces. Water has the potential to move rapidly through subsurface materials which has many open, interconnected spaces (ie., coarse sand, fissured sandstone). Conversely, clay and bedrock generally have poor water transmitting characteristics.

C-4: Tropical Hydrogeology

As shown on **Figure 21**, the bedrock over much of Africa are Precambrian formations which are dominated by relatively impermeable crystalline rocks such as granites, schists, quartzites, and **gneisses** (Houston, 1995). In these rocks, it is often necessary to drill 60-80 metres deep, wells often yield less than 2 m^3/day and it is often necessary to pump from considerable depths (Dijon, 1981). Groundwater which does move through these rocks is concentrated in geological structures such as faults, shear zones and joint systems.

Figure 21: Generalized distribution of Rocks in Africa



Sedimentary rocks (sandstone) are usually more **permeable** than crystalline (igneous or metamorphic) rocks. As shown on **Figure 21**, there are large sedimentary basins in central Africa. Local sedimentary deposits may exist along major rivers, lakes and ocean coasts.

In tropical environments, rock breaks down quickly, producing a zone of weathered material called saprolite or laterite. Surface soils are often underlain by a red-brown silty clay which does not function as a good aquifer (Selby, 1985). This material often grades into a silty sand containing some rounded fragments of unweathered rock (corestones). These deposits can yield significant quantities of water if coarser-grained materials are present. Corestones become larger and less rounded with depth until unweathered bedrock is encountered.

In humid tropical regions, complex saprolite profiles develop (Selby, 1985):

- a 0 to 2 m thick **SOIL ZONE** containing hard, dark red nodules in a sandy soil;
- a 1 to 10 m thick **CRUST** of reddish or brown blocks formed of cemented, hardened iron-rich nodules with tube-like cavities filled with red or ochre clay. Most minerals, except iron and aluminum oxides, have been leached from the crust;
- a 1 to 10 m thick **MOTTLED ZONE** of white kaolinitic clay with patches (mottles) of yellowish oxides. This zone is strongly leached and weathered;
- a 5 to 30 m thick **PALLID ZONE** of bleached kaolinitic clay;
- a **WEATHERED ZONE** up to 60 m thick which consists of deeply weathered rock still containing original rock structures;
- **UNWEATHERED BEDROCK.** Since the bedrock surface is generally far beneath the surface, few wells in tropical regions are drilled into pristine, unweathered bedrock.

As shown in Figure 22, groundwater is often found near the active weathering front, where permeabilities are higher than in the overlying, clay-rich soils and underlying unweathered bedrock. The underlying rock acts as an aquiclude, trapping groundwater in the immediately overlying weathering front (Key, 1992). As a result, *the goal of many well drilling programs in humid tropical regions is to drill wells into the upper 1 - 3 m (5 - 10 ft) of weathered rock.* Figure 23 shows areas in Africa where these weathered zone aquifers can be found.

Typically, yields are highest where the weathering front is located over highly fractured bedrock in fault zones or adjacent to dikes which intrude along fracture zones; these are also the areas of deepest weathering. Astier and Paterson (1987) found that well yields were inversely related to distance from interpreted faults or dikes for a distance of 3 km (1.86 mi); i.e., closer to structure = higher yield).

Weathering process result in the development of permeable sandy soils between valleys, fine sands with clay on valley sides and poorly drained clay soils in the valley bottoms (Farquharson and Bullock, 1992). Rainfall tends to pass quickly into the upper sandy soils but reaches layers of reduced permeability at relatively shallow depths (often at the top of the weathered saprolite layer). Thus, while runoff is initially down into the soil, lower permeability at shallow depths produces lateral throughflow downslope towards the valley bottom (Farquharson and Bullock, 1992).

Figure 22: Weathered Zone Well Yield with Depth

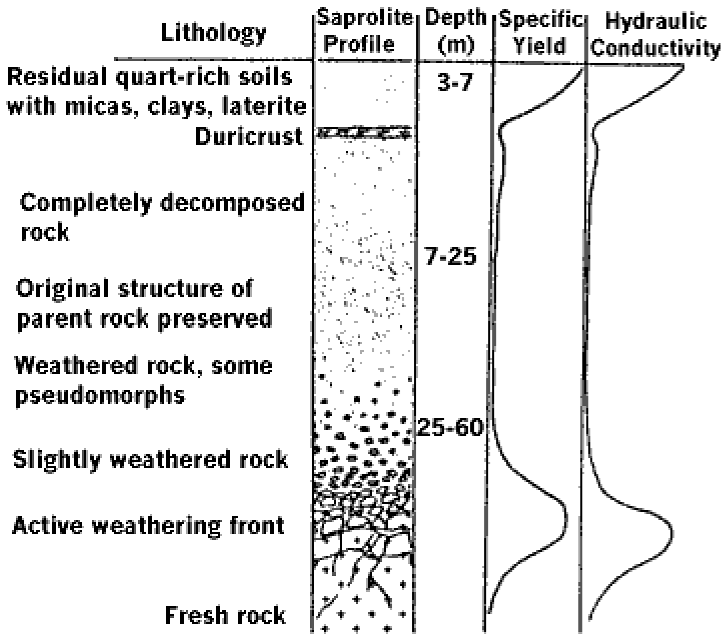
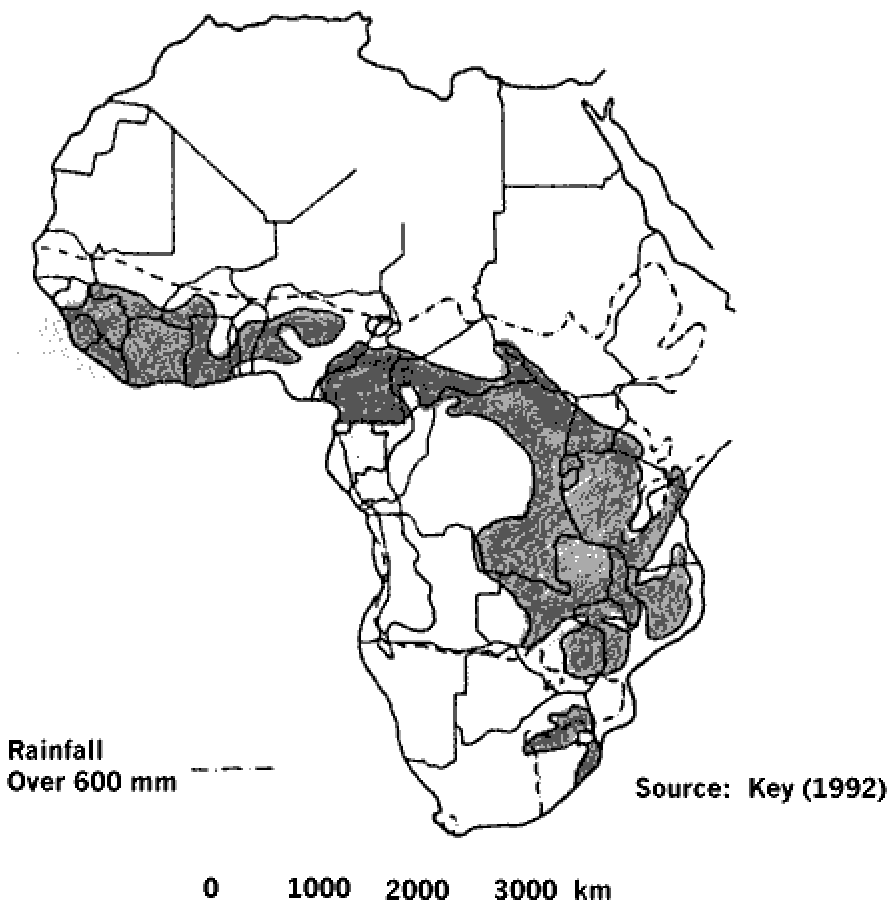


Figure 23: Location of Weathered Zone Aquifers in Africa



C-5: References

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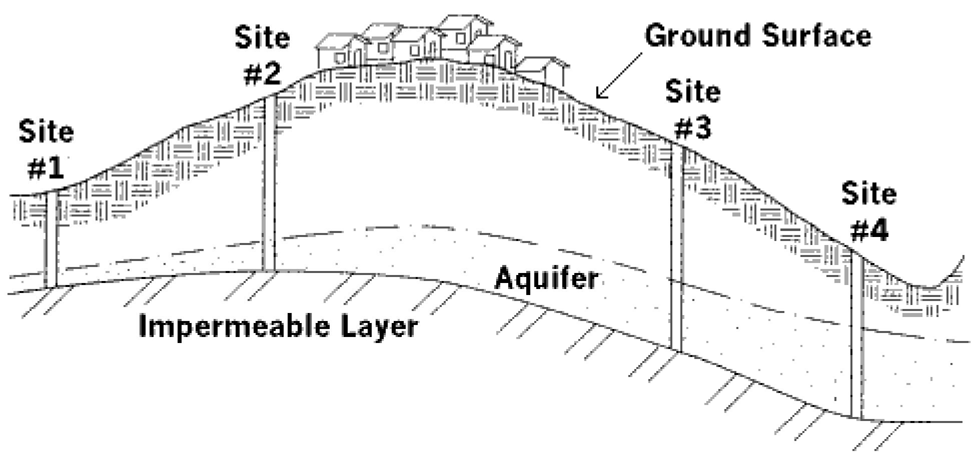
Appendix D

Well Siting Exercise

When deciding where to drill, often multiple sites are identified, each having advantages and disadvantages. The Action Agency, the Village Water Committee, the drillers, government representatives and hydrogeological consultants must together decide which site is best for the community.

Figure 24 is a simplified example of 4 alternative sites from which one must be selected. Discuss the pros and cons of each option and make a selection.

Figure 24: Alternative Well Sites



Site #1: This site should allow easy access to groundwater because the water table lies close to the surface of the ground. However, limited water would be available because the layer of impermeable rock also lies near the ground surface. Thus, slight fluctuations in the water table would drastically affect the availability of water.

Site #2: This site is closest to the village and, therefore, has the greatest accessibility. However, the water table is quite deep and may be difficult to reach. The aquifer cannot be penetrated too deeply, because of the position of the impermeable layer.

Site #3: The aquifer can be reached here without digging very far down. The aquifer can also be deeply penetrated, thus ensuring a reliable water source. However, the site is some distance from the village and below the homes.

Site #4: The most water can be reached with the least difficulty. The site is at the greatest distance from the village. It is in a low spot that may be subject to flooding.

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Appendix E

Well Shock Chlorination Exercise

A Lifewater well was just drilled to a depth of 30 meters feet. The pumping rod and riser pipe have been installed and, prior to sealing the well, it should be disinfected. The water level in the well is 8 meters feet below surface. What are the steps that should be taken to disinfect this well? How much sodium hypochlorite should be added? How much calcium hypochlorite?

1. Determine the volume of water in the well
   - Area of a circle = Pi r^2.
     Pi = 3.14
     r = radius = 5.08 cm (casing diameter = 4 inches) = .05 m
     Area = 3.14 x 0.05m x 0.05m = 0.00785 m^2
   - Height of water column = Well depth - depth to water
     well depth = 30 m
     depth to water = 8 m
     height of water column = 22 m
   - Volume = Area x Height
     Area = 0.00785 m^2
     Height = 22 m
     Volume = 0.00785 m^2 x 22 m = 0.173 m^3
     = 0.173 m^3 x 1000 L/m^3 = 173 L
2. Determine the amount of sodium hypochlorite to add to the well
3. Assume sodium hypochlorite is not available and calculate the amount of calcium hypochlorite which should be added to the well.

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Appendix F

Lifewater Canada Well Record

Well Location

Country:
Province/State:
Easting:
Northing:
Site Description:

Location Sketch

N
^

Scale:

Distance to nearest pollution sources (ft) - describe:

Depth (m)	**Soil Type** (Describe)	**Thickness** (m)	**Drilling Notes** (Drilling Speed, bit vibration, water temperature etc)

Depth at which water encountered:

Depth to Water Table:

Depth of Borehole:

Borehole Yield

Yield: Duration of Test (minutes):

Describe how yield measured:

Well Screen & Casing

Material (PVC, Other):	Casing/screen diameter:
Thickness (Schedule 40 or 80):	Length of screen sump:
Number of slot columns:	Vertical spacing between slots:
Length of slots:	Screen Length:
Installed length of casing:	Total length of screen/casing:

Describe screen centralizers (number, where/how attached):

Describe drive shoe (shape, material, size etc):

Well Completion

Gravel pack material diameter (inches):	Gravel pack volume:
Type of stabilizer material:	Stabilizer material volume:
Grout mix (sand:cement ratio):	Grout volume:
Pad concrete mix (sand:gravel:cement):	Thickness of cement pad:
Size of cement pad:	Well protected by fencing (Y/N):
Distance from ground to pump cylinder:	Cylinder diameter:

Well Development

Technique Used:	Development Time (hours):

Describe process (turbidity in discharge water over time and depth):

Chlorination

Type of chlorine used:	Volume of chlorine used:
Length of disinfection period:	Chlorine odour in discharge water (Y/N):

Describe how chlorine was mixed with well water:

Water Quality

Colour:	Turbidity:
Odour:	Taste:
Bacteria test type:	Bacteria Test Results:

Other tests or characteristics (pH, Total Dissolved Solids, nitrate, staining etc):

Completed Well Performance

Piston clearing cylinder top&bottom (Y/N):	Waste water drainage:
Sustainable pumping rate (Gal/min):	Pump stable:

Other (cylinder secured with safety rope? etc):

Date Drilling Started:

Date Work Completed:

Number of Workers:

Construction Foreman's Name (Print):

Foreman's Signature:

Action Agency/Lifewater Inspector Confirmation

Name (Print):

Signature:

Inspection Date:

Well Record Copies:
1) Lifewater Canada
2) Local Drill Team
3) Local Government

PHOTOGRAPHS: (Well Overview Required. Pump close-up, Surroundings, People Desirable)

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Appendix G

Solutions to Well Drilling Problems

Plan for the best and be ready to take corrective actions when your plans go wrong! This section of the tutorial is designed to help you solve the problems you will encounter when you drill wells. Don't be discouraged.... use your common sense and learn what you can from the situation you are in! Common problems include:

G-1: Excessive Fluid Loss
G-2: Borehole Caving
G-3: Drill Bit Jamming
G-4: Drilling Fluid Backflow
G-5: Objects Dropped Into Well
G-6: Resistant Beds Encountered
G-7: Contaminated Soil/Water-Bearing Zones
G-8: Flowing Wells
G-9: Marginal Aquifer Encountered
G-10: Casing Jams During Installation
G-11: Well Stops Producing Water
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G-1: Excessive Fluid Loss

Large amounts of make-up water is usually required and must be immediately available at all times when drilling in permeable sand and gravel. This is important because drilling fluid sometimes suddenly flows into permeable formations which are being drilled rather than circulating back up the borehole.

