Process of Drilling

Overview of the Drilling Process

A borehole is drilled by rotating a bit at the end of a 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 flud 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 gallons) 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 roate above the bottom of the buide 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 controls 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 well circulate from the Mud Pump through the bottom by-pass hose back to the pit. Add water as required to top-up the pits.

Turn the valve so that water flows into the drill swivel and make sure that no water is leaking from the swivel seals. If you have a water leak, re-direct the water through the by-pass hole or stop the mud pump. Loosen set screws and tighten gland nuts quite snug until leaking stops. Re-tighten set screws. It may be necessary to repeat this process during the drilling operation. Pump grease into the top and 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 30cm (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 winchh 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 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. 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 or the drill bit to jamb. 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.
- contaminated soil and/or groundwater
- a confined aquifer which causes water to flow out of the borehole under pressure.

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**! 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;

If it appears that the borehole has only penetrated a marginal aquifer see paragraph below on "When to Stop Drilling", 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 Water a tubing or blow-out water using an air compressor. 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. 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 <u>severe</u> well development problems).

Replace the drilling fluid with clean water or drilling mud prior to drilling into the aquifer. 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 paragraph below.

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.

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

Deciding Where to Drill

When drilling equipment is available, it is very tempting to get right to work drilling wells. However, wells should be carefully sited 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, and protected from contamination. While every borehole will not result in a good well, advanced planning with the community 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.

Aerial photographs, geologic reports, well logs and topographic maps are useful in studying these factors. Where available, specialists should be enlisted to use geophysical techniques to define subsurface conditions. This is most important in areas where air photo coverage and hydrogeological information are inadequate, where local rainfall is less than 700 mm/yr and where adequate water supplies are only available in rock . 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.

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 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).

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. 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). 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.

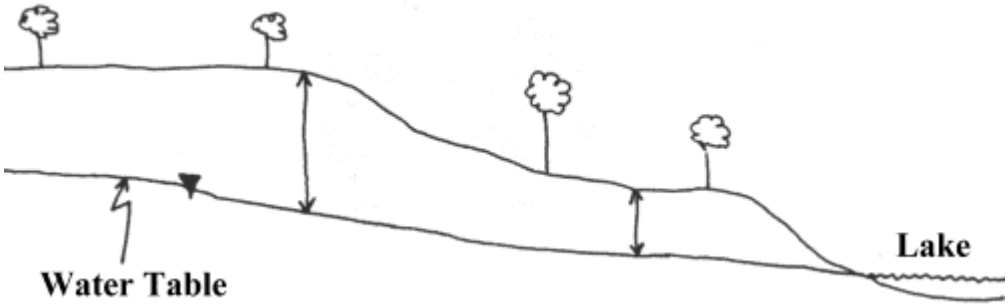
Vegetation

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).

Topography

The water table commonly follows the land surface. While the lowest areas (valley bottoms or depressions where water accumulates after rains) are generally the best places to drill 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.



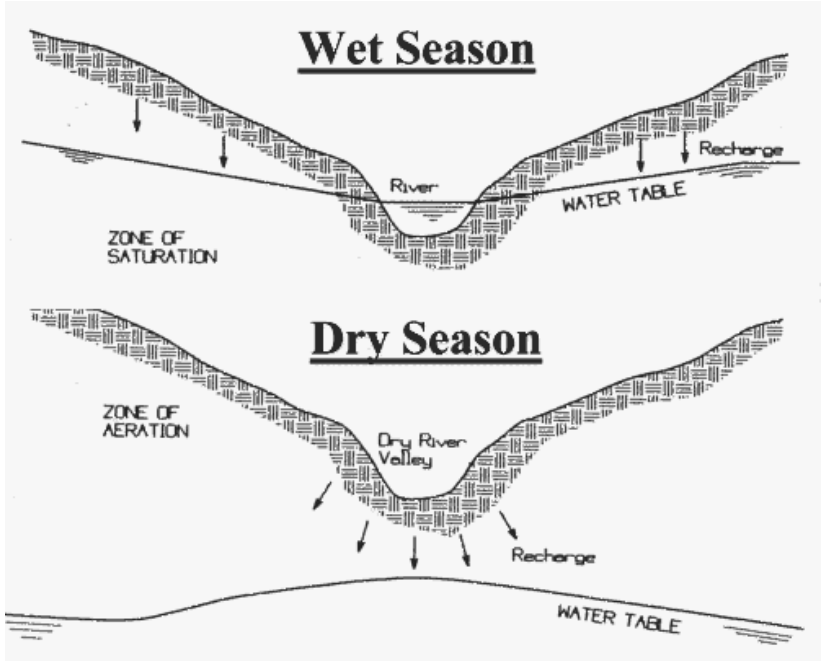
Depth to water

Surface Water

Successful wells are often drilled near rivers; groundwater may be available even if the river is temporarily dry. Reliable wells have even been located near broad sandy riverbeds which are active once every 5-10 years. 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.