If return circulation is suddenly lost, immediately switch the 3-way valve to direct the drilling fluid back to the pit through the by-pass hose (this minimizes the loss of valuable water). Then quickly pull-up the drill pipe 1-2 metres from the bottom of the borehole so that it is less likely to become jammed if the bottom portion of the hole collapses.

If drilling has been proceeding with a thick bentonite mud, the best possible action is then "to wait" (Australian, 1992). A waiting period may allow the fluid to gel in the formation and provide a seal sufficient to allow circulation to be restored. If drilling has been proceeding with water or natural mud, replace the fluid with a thick bentonite slurry, circulate it down the borehole and let it sit for a while. When ready to circulate back down the hole, hit the drill pipe rapidly with a hammer to jar loose the mud and open the pipe.

If waiting and thickening the drilling mud do not restore circulation, question why the circulation was lost. If the drilling fluid is being lost into a highly permeable saturation formation, it may be possible to construct an excellent well! Therefore, test the well yield before deciding to proceed with the steps outlined below.

If it is necessary to drill further, try adding thickening materials to the drilling mud. This may occur when extremely unstable formations or those containing open fractures are encountered. Almost any granular flake or fibrous material can be used to provide a wad to block a lost circulation zone. Local materials such as bran, husks, chaff, straw, bark, wood chips, cotton, feathers, or even fibre or wool bedding can usually be located readily and used (Australian, 1992). This material should be pushed down the hole and allowed to block the fractures.

The "gunk squeeze" method of sealing off a zone of lost circulation involves forcing a large amount of clay or cement into the zone of water loss (usually at or near the drill bit) and forcing it into the formation where it swells and fills-up any cracks (Australian, 1992). The best way is to mix a very high concentration (6 - 7 kg/L) of bentonite. Once mixed, immediately lower it into the borehole in a sealed bag or container which can be ruptured when opposite the lost circulation zone. This material can be forced into the formation by pressurizing the borehole or by pushing it with a block on the end of the drill string.

If the lost circulation zone cannot be blocked, drilling sometimes may proceed without return circulation. The cuttings are carried away into the formation cavities. It may be necessary to occasionally pump a slug of thick mud to clear the bottom of the hole (Australian, 1992).

Alternatively, casing can be placed to seal-off the problem zone. Ensure that the hole has fully penetrated the problem zone which is to be protected by the casing; Running the casing too soon may not overcome the problems for long. Finally, if none of these options work, it may be necessary to abandon the hole or to continue drilling using a air rotary drilling machine (Australian, 1992).

G-2: Borehole Caving

The main cause of borehole caving is lack of suitable drilling mud (see Section 5). This often occurs in sandy soils where drillers are not using good bentonite or polymer. The problem can be seen when fluid is circulating but cuttings are not being carried-out of the hole. If you continue to push ahead and drill, the bit can become jammed, the hole will collapse when you try to insert the casing or a huge portion of the aquifer may wash-out making it very difficult to complete a good well. The solution is to get some bentonite or polymer or, if necessary, assess the suitability of natural clays for use as drill mud (see Appendix H).

Borehole caving can also occur if the fluid level in the borehole drops significantly (see Footnote #1). Therefore, following a loss of circulation or a night time stoppage, slowly re-fill the borehole by circulating drilling fluid through the drill pipe (pouring fluid directly into the borehole may trigger caving). If caving occurs while drilling, check if cuttings are still exiting the well. If they are, stop drilling and circulate drilling fluid for a while.

Sometimes part of the borehole caves while the casing is being installed, preventing it from being inserted to the full depth of the borehole. When this occurs, the casing must be pulled out and the well re-drilled with heavier drilling fluid. When pulling the casing, no more than 12.19 m (40 ft) should be lifted into the air at any time; more than this will cause thin-walled (Schedule 40) PVC to bend and crack.

G-3: Drill Bit Jamming

The drill pipe and bit may become jammed when the drilling fluid is not allowed to thoroughly clean the borehole prior to stopping to add another joint of drilling pipe or the fluid is too thin to lift gravel from the bottom of the borehole. Therefore, if the drill bit starts to catch when drilling, stop further drilling and allow the drilling fluid to circulate and remove accumulated cuttings from the borehole. Then continue to drill at a slower rate. If it continues to catch, thicken the drilling fluid.

If the drill bit and pipe become jammed, stop drilling and circulate drilling fluid until it is freed. If circulation is blocked, try to winch the bit and pipe out of the borehole. Stop the engine and use a pipe wrench to reverse rotation (no more than 1 turn or the rod may unscrew!). Rapidly hit the drill pipe with a hammer to try and jolt the bit free.

If these actions are not successful, use lengths of drill pipe without a bit attached or Wattera tubing to "jet out" the cuttings. Attach the pipe or tubing directly to the discharge hose from the mud pump. Thicken the drilling fluid to ensure that the cuttings holding the bit can be removed. Then place tension of the stuck pipe with the drill rig winch. Once fluid starts to circulate out of the borehole, slowly push the jetting pipe/tubing down the borehole beside the jammed drill pipe until the bit is reached. When fluid starts to circulate out of the stuck pipe and/or it loosens, pull the stuck drill pipe and resume circulation of the thickened drilling fluid back down the drill pipe and bit. Remove the jetting pipe. If water freely circulates out the borehole, slowly lower the drill pipe and bit and resume drilling.

G-4: Drilling Fluid Backflow
Sometimes drilling fluid comes up through the drill pipe when you disconnect the swivel. This is caused by falling soil particles pressurizing drilling fluids at the bottom of the hole. Immediate action is required because this occurs when either the borehole is caving-in or when drill cuttings have not been cleaned well enough from the borehole. If you notice backflow of drilling fluid, immediately re-connect the drill pipe and continue circulation to clean-out the cuttings. If caving is suspected, thicken the drill mud while continuing circulation.

G-5: Objects Dropped Into Well

Unfortunately, sometimes wrenches, rocks etc are inadvertently dropped into the borehole when drilling. In addition, the LS-100 is often operated near its design limits with a high degree of structural stress on the drilling stems and tools; encountering unexpected layers of very soft sand or filter or hard rock can cause cave-ins or tool breakage and all the drill pipe can be lost in the hole.

If objects are dropped into the borehole after the final depth has been reached, it may be possible to leave them there and still complete the well. If this is not the case, it may be possible to make a "fishing" tool to set-up on the lost gear. For example, if a length of well screen falls down the borehole, it may be possible to send other sections down with a pointed tip on the end and "catch" the lost casing by cramming the pointed end hard into it. These types of "fishing" exercises require innovation and resourcefulness suitable to the circumstances - there is no single right way of doing this work. If sediment has caved in on top of the drill bit or other tools, circulation should be resumed in the hole and the fishing tool placed over the lost equipment.

If the lost tools/bit(s)/drill pipe are not critical, do not even try to retrieve them and just move over and start drilling a new hole. Even if the equipment is important, it is still best to start drilling at a new location while others try to retrieve it since considerable time can be spent on retrieval and there is a low likelihood of success.

G-6: Resistant Beds Encountered
Once a resistant bed is encountered and the rate at which the drill bit is penetrating the formation drops dramatically, a decision needs to be made whether to stop drilling or to continue. If the resistant bed is comprised of gravels, the drilling fluid may need to be thickened to lift-out the cuttings. If the resistant bed is hard granite, drilling with the LS-100 should cease. Other drilling methods should be found or drilling should be attempted at another location. ***Remember, to help as many people as possible and to get the best value for donor dollars, DRILL THE EASY BOREHOLES FIRST!!*** **It is not worth wearing-out the equipment by grinding away for hours and hours to gain a foot or two of borehole depth.**

G-7: Contaminated Soil/Water-Bearing Zones

It is sometimes necessary to drill through aquifers which contain contaminated water. In these situations, drill until a confining layer (clay or rock) is encountered. Insert the casing and then seal the annular space with a grout slurry. To avoid damaging the grout seal, let the grout cure for at least 12-24 hours prior to resuming drilling (Driscoll, 1986).

Grout is prepared by mixing 19.7 L (5.2 gal) of water with every 42.6 kg (94 lb) sack of cement (Driscoll, 1986); 5 volumes grout slurry can be made by mixing 4 volumes cement powder with 3 volumes fresh water (Australian, 1992). Alternatively, each sack of cement can be added to a clay-water suspension formed by mixing 1.36 - 2.27 kg (3-5 lbs) of bentonite with 25 L (6.5 gal) of water (Driscoll, 1986). This mixture helps hold cement particles in suspension, reduces cement shrinkage, improves the fluidity of the mixture and prevents excessive penetration of grout into these formations.

Cement grout is normally placed by just pouring it into the annulus. Alternatively, some grout could also be poured into the casing and/or the casing could be raised several feet and then pushed into the grout that accumulates at the bottom of the borehole. Place the grout in one continuous operation to form a good seal (Driscoll, 1986). Since irregularities in the size of the borehole and losses into formation may occur, the driller must be prepared to augment initial estimates of grout volume on short notice.

Where contamination is severe, follow special procedures to ensure that a very good seal around the casing is achieved (see **Appendix I**). When you finish grouting, ensure that you leave about 0.5 metres of grout in the casing (see Footnote #2).

G-8: Flowing Wells

Sometimes the water in a confined aquifer is under so much pressure that it will flow out the top of a well which is drilled into it. Special precautions and construction techniques must be used to control the water pressure and flow or serious environmental problems can result. The free flow of excess water to waste can result in the depletion of a valuable resource and in unnecessary interference with other well supplies. Free flow from the well casing or a breakout of uncontrolled flow around the well casing can cause serious erosional and flooding problems on the owner's and adjacent properties that may be very difficult and costly to correct.

Sometimes natural flow can be brought under control by extending the well casing 1.5 - 6 m (5 - 20 ft) into the air. This can allow the pressure in the pipe to balance that within the aquifer. A spout with a tap can then be installed in the side of the casing. A hand pump can be installed at a later date if the pressure in the pipe drops over time.

G-9: Marginal Aquifer Encountered

Sometimes a very thin or relatively impermeable aquifer is encountered which must be developed to provide a reliable water supply. Ensure that the borehole penetrates the full thickness of the aquifer, extending as far below it as possible. Install the well screen adjacent to the entire aquifer thickness with solid casing installed above and below it. After developing the well, install the pump cylinder as low as possible in the well.

If a well is being completed in a fine sand/silt aquifer within 15-22 m (50 - 75 ft) of ground surface, a 20 cm (8 in) reamer bit has sometimes been used (e.g. Bolivia). This makes it possible to install a better filter pack and reduces entrance velocities and passage of fine silt, clay and sand particles into the well.

Yield can be maximized by adding a small amount of a polyphosphate to the well after it has been developed using conventional techniques. The polyphosphate helps remove clays that occur naturally in the aquifer and that were introduced in the drilling fluid (see Footnote #3).

Enough time must be allowed between introduction of the polyphosphate and development, usually overnight, so the clay masses become completely desegregated (Driscoll, 1986). After the polyphosphate solution is surged into the screen (see Footnote #4), water should be added to the well to drive the solution farther into the formation.

G-10: Casing Jamming During Installation

Sometimes it is not possible to lower the casing and well screen to the bottom of the hole. This can be due to part of the borehole collapsing, clays in the aquifer swelling and reducing the size of the borehole or the borehole being crooked resulting in the casing digging into the wall of the borehole. These problems are most common where 10 cm (4 in) schedule 40 casing is being inserted into a 15 cm (6 in) borehole. This is because the outside diameter of the casing couplers is 13 cm (5.25 in), leaving an annular space of just over a quarter inch on each side of the casing! It does not take much swelling of clays or slight deviation from vertical to result in the casing jamming.

If the casing does not slide freely into the borehole, it is not advisable to try and force the casing down. Striking it hard in an attempt to drive it may cause the screen to deform; rotating and pushing it down can cause the screen openings to become hopelessly plugged with fine materials.

To avoid these problems, minimize the amount of pull-down pressure when drilling so that the bit can run freely under its own weight. Also, casing there is no problem with casing jambing when 7.6 cm (3 in) schedule 40 casing is used. Keep in mind, however, that a 7.6 cm (3 in) casing is too small to take a 6.4 cm (2.5 in) pump cylinder or most submersible pumps. Usually, however, these issues are not a concern.

If you need to construct a 10 cm (4 in) well and the casing has jammed, the best solution is to pull the casing / screen from the borehole. This involves cutting the casing into 6-12 m (20 - 40 ft) lengths (longer than this will result in the casing bending and cracking). Slowly re-drill the borehole with a 15 cm (6 in) reamer bit or, if available, a 18 or 20 cm (7 or 8 in) bit. Concentrate on the portion of the borehole where the casing jammed. While this can take several hours, it often eliminates blockages and allows the casing to slide to the bottom of the borehole. As soon as the reaming is completed, re-glue and re-insert the casing.

If it still jams, your last resort is to try and "wash" the casing down by installing the drilling rods down inside the casing and circulating drilling fluid through a wash-down valve (see **Section 7**). Fluid is pumped down through the casing and out the bottom of the screen where it will pick-up and carry soil particles back up to the surface between the casing and the hole walls. The amount of water passing through the screen openings can be minimized by attaching a surge block to the lower end of the drill string. Be sure to secure the pipe with a rope to prevent the casing from dropping if the blockage was localized and is removed with the circulation process. Failure to do so could result in the casing dropping to the bottom of the hole without the casing extending to the surface. When the casing is finally installed to the appropriate depth, stabilize the open bottom end of the casing by pouring in 30-60 cm of coarse gravel into the well. If the casing still jams above the water bearing formation, the only other option is to obtain and install 7.6 cm (3 in) casing and well screen.

G-11: Well Stops Producing Water:

A well can suddenly no longer provide the same amount of water that it did before. If you move the pump handle and it feels OK but little or no water comes out the spout, the well may be dry. Confirm this by measuring the water level in the well and try to determine which of the following causes is responsible:

- Natural Lowering of the Water Table: Water levels in shallow dug and bored wells experience large fluctuations due to climatic conditions. The natural seasonal change in water level often will often be several metres. This is likely the cause of the drop in yield if the level of water within the well does not rise up, even several hours after pumping. All that can be done is to construct a new well, ensuring that the well casing is set far enough below the water table (ideally 5 to 10 metres) to assure an adequate water supply during the dry summer periods when the water level declines. Also, check how many people are drawing water from the

- Well Water Interference: The construction of water and sewer mains, drainage ditches and highways (road cuts) can occasionally affect ground-water levels and interfere with nearby shallow wells. In addition, the static water level in a well may be affected by large withdrawals of ground water from nearby large capacity wells or de-watering equipment for construction works (see Footnote #5). The potential for well interference depends greatly on the lithology of the producing formation and the magnitude of well usage.

- Screen Blockage: Sometimes the problem is that the well screen has plugged-up with fine sand and silt particles, with accumulated iron deposits or with growths of nuisance bacteria (naturally occurring, non-health related bacteria with can produce rotten egg smells, random slugs of iron rich water etc). This is likely the case if the water level in the well is near its original construction level but drops to the bottom of the pump cylinder as soon as the well is pumped. The well should be extensively re-developed to try and restore the efficiency of the screen and gravel pack (see **Section 10**). Unfortunately, if the problem occurred once, it will probably occur again. Be prepared to repeat the development process as needed to extend the life of the well.

G-12: Footnotes & References

[1] The drilling fluid prevents caving of the borehole because it exerts pressure against the wall. As long as the hydrostatic pressure of the fluid exceeds the earth pressures and any confining pressure in the aquifer, the hole will remain open. The pressure at any depth is equal to the weight of the drilling fluid column above that point.

[2] Before drilling out the grout plug, the effectiveness of the seal can be checked by measuring water-level change in the casing over time. In wells with a low static water level, the casing can be filled with water or drilling fluid and later checked for any water loss. If the static water level is high, the casing can be nearly emptied and any influx of water into the casing can be measured.

[3] Frequently used polyphosphates include sodium tripolyphospate [$Na_5P_3O_{10}$), sodium pyrophosphate ($Na_4P_2O_7$), tetra sodium pyrophosphate (NaP_2O_7) and sodium hexametaphosphate ($NaPO_3$) (Anderson, 1993).

[4] About 6.8 kg (15 lb) of a polyphosphate should be used for each 400 L (100 gal) of water in the screen. 0.9 kg (2 lbs) of sodium hypochlorite should also be added to every 100 gal of water in the well to control bacterial growth promoted by the presence of polyphosphates (Driscoll, 1986). Polyphosphates should be premixed before introduction into the well because they do not mix easily with cold water. Occasionally the mix water is heated to help dissolve the chemical (Driscoll, 1986). Polyphosphates should **NOT** be used in formations with thinly bedded clays and sands because these chemicals tend to make the clays near the borehole unstable, causing them to mix with the sand (Driscoll, 1986) continually passes into the borehole during pumping (Anderson, 1993).

[5] When a well is pumped, the water level in the immediate area of the well is lowered and a cone of depression develops around the well. The size and the shape of the cone will depend on the aquifer characteristics of the water-bearing formation in which the well is completed and the rate of pumping. This is likely the cause if there are two or more wells located within 100 m of each other and if water levels return to normal in both wells once pumping has stopped or within some reasonable time afterwards. Water level recovery depends on the quantity of water withdrawn from the aquifer and the length of time the wells were pumped. All that can be done is manage the rate at which water is taken from the interfering wells.

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Appendix H

Assessing Natural Clays: For Use as Drilling Mud

In many situations in remote parts of third world countries, bentonite or polymer is not available. Without these substances, holes often start to cave in and wells can not be successfully completed. Where industry-grade bentonite or polymer is not available, the suitability of locally available clays should be assessed prior to the start of drilling. This can be done using a **Free-Standing Swell Test.**

What You Need:

1. One Free Standing Swell Test Kit, containing:
    - 4 - 100 ml.round free-standing graduated cylinders (self-supporting)
    - 1 - Hand Sieve Set:
        - 1 - #73 O-Ring (2 spares included)
        - 1 - 2" diameter 48 Mesh screen cloth
        - 1 - 2" diameter 200 Mesh screen cloth
        - 1 - PVC fines container (male threads) (Genova Products 2" Fitting #71820)
        - 1 - PVC Screen cloth Holder (female threads) (Genova Products 2" Fitting Cleanout body #71619)
    - 49 assorted Ziplock bags (small)
    - 24 1.5 ml. Snap-top bottles
    - 1 - 30 gm. Container of Reference Bentonite
    - 1 - Hand Balance Beam (black wire)
    - ? - 2.0 gm. Reference Weights

2. The following items should be found on-site:
    - Fresh, clean, *"soft"* water
    - Clay samples
    - Small, thin spatula
    - Hot oven
    - Grinding stone or rolling pin

3. If the following items are available, they can be substituted as necessary:
    - Accurate low-weight scale AND/or

- Balance with 2 gm. weight AND/or
- Accurate teaspoon-size measuring spoon

Sample Collection:

The best deposits of sodium bentonite are found in areas formed from old volcanic ash deposits. Therefore, if possible, collect clay samples from areas affected by ancient volcanic activity. If these deposits are not found in the country, try collecting clay samples from brackish swamps. Collect several hands-full of each clay to be tested.

Hand Sieve Set Assembly:

To assemble the hand sieve set:

1. position the Screen Cloth Holder (larger diameter PVC part) with the treads up.
2. Place one O-ring into the recess just below the threads.
3. Place the screen cloth gently on top of the O-Ring, and start twisting the Fines Container (smaller diameter part) into place.
4. Turn the device over, such that the O-Ring and the screen cloth are visible.
5. As you tighten the Fines Container, you may need to nudge the O-Ring outward into the recess.
6. Finish tightening the fines Container, until it is HAND TIGHT *(Please use only one O-Ring* as there are three O-Rings provided with the Test Kit, but the extra two are intended as spares. You will need to dis-assemble this to remove the fines.)

Sample Preparation:

1. Take a small amount of the collected sample (1-2 cups). Flatten it as much as possible and break it into small pieces.
2. Dry it in a hot oven (200-300 degrees F) for 1 hour.
3. Then crush it as fine as possible.
4. Place it back in the oven and continue to dry and periodically crush the sample with rolling pins or flat stones.
5. Periodically place the crushed sample into the hand sieve Set and rap the Sieve Set aggressively until you observe that material no longerfalls through the screen cloth.
6. Transfer the coarse material back to the grinding step.
7. Continue this process until the sample is a fine, dry powder which can be easily blown off of an open, outstretched hand.
8. It is **Very Important** to thoroughly dry and powder clay samples prior to weighing them since bentonite in chunks weighs only 68

lbs/ft3 while powdered bentonite weighs only 55 lbs/ft3 or 0.88gms/cm3 (there are more air voids in powdered clay).

9. To remove the ground material from the Sieve Set, first remove any remaining traces of coarse particles from above the screen cloth.
10. Then twist apart the two PVC pieces carefully to collect the ground powder.
11. When finished, gently wash and dry the parts of the Sieve Set.
12. The screen cloth may be dried in the oven, (just a minute or two should do) before grinding the next sample.

Water Source:

1. Use water which is as pure as possible. Ideally, fresh rainwater should be used. Water should be sediment free and should be as soft as possible (calcium and magnesium can interfere with the swelling of sodium bentonite clays). If possible, use water with a relatively high pH (8-9) to reduce the calcium and magnesium content. If necessary, use soda ash to raise the pH of the water.
2. If water is run through a water treatment filter to purify it, ensure that it is passed through an activated carbon filter to remove any residual chlorine or iodine prior to the test.
3. To minimize variability, collect sufficient water in one container to test all the samples and then draw water for each test from the same container.

Free Standing Swell Test Procedure:

1. Just prior to the test, measure out a 2 gram sample of powdered clay.
    - ***Option 1:***
        - Hang the Balance beam on a branch or a nail.
        - place a 2 gram reference weight on one side of the Balance beam.
        - Punch a hole in one of the included Ziplock Bags, and hang it on the other side of the Balance Beam.
        - Then, fill the Ziplock bag with dry, finely ground sample until the Balance Beam hangs level.

    - ***Option 2:***
        - Estimate the proper weight by measuring 2.3 cm3 clay (0.5 tsp.clay or the equivalent volume of 46 drops of water). This amount of clay would fill TWO of the 1.5 ml. snap-top bottles to just over 2/3 full.
          (If possible, use all four graduated cylinders so that up

to four clay samples can be tested at the same time.)

- Fill the cylinders to the 100 ml. mark with the clean water.
- Transfer small amounts (0.25 gm.) of the powdered clay onto the surface of the water using the thin spatula. ***Without Stirring,*** wait for it to absorb the water and sink on its own. Be patient, this might take as much as 4-5 minutes.)
- As soon as the last clay has disappeared from the surface of the water, gently drop the next small amount of powdered clay into the cylinder.
- Continue this process until all of the 2 grams of clay has been added to the sample.

Assessment:

1. Wait 18 hours, then measure the thickness of the layer of clay sludge on the bottom of the cylinder.
2. Do not shake or otherwise disturb the sample during this waiting or measuring process.
3. Clays which are suitable for use as drilling mud should have swelled to the 12-16 ml. (cm3) mark on the cylinder.
4. If clays have swelled only to the 4-6 ml. mark, they will not effectively coat the side of your borehole during the drilling process and should not be used as the thickening agent.

Last Resort Options:

1. If you cannot buy bentonite or find any suitable clay deposit, try drilling a borehole in clay soils without any thickening agents.
2. Drilling in sandy soils has a very low chance of success and will likely collapse prior to the casing, gravel pack and cement grout being in place.
3. If all other options have failed, try using finely ground seeds from guar plants (guar gum). It must be extremely finely ground (0.0001 microns). as a last resort, try adding potato starch (corn Starch is not quite as good) to the drilling water to enhance the performance of your drilling mud. However, ***it must be emphasized*** that these organic starches provide an ideal food source for bacteria and will quickly rot and start fermenting once introduced into the borehole!
4. Add starch as late in the drilling process as possible and ensure that the well is completed and starch pumped out within 6 hours of it being added to the hole.

5. Thoroughly rinse the hole with chlorinated water just prior to setting the well screen and casing and float the gravel pack into the hole while running chlorinated water up the annular space.
6. Once the well is complete, pump it for as long as possible and then shock-chlorinate it before leaving it for the night.

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Appendix I

Methods For Grouting Casing

In general, it is good practice to place a grout seal around the upper portion of well casing to help prevent contaminated surface water from entering the well. In other situations, grout may be placed around the entire length of casing or within the casing itself. These situations are outlined below and various techniques for placing grout are described.

Tremie Line

The most common use of grout is to seal the annular space between the top of the filter pack and the ground surface. For shallow wells the water table does not extend far above the filter pack, it is often possible to mix cement and water (no sand or gravel) into a thin paste and pour it into the annular space. However, in deep wells in which the gravel filter pack is far below the level of water in the annulus, this procedure would lead to separation of the sand and cement leading to formation of a poor seal. To prevent this, the following procedure can be followed:

- Ream-out the borehole to 18 cm (7 in) diameter.
- Insert a 7.6 cm (3 in) diameter well screen and casing and "float-in" your gravel pack.
- Insert a 1 inch diameter "tremie" pipe down the annular space to the top of the gravel filter pack (the outer diameter of the couplings for the 7.6 cm (3 in) PVC schedule 40 pipe is 10.8 cm (4.25 in). In a 18 cm (7 in) borehole, this will leave a 3 cm (1.25 in) gap to insert your tremie pipe)
- Using a funnel, slowly pour cement grout into the tremie line. Gradually lift the line ensuring that the bottom of the line stays below the level of cement accumulating in the annular space.
- When the annular space is filled, remove and wash the tremie line.

Modified Halliburton Wiper Plug Method

When heavily contaminated soil or a severely polluted surficial aquifer are encountered, well casing should be securely grouted into an underlying rock or clay layer. This should also be done when moving from mud rotary to air hammer drilling to ensure that the hole does not cave-in. In order to securely grout a casing, the following procedure should be followed:

- Unless you have special small bits, ensure that you use 10 cm (4 in) diameter casing ... you will not be able to drill-out the cement inside 7.6 cm (3 in) diameter casing!!
- Make sure that the seals on the drill rig and mud pump hoses are in good condition and that they are tight.
- Make an adaptor so that the drill pipe fitting on the LS-100 can be attached with a water-tight seal onto the top of the casing. If this is not possible, have an extra 3m (10 ft) length of casing with a glued-on coupler and a 3 m (10 ft) ladder ready.
- Calculate the volume of the inside of the casing. The volume of a 10 cm (4 in) diameter casing is 8 litres/meter (0.09 ft^3/ft or 0.64 USG/ft). Subtract 8 litres from this estimated volume and then measure-out this amount of water into a barrel.
- Calculate the volume of the annular space. The annular space for a 15.24 cm (6 in) diameter borehole with a 10.16 cm (4 in) diameter casing is 8 litres/meter (0.09 ft^3/ft or 0.64 USG/ft). Multiply this number by 1.3 (30%) to allow for wash-out down hole etc. If you suspect that there has been much caving in the hole, increase the volume by up to 100%.
- Place the well casing into the hole, ensuring that it is suspended about 0.3 meters (1 ft) about the bottom of the borehole.
- Mix-up a volume of cement equal to the volume estimated above. Neat cement grout yields about 37 litres (9.7 USG or 8.1 IMG) of slurry per 94 lb bag (1 ft^3) which is mixed with 23 litres (6 USG or 5 IMG) water. Do **NOT** add any sand or gravel. Mix it smooth (no lumps) until it is like thin pudding or thin yogurt.
- Pour the cement grout down the inside of the casing.
- After the cement is placed in the casing, lower the drill rig swivel/quill until the drill pipe fitting makes a water tight seal with the adaptor on top of the well casing. Then pump the measured volume of water down into the well casing behind the cement. This can be done by filling all the hoses with water and then placing both the suction hose and the recirculation hose into the barrel containing the measured volume of water. Start the mud pump and then use the 3-way valve on the drill rig to control the

rate at which water is pumped into the casing. SLOW pumping is GOOD!