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.



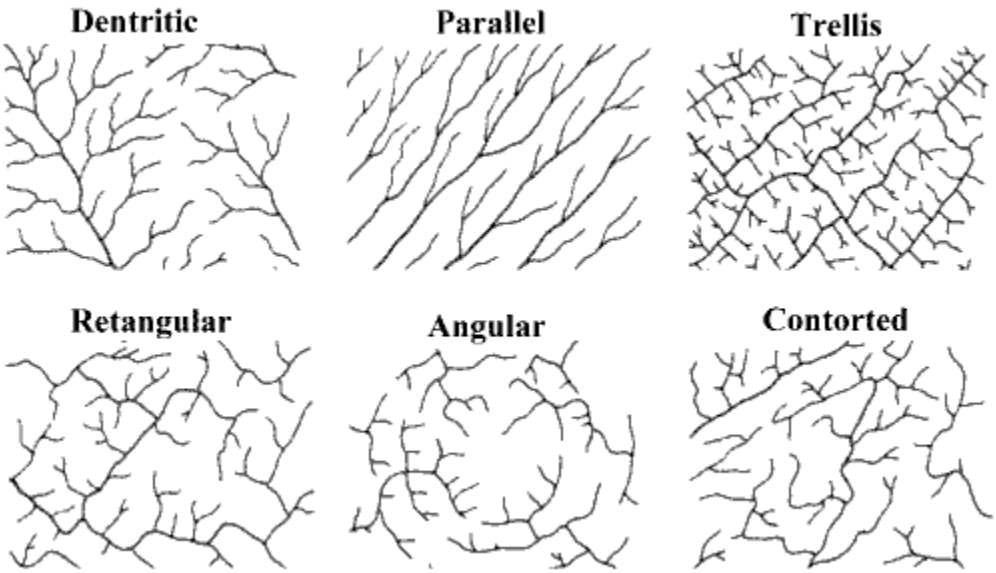
Finally, surface drainage patterns can be used to determine rock type.

- Trellis and rectangular drainage develops

where dipping, fractured sedimentary rocks are present; these are the most favourable areas for high yield aquifers.

- 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.

Drainage Patterns



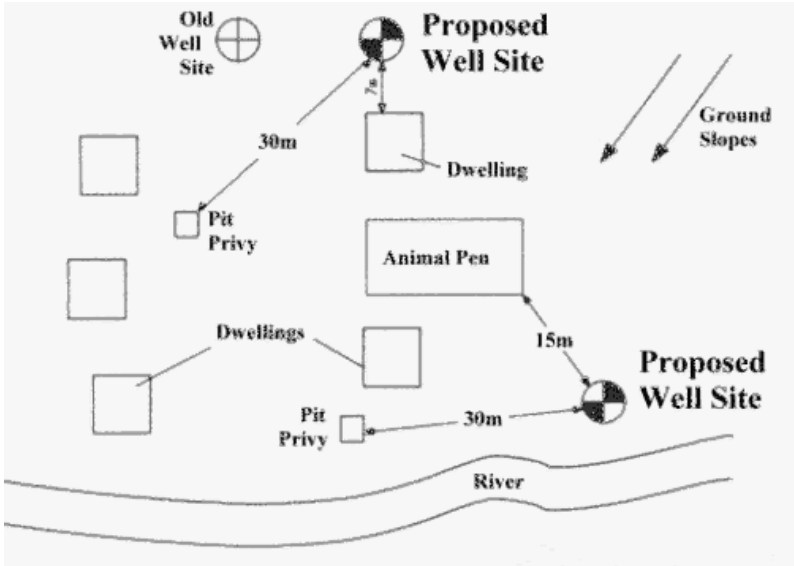
Sources of Contamination

Well water should be tested 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.

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).

Separation Distances from Contaminant Sources



Accessibility

Issues of accessibility to well should be clearly addressed in the Community Water Supply Agreement. 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. 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. 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.

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.

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 .

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.

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.

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.

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".
- As mentioned earlier, after you stop drilling, ensure that the borehole is kept full of drilling fluid until the casing and screen have been inserted into the well, gravel packed and the sanitary grout seal placed..

The well screen is the "**heart of a well**" and the filter pack 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.

Well Development Basics

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.

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.

Well Development Techniques

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. 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.

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 meters below the bottom of the pump cylinder would greatly increase the suction effect on the isolated sections of screen.

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. 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. Be prepared to bail and bail and bail and bail ... it is hard work and can take all day!