- If it is not possible to create a water tight seal with the drill pip fitting, wait until the cement is inside the casing and then tightly push or glue on the extra 3.05 m (10 ft) length of well casing. Ensure that you accounted for this extra length of casing when you calculated the volume of water to add. Standing on top of the ladder, slowly add water into the casing until the entire measured volume of water has been added. Since cement weighs 14 lbs/gallon and water weighs 8.3 lbs/gallon, the extra 3.05 m (10 ft) of water will push the cement down an extra meter (3 feet).
- Once all the water has been added, gently push the casing downward to ensure that it is seated in the rock or confining clay layer. This helps ensure that there is a complete seal at the bottom of the casing.
- Then use several shovel full of dirt to plug-off the ditch leading from the borehole to the mud pits.
- If water is leaking out of the plumbing joints and/or drilling mud is draining back down into the annulus, then cement is leaking back up the casing. Tighten joints to reduce leakage. While some leakage is not desirable, it is not a crisis either... it will merely require the drilling out of a little extra cement.
- Wait 24 hours before you start to drill inside the casing. If in doubt, wait longer rather than shorter. If you start drilling and find that the cement is not set-up, wait another 12 hours.
- Drill-out the cement using a 10.16 cm (4 in) roller bit.

Wiper Plug Method

If for some reason the Modified Halliburton Wiper Plug Method described above will not work, consider the following method which uses a plug to push the grout down into the casing and up the annular space:

- Take 1 or 2 empty cement sacks and wad them into a tight ball.
- Once the measured volume of grout is placed in the casing, insert the cement sack ball (the "wiper plug") in the casing.
- Use drill pipe to slowly force the wiper plug down the casing until it is just above the bottom of the casing.
- Use several shovels full of dirt to plug-off the ditch leading from the borehole to the mud pits.
- Leave the drill pipe in-place for 1-2 hours to let the cement set enough so that it wouldn't come back up the casing when the drill pipe is removed.

- Do not leave the drill pipe in the casing for an extended period of time. If you do and some cement leaks back through or around the wiper plug .... it will set around the drill pipe and make it a permanent installation!
- After 1-2 hours, slowly start to pull-up of the drill pipe. If drilling mud ponded around the top of the borehole starts to drain back down into the annulus, then cement is leaking back up the casing. Leave the drill pipe in the hole for another 15-30 minutes and try removing it again. Remember... some leakage is better then cementing your drill pipe into the casing!

Cement "Plastic Bag Plug" Method

Sometimes a borehole is drilled into poor quality water and it is determined that the best course of action is to backfill the lower portion of the hole and set the well screen at a higher elevation where better quality water is expected. When a wooden drive shoe is used at the bottom of a casing string, it is desirable to place a 30 - 61 cm (1 - 2 ft) cement plug in the bottom of the well to ensure that sediment cannot enter the well when the plug rots out. Both these procedures nvolve all or some of the following steps:

- Backfill the hole with cuttings until you are 61 cm (2 ft) below the desired completion depth of the borehole where you want the bottom of the screen to be.
- Mix-up 0.4 ft^3 (11 litres) of real thick cement & water mixture (no sand or gravel).
- Pour the cement into small plastic bags the easily fit down inside the borehole.
- Run the drill pipe with a blade bit down the borehole and move the pipe up and down to chop-up the bags and mix-up the cement.
- Remove the drill pipe and wait 1 hour for the cement to set.
- Insert the well screen and casing (with casing bottom plug) down into the borehole. Suspend the casing 6 inches off the bottom of the borehole and then put in the filter pack.

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Appendix J

Tips for Working With Concrete

Concrete is made from cement, sand, gravel and water. These ingredients are commonly combined in a 1:2:3 proportion to achieve maximum strength (1 part cement, 2 parts sand, 3 parts gravel). The amount of water used to mix the ingredients is by far the most important factor in determining the final strength of the concrete: *Use the least amount of water that will still give you a workable mix.* Generally between 20 and 30 L of water is mixed with each 50 kg bag of cement (see "Mixing Concrete" section below).

- Choice of Ingredients
- Estimating Quantities of material needed
- Concrete Reinforcement
- Mixing Concrete
- Finishing
- Curing

Choice of Ingredients:

- Cement: The most common used cement is Portland. It should be dry, powdery and free of lumps. When storing cement try to avoid all possible contact with moisture. Store away from exterior walls, off damp floors, and stacked close together to reduce air circulation.

- Water: In general, water fit for drinking is suitable for mixing concrete. Impurities in the water may affect concrete, setting time, strength, shrinkage or promote corrosion of reinforcement.

- Sand: Sand should range is size from less than .25 mm to 6.3 mm. Sand from sea shores, dunes or river banks is usually too fine for normal mixes. However, you can sometimes scrape about 30 cm of fine surface sand off and find coarser, more suitable sand beneath.

- Gravel: Optimum gravel size in most situations is about 2 cm. Finer gravel may be used to fill the annular between the borehole and the well casing.

***It is extremely important to have clean sand and gravel.* Even small amounts of silt, clay or bits of organic matter will ruin concrete.**

To see if sand is good for making concrete, fill a wide-mouthed jar half full of the sand. Cover with water, shake the mixture vigorously, and then allow it to stand for three hours. There will be a distinct line dividing sand suitable for concrete and that which is too fine. If more than 10% of the sand is too fine, concrete made from it will be weak. Other sand must be found or silt and clay washed out of the available sand. To wash sand, put it in a drum, cover it with water, stir thoroughly, let stand for a minute, and pour off the liquid. One or two such treatments will remove most of the very fine material and organic matter.

Estimating Quantities of material needed.

1. Calculate the volume of concrete needed.
2. Estimate the total volume of dry material by multiplying the required volume of concrete by 1.65 to get the total volume of dry loose material needed (this includes 10% extra to compensate for losses).
3. Add the numbers in the volumetric proportion that you will use to get a relative total. This will allow you later to compute fractions of the total needed for each ingredient. (i.e. 1:2:4 = 7).
4. Determine the required volume of cement, sand and gravel by multiplying the total volume of dry material (Step 2) by each components fraction of the total mix volume (Step 3) i.e. the total amount cement needed = volume of dry materials * 1/7.
5. Calculate the number of bags of concrete by dividing the required volume of cement by the unit volume per bag of cement (0.0332 m^3 per 50 kg bag of cement or 1 ft^3 per 94 lb bag).

For example, for a 2 m x 2 m x 10 cm thick pump pad:

1. **Required volume of concrete = 0.40 m^3**
2. **Estimated volume of dry material = 0.4 x 1.65 = 0.66 m^3**
3. **Mix totals = 1+2+4 = 7 (1:2:4 cement:sand:gravel)**
4. **Ingredient Volumes: 0.66 x 1/7 = .094 m^3 cement**
   0.66 x 2/7 = .188 m^3 sand
   0.66 x 4/7 = .378 m^3 gravel
5. **# Bags of cement: 0.094 m^3 cement / .0332 m^3 per 50 Kg bag = 2.83 bags of cement (use three bags)**

Concrete Reinforcement

Concrete can be made much stronger by reinforcing it with steel rods (rebar or rerod) that are embedded in the concrete. Reinforced concrete should be at least 7.5 cm thick. Rerod should take up 0.5% to 1% of the cross-sectional area. The rebar should be placed within the concrete form and be located at least 2 cm from the edge of the form. It should be placed in a grid pattern so that there is never more than 3 times the final concrete thickness between adjacent rods. (With a final thickness of 10 cm use a grid spacing of 25 cm). All intersections where rods cross should be tied with wire. The proper space from the bottom of the pour in a slab is one third the height of the final thickness. It can be achieved by setting the rod grid on a few small stones before the concrete is poured or simply pulling the rebar grid a couple of centimeters up into the concrete after some concrete has been spread over the whole pour.

Mixing Concrete

Concrete must be thoroughly mixed to yield the strongest product.

A. Mixing by Machine: Add about 10% of the mixing water in the drum. Then gradually add water uniformly with the dry materials leaving another 10% to be added after the dry materials are in the drum. Allow 5 or 6 minutes after all the materials are in the drum.

B. Mixing by Hand: The mixing area must be both clean and water tight. Use the following procedure:

1. Spread the sand evenly over the mixing area.
2. Spread cement evenly over the sand and combine until the colour is uniform.
3. Spread the mixture out evenly and add the gravel on it and mix it thoroughly again. All dry materials should be thoroughly mixed before water is added.
4. Shape dry mix into a pile and form a hollow bowl in the centre. Pour some of the water into the bowl, gradually mixing in the dry mixture until all the water is adsorbed. Re-form the pile and bowl, add and mix more water. Repeat until concrete is ready to pour.

A workable mix should be smooth and plastic (not wet and runny or dry and crumbly). If the mix is too wet, add small amounts of sand and gravel (in the proper proportions) until the mix is workable. If the mix is too stiff, add small amounts of water and cement until the mix is workable. Note the amounts of materials added for future batches.

Finishing

Once the concrete is poured into the form, its surface should be worked to and even finish. Where the surface will later be walked on it should be kept somewhat rough to prevent people from slipping when it gets wet. This texture can be achieved by finishing with a wooden float (trowel) or by lightly brushing the surface.

Curing

After the forms are filled the concrete must be cured until it reaches the required strength. Curing involves keeping the concrete damp so that the chemical reaction that causes the concrete to harden will continue for as long as necessary. Once the concrete dries the chemical hardening will cease and cannot be reactivated. The best way to keep the concrete wet in very hot countries is to plug to drainage channel soak-away pit and then fill the concrete pad and drainage channel with water. Water can be added as needed to keep the concrete covered.

Another easy way to keep the concrete from hardening too quickly is to cover the exposed surface with a damp protective cover. The covers can be canvas, empty concrete bags, burlap, palm leaves, or straw. The covering should be kept damp so that it will not absorb water from the concrete.

It is a good idea to place many thorn branches over the pad area and appoint local people to watch over the pad to ensure that people do not walk on it during the curing process.

The concrete forms can be removed in 3 to 6 hours if no load is on the structure. The pad will take 4-7 days to harden completely if it is going to be moist cured. If possible, wait this long before finishing installation of the pump.

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Appendix K

How to make a Bush Handpump

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The Zimbabwe pump (also known as the Bush Pump) is build around a down-hole cylinder containing a piston. It is called a "positive displacement pump" because it displaces an amount of water equal to the distance the piston travels. The amount of water pumped is limited by the piston diameter and length and the number of pump strokes per minute.

Pump cylinders are connected by pump rods to a lever handle (see Figure 25 and Figure 26). A wooden hand grip can be attached directly to the pump rods if:

- **There is limited money available to build a pump;**
- **The water table is less than 6 m (20 ft) below surface and the well is less than 9 m (30 ft) deep;**
- **There are less than 100 people dependent on the well and pump.**

While this can save several hundred dollars, it will make pumping more difficult for young children and, if users are not careful to pull straight up, the pump rods can become severely bent.

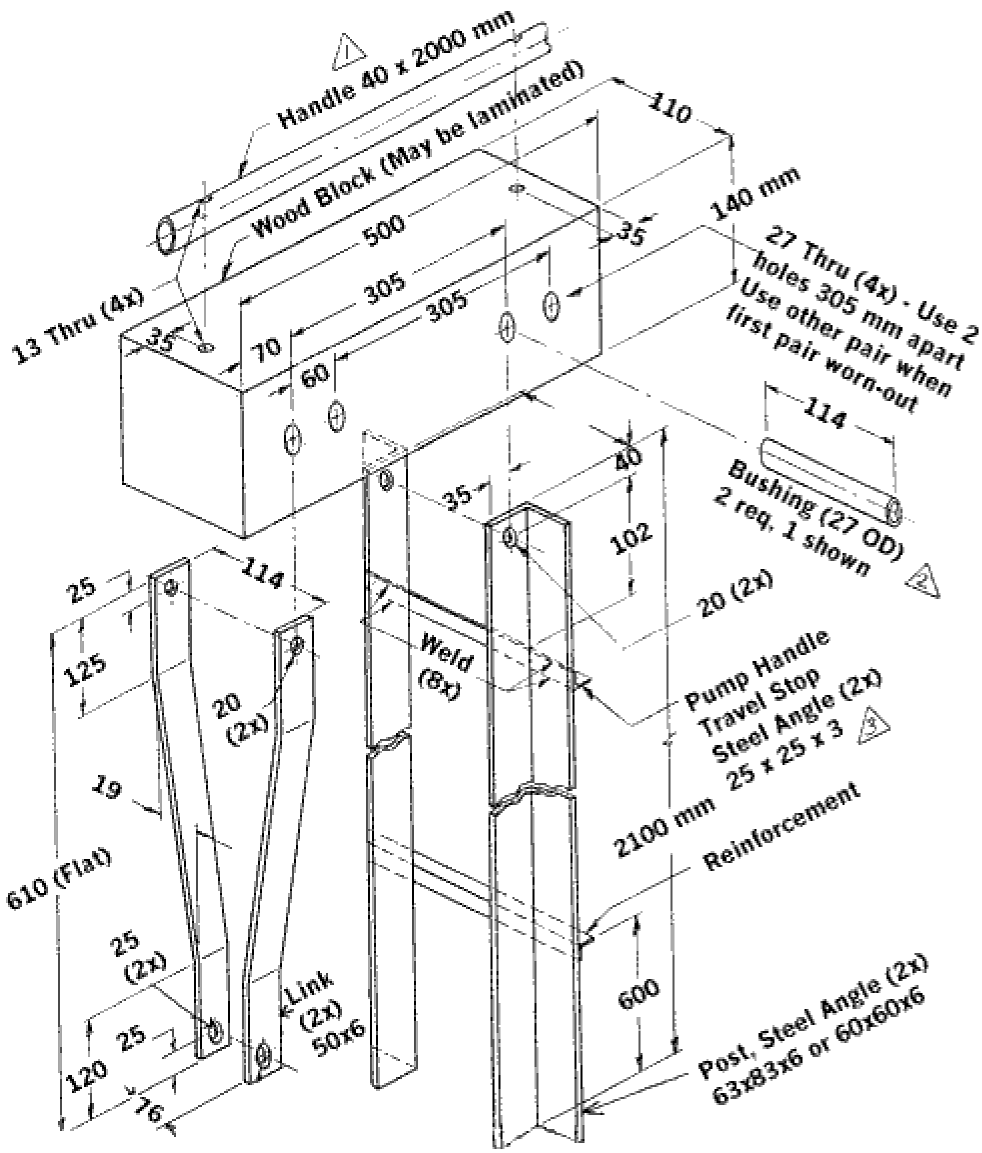
The rising main is usually made of PVC. Galvanized rod is commonly used for the pump rod. Reinforced steel can be used but it is likely to rust.

The Zimbabwe pump stand, handle and bearing usually are the first parts to wear out and are also relatively easy to build. For this reason, they should be considered the principle elements for local manufacture:

1. The main pump bearing is made of wood. It can be one solid wood block or can be made from three laminated pieces. The wood bearing works best if it is first soaked with oil

2. The handle may be made of wood, but a steel pipe is usually used for strength. Attach the handle to the wood block with 12 or 13 mm diameter bolts, 200 mm long **(see Item #1 on Figure 25)**. Use large-area washer (45 OD x 13 ID) and lock washer (13 ID) between each nut and block.

Figure 25: Bush Pump Fabrication

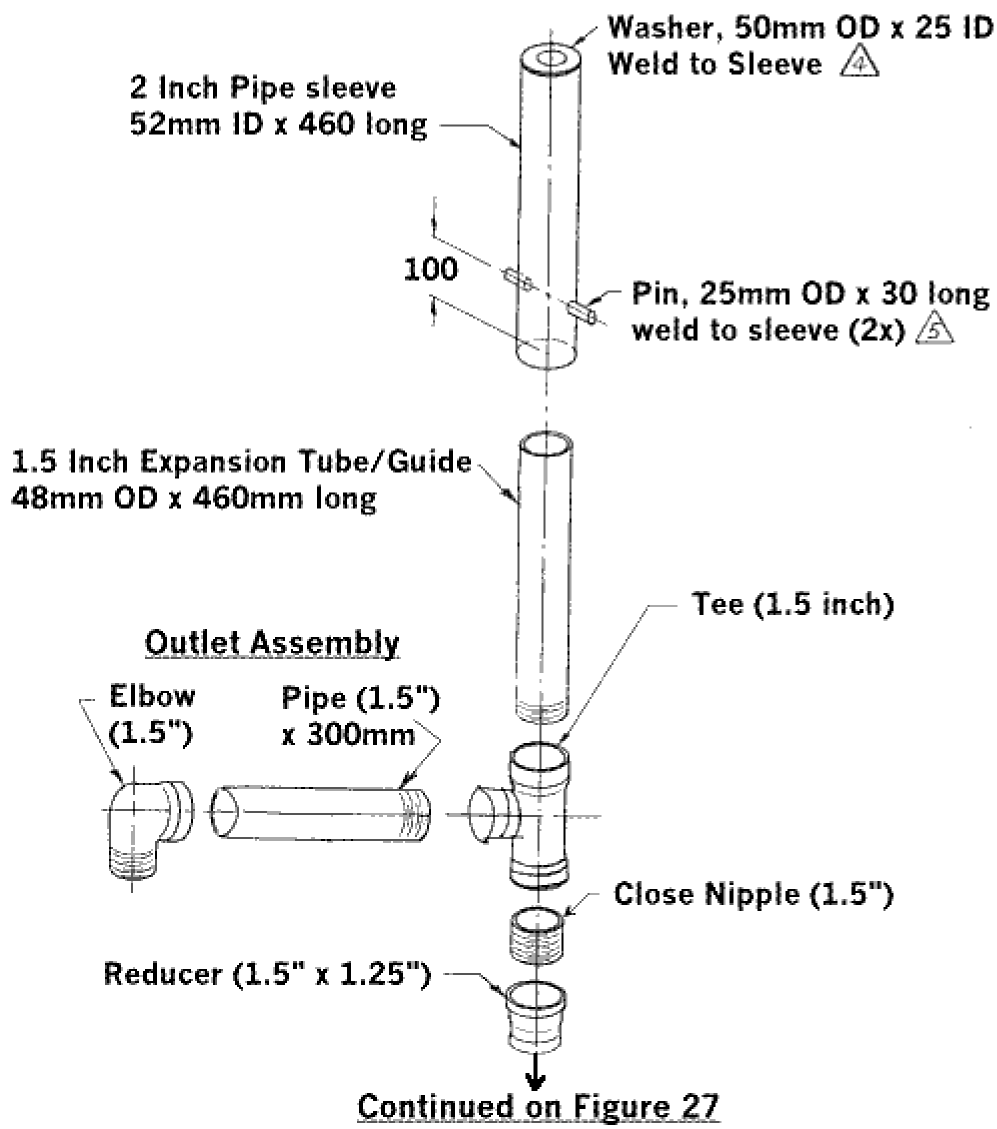


3. The bushings should be 3-4 mm longer than the width of the block of wood **(see Item #2 on Figure 25)**. This will allow bolts (20 mm dia, 150-165 mm long) to be completely tightened without the block being stuck tight between the steel pump supports. If the bushings are the correct length, the block will freely rotate up and down without significant sideways movement. Before assembling, soak the holes in the wood liberally with oil. Used engine oil may even be used. Use 20 mm ID lock-washers behind each nut

4. The aft handle bolt should hit the "pump handle travel stop" angle iron bar when the end of the handle is all the way down **(see Figure 25)**.

5. Use one or two large-area washers (#1,2 or 3 with 1/2 inch ID) on top of the 25 mm ID washer which is welded to the top of the pump sleeve **(see Item #4 on Figure 26)**. Alternatively, instead of using a 50 mm OD x 25 ID washer, use steel plate (3 mm thick or more) cut to fit with a center hole the diameter of the pump rod. If the end of the 5 cm (2 in) pipe is threaded, screw-on a 5 cm (2 in) cap with a hole (diameter equal to the pump rod diameter) drilled in the center. When the pump rod is inserted through the top of the pump sleeve, secure it in place using two nuts, tightened against each other.

Figure 26: Bush Pump Outlet Assembly Detail

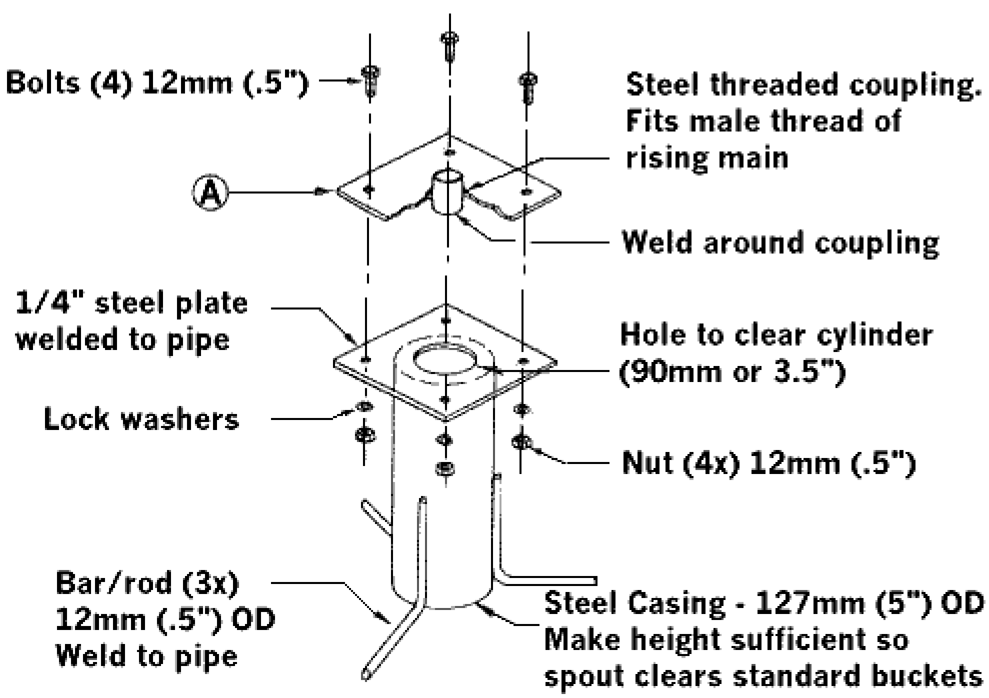


6. It is really important to line-up the two pins which are to be welded onto the pump sleeve **(see Item #5 on Figure 26)**. This can be done by drilling a 2 cm (1 in) hole right through both walls of the pump

sleeve, inserting a pin into the hole until it is flush with the inside of the pipe wall and then welding. An even better way to align the two pins is the make a "jig" using the two flat-bar links shown on figure 25. Attach the links to the wood bearing block and then lay the links on their long edge on a flat surface straddling the 5 cm (2 in) pipe. Make sure the pipe is parallel to the two links and raise the links 6 mm (1/4 in) so that the pins will be centered on the pipe wall. Insert the steel pins in the 2 cm (1 in) holes at the end of the links and position the pipe so that the pins will be located at the specified distance from the bottom end of the pipe. Tag-weld the pins, remove the links and finish welding. After the pins are attached to the pump sleeve, install 2 steel washers (50 mm OD x 25 mm ID x 3 mm thick), on each pin - one on each side of the flat bars which link the wooden bearing block to the pump sleeve (total of 4 washers required).

7. The outlet assembly should be supported on a reinforced casing base **(Figure 27)**. Install the reinforced casing base as follows:
   - Place the steel base over the PVC casing before pouring the concrete pad. Allow concrete to dry 2-3 days.
   - After installing the cylinder and rising main, attach the rising main to the welded coupling in the casing base plate, position the plate on the base and secure with 4 bolts (**see item "A" on Figure 27**)
   - Install outlet assembly (figure 26) to welded coupling (item A).

Figure 27: Bush pump casing reinforcement



Difficult/Expensive Parts

The most difficult part to get for making a Bush or Zimbabwe pump is often the large bolts (20 mm diameter, 150-165 mm long) used to connect the wood block bearing to the angle iron pump post (Figure 25). The most difficult part to make is welding the pins onto the pump sleeve (Item #5 on Figure 26). Depending on the availability of material, the most expensive parts to make are often the pump post made from angle iron (Figure 25) or the casing reinforcement base (Figure 27)

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Appendix L

Making Cup-Leathers

Most handpumps use neoprene or leather seals (cup-leathers) inside the cylinder to force water up the rising main when the piston is moved. When the cup-leathers are worn-out, you will have to pump very hard to make water come out the pump spout and it may come in a small trickle or not at all. If the water level in the rising main is not higher than the water level in the well, there may also be problems with the foot valve (see Section 17).

Cup-leathers wear-out over time and are the most common problem resulting in handpumps not working anymore. Their effective life depends on the amount of sand being pumped with the water, the smoothness of the cylinder walls and the amount of pump use. *Typically, they should be changed every 6-12 months*. When cup-leathers wear-out and replacement leathers are not readily available on local markets, pumps are often removed (and destroyed) by villagers trying to access the badly needed well water.

Villagers dependence on foreign suppliers can be reduced by locally manufacturing cup leathers! Cup-leathers (or "seals") for 5 cm and 6 cm (2 and 2.5 in) diameter cylinders can be made by drawing a leather disk soaked in paraffin wax into a PVC plastic pipe by use of a wood mould and a steel threaded rod, with the use of a threaded handle or crank. The leather disk is formed into a cup shape and then trimmed to size. The cup-leather is then placed on the pump piston and the piston and cup-leather is put back inside the pump cylinder of the appropriate size.

Steps in making pump cup-leathers:

1. The leather should be tanned and about 3 mm or 1 mm (1/8 in or 1/32 in) thick -- better to be thinner than too thick as the leather will swell with wax and then again with water in the pump. The leather should be placed so the rough side is next to the mould and the smooth side is next to the cylinder wall. When cutting the leather disk use a very sharp knife or razor knife pull the leather toward the straight knife edge. Do not saw the leather with the knife, as it's a lot of work and the edge will not come out smooth.

2. Soak the leather in hot paraffin wax. Use a double boiler (pan

with water on the bottom and another pan or pot on the top to heat the wax in) as you do not want the wax to boil, and there is always danger of it catching on fire. (It should never be left unattended and best done outside). Soak the leather in the hot wax for 15 minutes turning it over several times. If paraffin wax (canning wax) is not available, white candle wax can be used, but in any case the type of wax must be non-toxic.

3. Put the leather disk on the wooden mould. The wax and the leather are very hot and care should be taken to have all the equipment ready so no time will be lost and the disk can be put on safely without being burned (it works best with two people). It needs to be done quickly as the wax cools fast and the disk will not draw into the PVC pipe. Again make sure the rough side of the leather is next to the mould and the smooth side is next to the pipe. The leather should be drawn into the PVC pipe (by tightening the handle) until it is just past the tapered portion of the pipe. Let the leather cool for a hour or so.

4. Remove the new cup-leather from pipe and mould. Enlarge the centre hole as necessary to snugly fit on the pump piston. Then trim the top edge of the cup leather (the size of the disk was set to have about 3.2 mm (1/8 in) trimmed off the top edge after it is made into a cup-shape). The top edge of the shaped cup leather can be evenly trimmed by removing the wood mould and pushing the leather back into the PVC pipe until just 3 mm (1/8 in) is sticking above the rim of the pipe. It can then be trimmed with a sharp knife. If possible, bevel the edge so that it slopes down towards the inner edge.

5. At this point you are ready to put the new cup-leather on the pump piston, and then put the piston with the new cup-leather back in the pump cylinder. If you do not put the pump back together at this time, store the new pump cup-leather in a cylinder (pipe) of the same size as the pump cylinder. As the cup-leather will start to lose its shape it will not fit in the cylinder and new cup-leathers will need to be made.

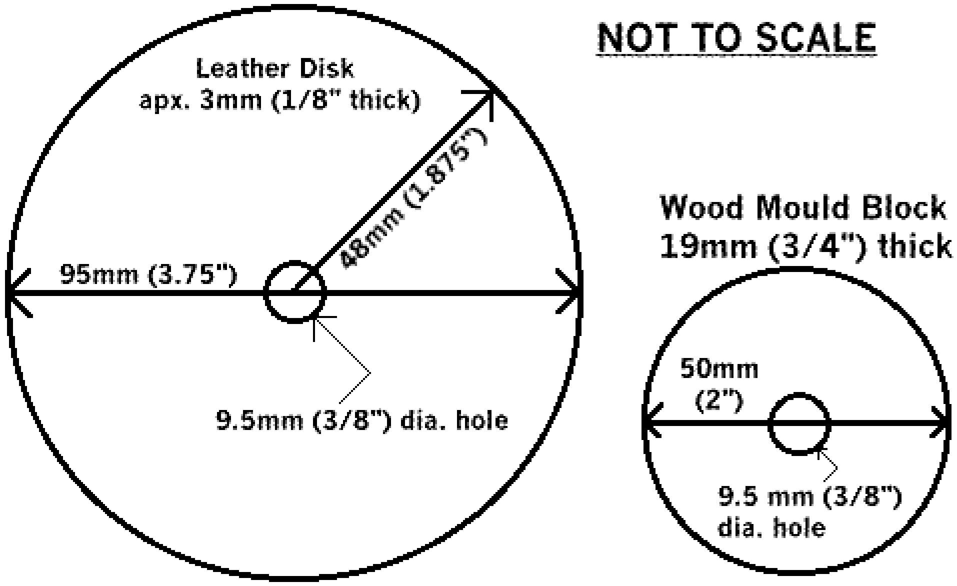
2 1/2 INCH CUP-LEATHER FOR 2 1/2 INCH PUMP CYLINDER

(*For metric conversions see below*):

Leather disk: 3 3/4 inch diameter (1 7/8 inch radius) and 1/8 inch thick + or - 1/32 of a inch. A 3/8 inch hole in the centre of the disk is punched to fit the 3/8 inch threaded rod on the cup-leather maker **(Figure 28)**. After the disk has been formed into a cup shape, about 1/8 inch of rough top edge is trimmed off.

Wood mould block: 2 inch diameter and 3/4 inch thick. This block can be made by using a 21/2 inch power (drill) hole-saw and then filing down to the 2 inch diameter size. A 3/8 inch hole is drilled in the centre of the wood mould to fit on the 3/8 inch threaded rod on the cup-leather maker.

Figure 28: Design for 2.5 Inch Cup-Leathers



Leather disk: 9.53 cm diameter (4.78 cm radius) and 3.2 mm thick or .3 mm. A 95 mm hole in the centre of the disk is punched to fit the 95 mm threaded rod on the cup-leather maker **(Figure 28)**. After the disk has been formed into a cup shape, about 3.2 mm of rough top edge is trimmed off.

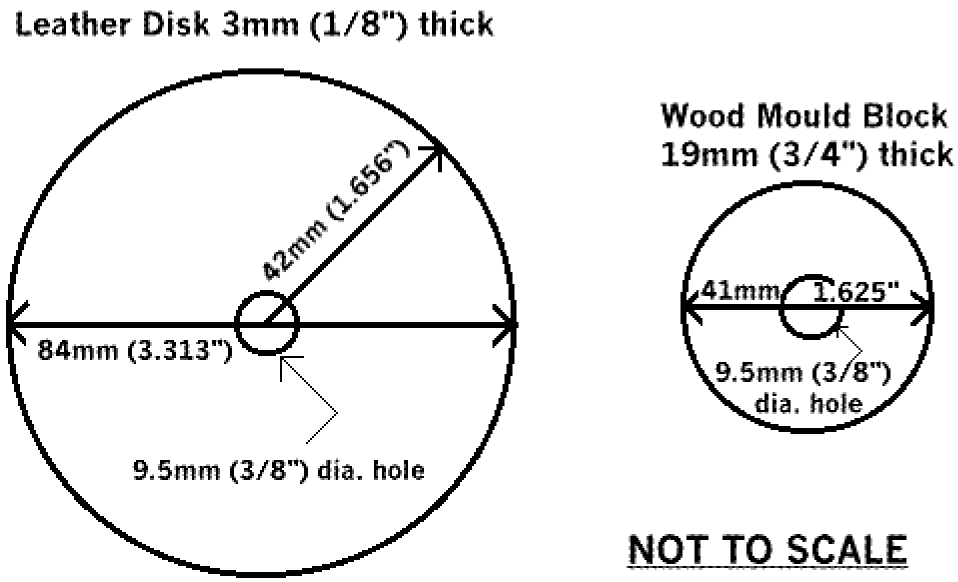
Wood mould block: 5 cm diameter and 2 cm thick. This block can be made by using a 6 cm power (drill) hole-saw and then filing down to the 5 cm diameter size. A 95 cm hole is drilled in the centre of the wood mould to fit on the 95 cm threaded rod on the cup-leather maker.

2 INCH CUP-LEATHER FOR 2 INCH PUMP CYLINDER

Leather disk: 3 5/6 inch diameter (1 21/32 inch radius) and 1/8 inch thick + or - 1/32 inch. A 3/8 inch hole in the centre of the disk is punched to fit the 3/8 inch threaded rod on the cup-leather maker **(Figure 29)**. After disk has been formed into cup shape about 1/8 inch of rough top edge is trimmed off.

Wood mould block: 1 5/8 diameter and 3/4 inch thick. This block can be made by using a 13/4 inch power (drill) hole-saw. Then drill a 3/8 inch hole in the centre to fit on the 3/8 inch threaded rod.

Figure 29: Design for 2 Inch Cup-Leathers



Leather disk: 9.74 cm diameter (4.21 radius) and 3.2 mm thick or 0.3 mm. A 95 mm hole in the centre of the disk is punched to fit the 95 mm threaded rod on the cup-leather maker **(Figure 29)**. After disk has been formed into cup shape about 3.2 mm of rough top edge is trimmed off.

Wood mould block: 4.13 cm diameter and 1.91 cm thick. This block can be made by using a 4.45 cm power (drill) hole-saw. Then drill a 95 mm hole in the centre to fit on the 95 mm threaded rod.

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Appendix M

Iron & Turdidity Treatment

Iron and Manganese Treatment

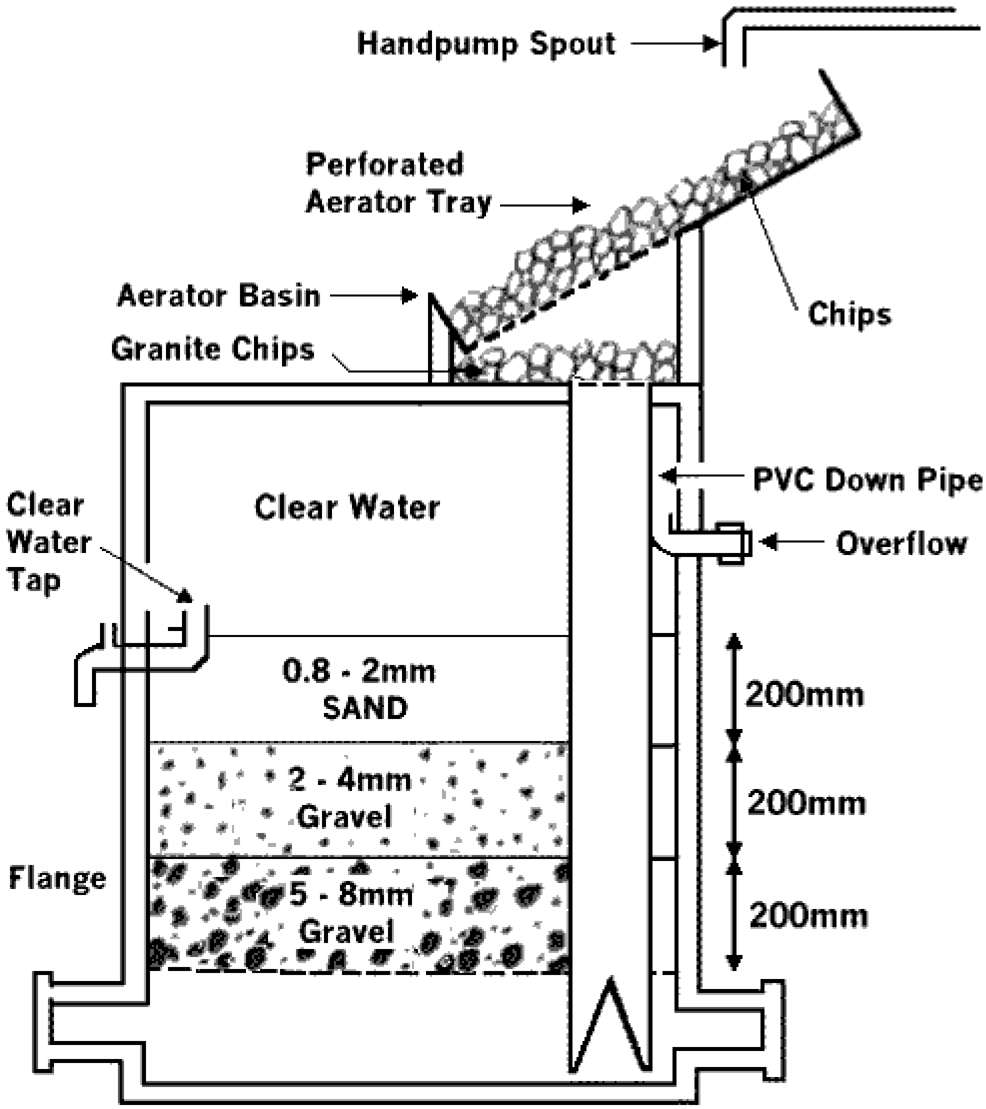
Iron and manganese is naturally present in many aquifers throughout the world. While iron can start causing aesthetically undesirable taste and odour problems at concentrations above 0.3 ppm, concentrations of up to 3.0 ppm are often acceptable to local people; higher levels could cause people to revert to traditional unprotected sources (Patnaik, 1987).

If people are not willing to drink the water because of the bitter, metallic taste or reddish staining caused by high iron levels, then treatment of the water should be attempted using one of the following procedures. It should be remembered, however, that the well screen may rapidly become encrusted with iron deposits, reducing the yield and finally causing failure of the well (Patnaik, 1987). In addition, iron deposits in the cylinders of deep well handpumps accelerate the wear on leather cup seals.

In many cases aeration causes dissolved iron to form fine particles which can be removed by filtration through sand. As described by Patnaik (1987), the Danish International Development Agency has developed a low maintenance filter which has been proven effective in treating iron concentrations as high as 32 ppm (see Figure 30)!

The unit consists of a 1.5 m high cylinder which is installed directly below the down-spout of the pump cylinder which is mounted on a raised platform or mound. Water is pumped onto a perforated aerator tray and then flows upwards thorough a layered series filter and sand layers. The filter media is cleaned by opening a valve or removing a flange so that water flows quickly down through the sand, flushing out the accumulated deposits.

Figure 30: Iron Removing Filter



Turbidity Treatment

Wells screened in clay, silt, or very fine sand may produce coloured or turbid water. These fine materials may partially plug the screen and reduce well yield and will cause excessive wear of the pump cylinder and rubbers. These problems can be addressed in several ways:

1. Proper well development improves the sand-free quality of the well water and the water transmitting characteristics of the formation. In established wells, the appearance of sand may indicate that the wells have been overpumped and/or that much of the well screen has become plugged. Extensive re-development of the well can sometimes overcome these problems.

2. Sand commonly enters wells if the openings of the well screen (slot size) are too large, if the gravel pack contains material which is too coarse or fine, if insufficient gravel pack material was placed around the screen or if the well screen was partially positioned against a formation layer of fine sand, silt or clay. If extensive re-development is not successful, positioning the pump cylinder 1 or 2 meters above the top of the well screen will sometimes reduce turbulence and prevent fines from being pulled into the well.

3. If the water still does not clear, it can be simply treated by placing it in clean, covered containers and letting it sit for 12 to 24 hours. Water should then be dipped from the top, taking care not to agitate the contents. If possible, disinfect (chlorine) the water prior to use if possible. Thoroughly clean the jar prior to refilling.

4. Turbidity can also be treated with a Horizontal-flow Roughing Filter. Raw water falls over a weir into a inlet chamber in which coarse solids settle and flow is evenly passed through a perforated separation wall. Water then flows horizontally through a sequence of coarse (25 mm), medium, and fine (4 mm) filter chambers. The filter boxes could be 1 - 2 meters wide; their length (extending up to 10 meters long) depends on the raw water quality and the hydraulic filter load (design velocity should be 1 m/hour). In general, 20 L of filter plus 10 L of sand should be used for every 30 L/day required treated water. After a year or so, the filter packs will become loaded with retained solids and the media should be cleaned or replaced.

5. If available and transportable (they are heavy and fragile), pre-formed screens consisting of a slotted pipe surrounded by resin bonded sand can be attached to the bottom of the pump cylinder. Whenever the cylinder is pulled to change pump leathers, the pump screen should be cleaned. It may be possible to make a screen by wrapping filter cloth around a slotted pipe. Depending on the availability of local materials, it may even be possible to insert a secondary filter media (sand) between the cloth and the slotted pipe.

6. Finally, if nothing else works, try installing a secondary sand pack and well screen (with a smaller slot size) in the well. Lower a 3.8 - 5.1 cm (1.5 - 2 in) diameter pipe to the bottom of the well; the pipe should extend several feet above the top of the well screen. The pipe should have very fine slots or be wrapped with a filter cloth and the space between the pipe and the well casing/screen

be filled with a uniform fine to medium grained sand. If the pipe blocks over time, both it and the inner sand pack could be washed from the well and a new pack inserted.

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Appendix N

LS-100 Mud Rotary Drill Rig

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The *LS-100* is the first fully *MAN PORTABLE* rotary drilling machine designed to drill 6 inch diameter boreholes to depths equal to & greater then 100 feet.

The **LS-100** is presently being used in 25 countries around the world to expedite relief efforts and provide clean drinking water in drought stricken areas. Because of its unique design and simple parts, the LS-100 has many advantages including that it:

- **is inexpensive**
- weighs 850 lbs and can be easily taken apart and carried or transported by pick-up truck, trailer or animal to areas inaccessible to larger rigs.
- is capable of being assembled in minutes (**see Appendix P**)
- is easy to maintain (**see Appendix Q**)
- can be operated by 1 person with minimal **Training.**

As detailed in **Appendix O**, Key Components of the LS-100 include:

- **Heavy duty drill frame designed for easy transport with removable drilling table with slips and stabilizer bars**: acts as structural support for drilling equipment
- **Power head**: the drill pipe (1.25 inch dia.) and drill bit are rotated by a 5-HP Gas or 4.5-HP Diesel engine with a 25:1 gear reduction transmission and a centrifugal clutch. Power head breaks-away for quick access to bore hole

- **2,500 lb Brake Winch with Hoist and Pull Down Capability**
- **Water entry swivel**: used to channel drilling fluid down the rotating drill pipe
- **3-Way Industrial Fluid Ball Valve** and quick disconnect hoses
- **Drill pipe**: hollow, strengthened steel pipe with heat-treated thread connections that channels drilling mud down to the bit.
- **Drill bits**: the cutting tool attached to the end of the drill pipe that allows the drill to bore a hole through soil and rock (see Drill bits.

Also needed is a **mud pump** (5-HP Gas or 4.5-HP Diesel engine drives a 2-inch Monarch pump) to circulate mud down the drill bit and back up to mud pits. Without this separate piece of equipment, the drill rig cannot be used for conventional "Mud Rotary" Drilling.

Click Here for Detailed LS100, LS150 and LS200 Information, Prices, Weights & Dimensions

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Appendix O

LS-100 Part List

Click **HERE** if there is no button bar on the left side of your screen!

Mast

The mast is self contained, detachable from the base and contains a traveling shuttle which raises and lowers the attached rotary mount.

The Mast

Shuttle & Winch

The shuttle is driven by chain attached to a two speed hand winch that provides both hoisting and pull down capabilities. **The winch includes a handbrake which is used when the winch ratchet lock is released to lower the rotary.**

Winch

Rotary Mount

The rotary mount accommodates an engine-driven post hole digger. The throttle is modified to control engine speed.

Rotary Mount

Rotary Mount - Hinge

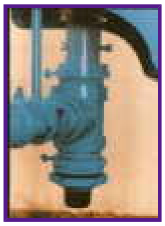
The rotary mount is ***hinged*** to the shuttle so that the rotary can be swung away to either side to enable well casing to be installed without removing the rig from over the hole. Quick removal of the rotary also allows for hand portability.

Hinge

The Swivel & Quill

The swivel and quill connect the drill pipe to the rotary power unit, allowing drilling fluid to pass through the swivel, into the quill and down the drill pipe to the bit. The side-entry swivel assembly was simplified by replacing bearings with low cost seals that are readily accessible for greasing. The swivel housing is secured by an adjustable support rod and clamp so seals ride at the proper surface of the quill.

Swivel



The Quill

A partially hollow and perforated quill couples the output drive to the rotary drill pipe. The quill is equipped with a hex nut the same size as the compression caps allowing the use of a special spanner wrench to unthread the quill from the drill pipe.

Quill

3-Way Valve

The 3 way valve, conveniently located on the mast, provides quick access for directing drilling fluid to the borehole or back to the mud pit. This is very useful when connecting new lengths of drill pipe or when loss of circulation occurs.

3-Way Valve

Slips

The table base is equipped with a slip which provides an easy way to quickly and conveniently support drill pipe while it is being threaded and unthreaded from the rotary. Slips can also be provided to support well casing in the hole while additional lengths are being glued-on.

Slips

Drill Pipe	**Inventory showing Drill Pipe**
The machine will accommodate a lightweight drill pipe for air or mud rotary drilling, auger, or with the use of air hammer percussion tools with a break-out system.	

Prior to leaving for a drill site, it is important to carefully examine the checklist to ensure that you have all the items necessary to finish the job. When drilling hours from your home base, you may not be able to return home to pick-up a missing coupling, an extra drill bit or a replacement swivel seal!

Parts List

Index #	Qty.	Part or Sub-Assembly Name
1	1	**Mast Assembly**
2	1	Hose Assembly, Pump to Flow Control Valve
3	1	Hose Assembly, Flow Control Valve to Entry Swivel
4	1	5-HP Rotary Engine
5	1	**Rotary Transmission** (25:1 ratio, with centrifugal clutch)
6	1	Support Bracket, Power Head
7	1	**Side Entry Swivel & Support Bracket Assembly**
8	1	**Slide, Break-out Slips**
9	2	Stabilizer tubes
10	2	Set Screw (Stabilizer Tube Locks)
11	1	Base Assembly
12	3	Bolt - 1/2-inch Coarse Thread: Lock-washer
13	1	**Shuttle Assembly** (Support item #6)
14	2	**Hinge Pin** (attaches item 6 to item 13)

15	1	Roller Chain #40
16	1	**3 way Mud (Air) Flow Control Valve**
17	1	**Winch Assembly**
18	1	Chain Tensioner Assembly
19	3	**Tie down ropes**
20	2	"C" Spanner Pipe Wrench
21	1	Hex Spanner Wrench, Break-out
22	1	**Drag Bit**, 5-7/8 inch
23	3	Drag Bit, 3-7/8 inch
24	1	Hole opener/Reamer, 5-7/8 inch
25		Drill Pipe, 1-1/4 inc Pipe, 5 feet long
		Optional Extras
26	1	Spare Clutch, Centrifugal
27	2	Spare Seal, Pump Shaft
28	2	Spare Seal, Water Entry Swivel
29	1	Tool Kit
30	1	Suction Hose with Intake Screen & Foot Valve
31	1	Hat, Safety
32	1	**Mud Pump** (Monarch Model BSGF-8)

Notes:

1. Items (4) and (5) are packaged assembled as a unit.
2. Items (6), (13), (15), (16), (17) and (18) come mounted on the Mast Assembly (1).
3. Not Shown: Container with Joint Grease; Bag with Assembly Hardware.

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Appendix P

LS-100 Assembly Instructions

Click **HERE** if there is no button bar on the left side of your screen!

Before you begin assembling the LS-100, unpack the shipping crate in a secure, dry, clean area to ensure that all the **parts** are still in the crate. When assembling or repairing the LS-100 and mud pump, it is helpful to make reference to Figure 1 below which shows the various components of the LS-100.

1. Remove Base (11) from the crate and install stabilizer tubes (9) and secure with set screws (10). Remove Mast Assembly (1) from crate and install onto Base with the 1/2-inch bolts (12) using a lock-washer under each head.

2. Remove Rotary Assembly (4) & (5) from carton. Place assembly on the shuttle bracket (6) while guiding the 2 bolts into the hinges.

3. Note that the push-pull type throttle comes installed. If the throttle keeps retracting, ensure that the throttle spring on the engine has been removed.

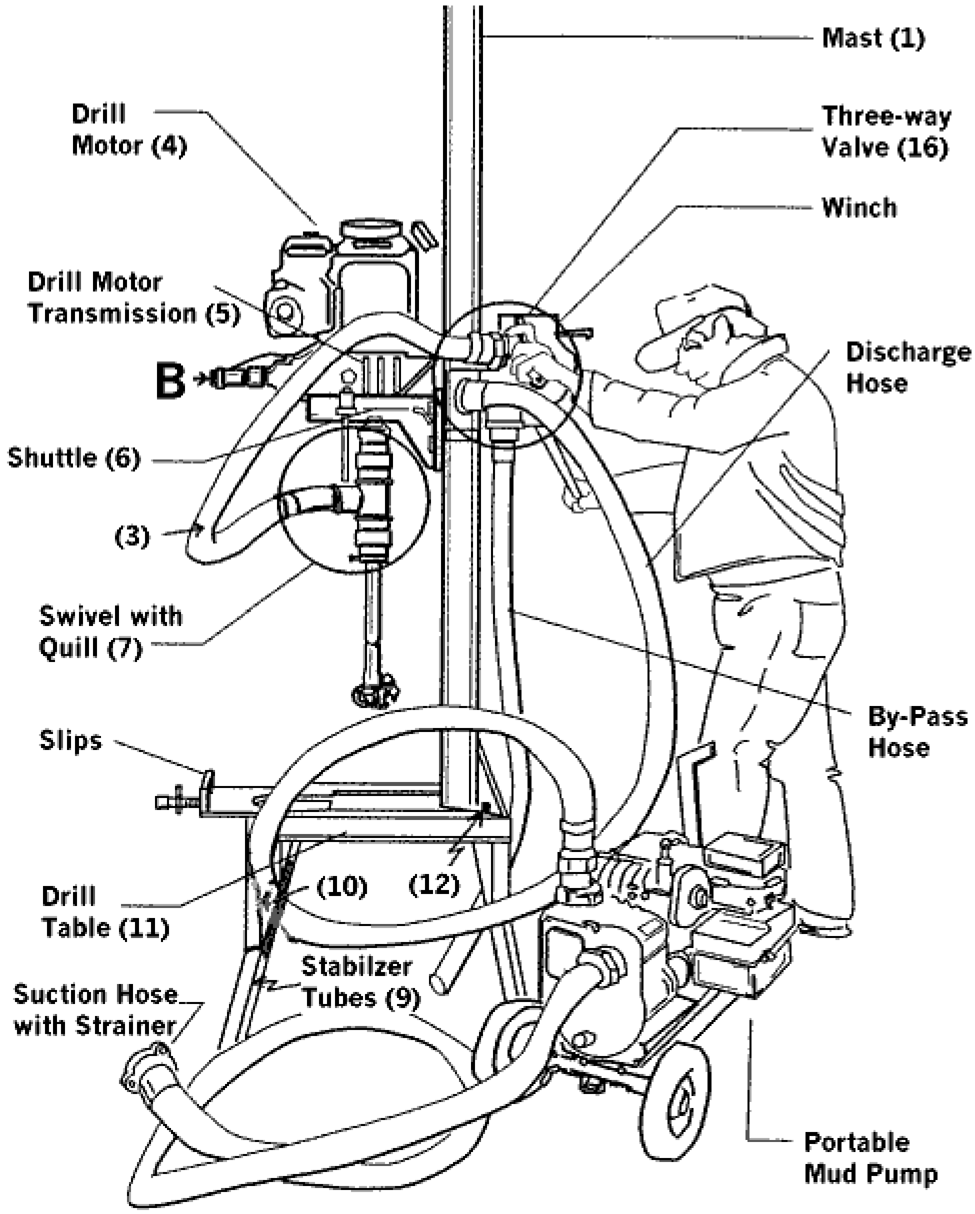
4. Connect side Entry Swivel to 3 way Valve with short 5' Hose Assembly (3).

5. Connect the by-pass hose to the nipple in the bottom of the 3-way valve.

6. Connect the mud pump discharge hose to the side port of the 3-way valve.

7. Connect the mud pump suction hose to the suction port of the pump and place the foot valve in the suction pit.

Figure 31: LS-100 Assembly



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Appendix Q

LS-100 Maintenance

Click **HERE** if there is no button bar on the left side of your screen!

Maintenance is a critical but often overlooked aspect of water development projects. Often it is not considered until there is a crisis because machines have broken down at a critical time or wells stop producing water during dry seasons. Special attention must be given to properly maintain critical drill machine components including:

- LS-100 Engine and Transmission Oil Levels
- Swivel/Quill Assembly
- LS-100 Chain, Bearings and Mast Lubrication
- Mud Pump

LS-100 Engine and Transmission Oil Levels

1. Check oil level in the engine crank case before beginning a new hole, and each day thereafter during the drilling operation add oil if necessary. **Note:** change oil after first five hours of operation, thereafter every 25 hours of operation. Use oil as recommended in the engine maintenance manual.
2. The oil level in the transmission case does not need to be checked between oil changes unless there is an obvious leak.
3. For all other maintenance of the engine and transmission refer to the operators manual which is included with the equipment.
4. The frame itself requires little or no maintenance.
5. Inspect, clean, replace (if necessary) and re-grease the swivel seals after each borehole.

Swivel/Quill Assembly

If properly maintained, one set of seals should last for 1000 feet of drilling. If not properly maintained, **sand can come in contact with seals, mix with the grease and act as a grinding wheel, causing grooves to form around the quill within 1 hour. Once this occurs, leaking can not be stopped**. This problem is the number one cause of LS100 drill rig breakdown!! To ensure that this does not happen, follow the proceedure listed below prior to drilling EVERY DAY:

1. Loosen the set screws on the upper and lower compression nuts.
2. Loosen the upper and lower compression nuts of the water entry swivel, remove the 3/8-inch bolt from the shaft, and pull out the quill.
3. Look for any grooves or notches worn into the quill at the position of the seals. If these signs of wear are noticed, replace the quill with one that is new or reconditioned. Worn quills should be immediately reconditioned by welding over the wear points and then smoothing the quill down using a lathe.
4. Apply grease liberally to the inside surfaces of the seals. Do not apply grease to the outside of the seals or to the seal seats on the swivel housing.
5. Reinstall the quill, insert the 95 mm (3/8 in) bolt and tighten the bolt lock nut. A lock nut must be used to keep the bolt from vibrating off during rig operation.
6. Tighten the upper compression nut until it is snug. Engage the rotary and, circulating clean water, continue to tighten the compression nut until the quill starts to bind. Then loosen slightly and lightly tighten the compression nut set screw an Allan wrench.
7. Repeat tightening procedure for the lower compression nut.
8. Using a grease gun, pump grease into both top and bottom compression nuts through the grease fittings. Keep adding grease until it is no longer easy to inject grease. Do not force grease into the fitting or continue to inject grease until it becomes visible at the top or bottom of the fittings.
9. If any leaks are observed from the upper or lower compression nuts during rig operation, loosen the set screws and tighten the compression nuts immediately. If leaking stops, re-tighten the set screw and continue drilling. If the leaking does not stop, stop drilling and re-prepare the swivel and quill assembly by repeating all the above points immediately.

LS-100 Chain, Bearings and Mast Lubrication

On the LS-100, oiling is most often needed on the chain and the winch bearings. Keep the chain lightly oiled; DO NOT USE GREASE on the chain as this will accumulate dirt and thus increase the wear of the chain. Apply a few drops of oil occasionally to sprockets and shafts and winch gears and shafts. Occasionally oil the front and back surface of the mast where the shuttle makes contact. Also apply a few drops of oil to the throttle control cable.

Mud Pump

1. Check oil level in the engine crank case before beginning a new hole, and each day thereafter during the drilling operation; add oil if necessary. **Note:** change oil after first five hours of operation, thereafter every 25 hours of operation. Use oil as recommended in the engine maintenance manual.
2. After each borehole, remove the drain plug from the pump housing and clean out sand, gravel or other debris that may have accumulated by flushing the pump with clean water.
3. For all other maintenance of the engine refer to the engine operators manual which is included with the equipment.
4. Replace the seals in the mud pump when a leak is detected at the pump shaft.
5. Inspect the impeller and replace it if it is badly worn. **Drilling is very hard on the mud pump and it will be necessary to replace it after 10-20 wells have been drilled.**

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Appendix R

Village Well Agreement

Prior to work beginning in a new village, community leaders must sign a water supply agreement which specifies community involvement including:

1. **an agreed upon financial contribution towards project cost.**

2. **In poor communities which have little money, some goods and services can be contributed instead (coconuts, dry fish, palm butter, mangoes, charcoal etc). However, we have learned that some cash payment (even $50 or $100) must still be required. Money can usually be raised for funerals for people who died from drinking contaminated water. Raising and giving cash money for a safe drinking water supply is an important sign of committment. For villagers to carry produce to market, sell it, and then hand over the money is a critical step towards communities taking ownership of their new water supply. Handpumps are rarely broken in communities which have payed money towards the project. They helped buy it, they help care for it. Conversely, hand pumps are frequently not working for extended periods of time in villages which did not contribute cash money... as the villagers grow frustrated with Lifewater for not coming to "fix our handpump that we planted in their community";**

3. **continuous night time security for all equipment and supplies. If items are stolen, the project will be terminated;**

4. **continuous supplies of clean water for drilling fluid. Hours and quantities which must be carried to the drill site are specified since disruptions to the supply of water can lead to serious drilling problems;**

5. **Details on donor thank-you letters to be written by village leaders;**

6. **free and open access to the water by all people, regardless of race, religion, sex, political persuasion or status within the local community. The agreement should stress that the community and not any single influential person in the village owns the well;**

7. **two people to be trained in routine pump maintenance. Since women have a major responsibility for water-related activities in most developing countries, their involvement in the repair team should be of primary concern;**

8. **$20/year to cover the cost of annual maintenance parts and labour.**

In addition, the following items are often included:

- quantities of materials which must be collected and brought to the site ahead of time. While the community's ability to pay must be considered, keep in mind that each well requires key tools and supplies which must be acquired prior to workers leaving for the selected drill site (see Table 3 - Section 3.3)

- 4 labourers to work under the direction of the Lifewater team;

- accommodation and meals for the Lifewater team during the period of well construction (usually 2-6 days);

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Appendix S

Pricing & Business Issues

Selecting Drill Trainees:

People to be trained in using the LS-100 should:

1. **be available for training and not expect to be paid for the training or guaranteed employment;**
2. **have a high degree of technical aptitude;**
3. **have experience with physical, hands-on type work;**
4. **understand basic water supply concepts and ideally have related experience;**
5. **be meticulous about details and maintenance;**
6. **be willing to provide a long-term time commitment;**

Selecting Team Members

After working with the Drill Trainees, choose who will be on the final Team by consulting with local leaders and considering the following factors:

1. **Motivation: Trainees should genuinely want to provide rural poor with safe, dependable water supplies. This desire should be rooted in a deep desire to share God's love rather than a desire to gain employment and make money;**
2. **Trust: There can not be on-going concerns over theft of money, equipment or supplies;**
3. **Ability: Technical/Mechanical ability, related experience, learn without being told twice and LOTS of common sense!**
4. **Enthusiasm: Look for people who take the initiative of finding work to do rather than always waiting to be told what to do;**
5. **Team Dynamics: Team members must get along well. Try to minimize the number of potentially divisive political, economic, tribal or religious splits within the team. In addition, one person should not be so domineering that the drill team or Action Agency can not work efficiently or be open & accountable;**
6. **Other: Leadership skills, business experience, inventiveness, problem solving skills, ability to drive;**

Estimating "Per Well" Costs

In estimating the cost of constructing a well, consider:

- **Material Cost;**
- **Overhead Cost: Office expenses, vehicle repair & fuel etc;**
- **Depreciation: Reserve to replace drill rig, mud pump and vehicle;**
- **Labour and Benefits: Retirement plan, injury support fund etc;**
- **Required Profit Margin.**

Material Cost

The cost of materials should be based on local replacement. This is particularly important for items like PVC pipe which may be initially shipped into the country to help start the drill program. Although shipping supplies may be necessary to help get a program started, self-sustaining programs can not be based on importing material.

Overhead Cost

The cost of support staff, renting office space, computers and typewriters, vehicle use expenses etc. should be kept as low as possible. These expenses are particularly critical when few wells are being constructed. In general, try to keep overhead to less than 10% of the amount charged for a well.

Depreciation

- Trucks often need to be replaced every 5 years. Given a price of $5,000 to locally purchase a used vehicle and an average of 10 wells constructed per year, this works out to $100/well!
- Count on replacing the LS-100 drill rig after 1.52 km (5000 ft) of drilling. This can be taken into account by setting aside $3.28/m ($1/foot)of drilling;
- Depending on hours of use and the type of material being drilled, mud pumps may need to be replaced after 760 m (2500 ft) of drilling. This works out to an average replacement cost of $0.65/m ($0.20/ft) of drilling.

Labour and Benefits

Labour rates should be set so that they are in-line with local pay-scales. If people are working full-time constructing wells for others, they should be paid enough so that they can support their families. Separate rates of pay should be established for a borehole and for a cement pad & handpump since sometimes just a borehole is drilled (and a submersible installed by others) and sometimes an existing well is rehabilitated with a new pad and pump. As a rough guide, consider $100 for a borehole and $100 for a pad & pump.

In some countries, there is cultural expectations that employeers will take care of their employees when they are sick, injured or retired. If you and your organization are not prepared to take-on this responsibility, it would be worthwhile to help the team establish a local fund to cover these items. Money for this fund could be taken from the labour stipend (see above).

Profit Margin

It is really important that National Drill Teams work towards becoming financially independent. This breaks the cycle of dependence on foreign aid and enables Lifewater to focus their resources on helping new crews get trained and equipped. This can be done by constructing wells and handpumps for government agencies, in-country aid & development groups and drilling private wells.

The Goal of Lifewater Projects is to supply rural poor with safe water. In order to raise the money needed to do this, National Drill Teams can construct one or two wells for profit and then use the proceeds to fund construction of a well for villages which can't pay full costs.

Drilling for Profit

The amount of money which can be charged for private wells is dependent on what local people, businesses and agencies can afford. However, the amount charged should *never be less* than the total, unsubsidized cost of constructing a well. As a general rule of thumb, charge twice the unsubsidized cost for a borehole and 1.5 times the unsubsidized cost for a cement pad and handpump.

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Appendix T

Making Safe Drinking Water

The first choice is to bring water treatment devices with you whenever you travel to a developing country. However, if you have forgotten to bring one, consider the following options to make safe drinking water:

Boiling: Vigorously boil water for 5 minutes. The flat taste of boiled water can be improved by pouring it back and forth from one *CLEAN* container to another. Also, a small pinch of salt can be added to each quart of water boiled;

Chlorination: Add 5-10 drops chlorine bleach per quart of clear water, thoroughly mixing it and allowed to stand for at least 30 minutes. The treated water should have a slight chlorine odour; if it doesn't, the dosage should be repeated and the water should stand for 15 minutes more. If this treated water has too strong a chlorine taste, it can be made more drinkable by allowing the water to stand exposed to the air (should be a light cover over the top to prevent insects, etc. from falling into the water). Pouring it back and forth between two *CLEAN* containers will also help.

As a last resort, if the above options are not available, consider the following:

UV Exposure: Make safe drinking water by putting clear water in a clean container and expose it to bright, hot sun for at least 8 hours;

pH Adjustment: Add lime to bring the pH above 10 for several hours. Expose the water to atmosphere for several hours to allow natural CO_2 reactions to bring the pH back down to at least 8.5 prior to drinking. **Please note that this should only be used as a last resort since the validity of this method to make safe drinking water has not been scientifically investigated**.

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Appendix U

Lifewater Packing List

"Get ready what you need, pack what you can and count on your luggage getting lost" (Trip Veteran)

Critical Items to Bring Overseas:

- Passport (make sure it wouldn't expire during your trip!)
- International Immunization Card
- Lots of $US (including $1 bills for tipping)
- Official Letter of Invitation: From your in-country host or the Agency you are representing. It should list the items you are carrying and specify what they will be used for. This letter will help a lot in certain airports where custom officers may ask you to pay duty on the items.
- Contact names and phone numbers (include a "back-up" plan in case you are not met at the airport!)
- Malaria Prevention Pills
- Water treatment pills or device
- Pills to treat Bacterial Diarrhea
- Water quality test kits (such as pathoscreen)

Medical

- Tension Bandage (Ace Wrap)
- Tylenol-3 or Demerol
- Topical Lydicain (local freezing agent)
- Athlete's Foot Powder
- Strip Bandages (cloth)
- Triple Anti-biotic Ointment (for cuts)
- Hydrocortisone
- Salt Pills
- Electrolyte (1/person/day)
- Gatorade Powder (enough to mix 2 liters/person/day)
- Prescription Pills to treat Bacterial Diarrhea (or Imodium)
- Handi-wipes (3 wet wipes/person/day to clean hands without water prior to eating)
- Steri-Aid Kit (emergency medical IV, sutures etc)

- Sun Tan Lotion
- Mosquito Repellent ("deet" such as "Deep Woods Off"
- Vitamin C (or Multi-Vitamin)
- Soap & shampoo
- Toilet paper
- Aspirin
- Iodine pills (for cuts and emergency water treatment)
- Cold remedy/antihistamines (Neo Citrin)
- Peptobismal (1/meal, 2-4 after dubious dining experiences)
- Pocket pill container
- Optional: Sleeping pills (note: high re-sale value to team members who didn't bring any when it is 100 degrees at night, they have not slept in days and their ear lobes are sweating!)

Miscellaneous

- Water bottle & water treatment device
- Small clasp knife (to peel fruit)
- 4 extra passport photos (for in-country visa paperwork etc)
- $1 US bills (for tipping)
- Duct Tape (repair luggage, plug bathtub, seal window screen)
- Work Gloves
- Sun Glasses
- Nil Odor (for bathrooms and boots that do!)
- Day pack (avoid putting belongings down in high risk areas)
- Cheap waterproof watch (leave expensive looking ones home)
- Travel clock
- Camera and film (Fujichrome slide film is best)
- Window screen (folds flat in bottom of suitcase and, with a little duct tape, can make an open window bug-proof leading to hours of pleasurable relaxation)
- Playing cards
- Writing paper & pencils
- Bible
- Laundry soap
- Flashlight with extra batteries (alkaline last longer)
- Small collapsible umbrella
- Multi-purpose screw driver (bits in handle)
- 3.81 cm (1.5 in) screws (a bunch plus an assortment of others)
- Bolts/screws for making bush pump (min. 2 sets if new program)
- Credit card & Travelers cheques (note: do not depend on them ... they may not be accepted or may take weeks to be cashed!)
- Optional: Pepper spray (do not pack in carry-on luggage)
- Optional: Small, self-supporting tent (even set-up in room with

many open windows) Smaller and more flexible than mosquito net

Gift Ideas

- Shirts (t-shirts and short-sleeve cotton button working shirts)
- Watches
- Work gloves
- Hard candy (good for motivating kids to haul water)
- Calculators
- Rubber boots/work boots
- Cover alls
- Drip irrigation systems
- Sun glasses
- Pocket bibles
- Medical supplies (re-hydration salts, antibiotics etc)

Clothing

- Hat
- Sandals
- Work boots
- House/plane slippers
- Underwear, socks
- Sweater (it can be surprisingly cold at altitude or at night during the rainy season)
- Bathing suit & towel
- Rain coat
- Women: Nice dress (with sleeves), cotton blouses & skirts
- Men: Cotton shirts, 1 pr shorts (big pockets), 1 pr work pants (long legs), tie, 1 pr dress pants, dress shirt
- Option: purchase native dress (women) or dress shirt (men) in-country. You probably want to buy one to bring back anyhow, they are cool and are cheap
- Eye blind (for sleeping on plane or in Arctic night-time sun)
- Ear plugs (when billeted near a disco)

Preventative (Before You Go)

- Immunization Shots (some start 3 months prior to departure!)
- First Aid Training
- Dentist check-up
- Blood Type team members (direct donate in medical emergency)

- Physical exam
- Leave important numbers at home (include traveler check numbers, photocopy of passport, embassy & team members home phone, fax & email numbers)
- Write key numbers on in-side of your belt (bandits rarely want your shorts!)
- If required, wire large amounts cash to contact person in-country (rather than carry it in)

Important Items to Take When Starting New Projects:

- Printed copies of the Lifewater Well and Pump Manual
- Poster size copies of some of the figures from the manual
- A container of Drilling Polymer
- Screen to sieve gravel for the Filter Pack
- Bolts needed to make Bush Pumps
- Tools (2 aluminum pipe wrenches, 1 plumbers pliers, 1 multi-head screw driver and assorted 3.81 cm (1.5 in) screws, hack saw with spare blades, grease gun, spare swivel seals for the LS-100)

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[Click Here for the Well Construction Tutorial]

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Water For Life

PO Box 456,
Kalona, IA
52247-0456
USA
Fax: (319) 656-3610, Phone: (319) 656-5433
This organization is focused on providing wells in Haiti.

Water For Survival

PO Box 6208,
Auckland,
New Zealand.
Fax: +649 5289759
Email: John La Roche, Director

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