Well Development

Before any decision can be made on well development, it is necessary to check on the exact situation that exists in the zone to be developed.

The overriding considerations are:

- Cost
- Time
- Tools, equipment and materials available
- Yield
- Likelihood of achieving the desired yield
- The risk of causing a decline in yield or loss of the well

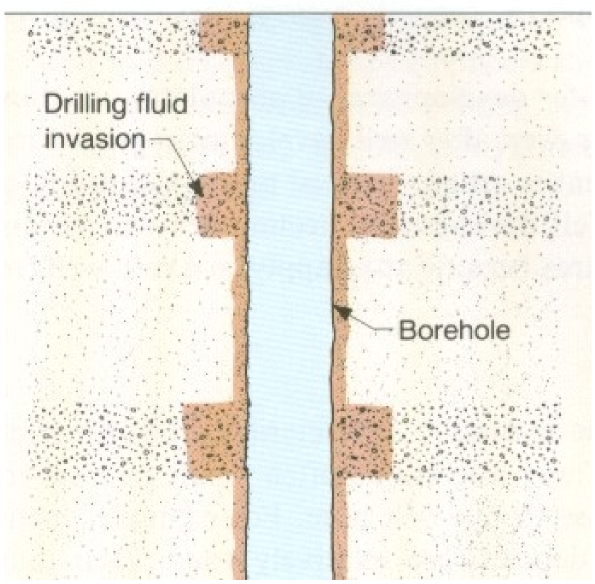
A secondary issue, but equally as important include:

- Drilling fluids used during the drilling process
- Type of drilling method employed
- The nature of the aquifer, its permeability and chemical composition
- Well type i.e. rock well or screen well

Development procedures are designed to create a non-turbulent flow into the well. As water from the aquifer flows toward the well, the flow lines crowd together as they approach the well. This crowding causes resistance. Any flow resistance decreases yield. It is to lessen flow resistance and improve permeability that we use well development techniques to remove any flow obstructions.

A process called well development must occur whenever a well has been installed in the subsurface. This will ensure proper hydraulic connection with the aquifer. Drilling fluids can be introduced into the adjacent aquifer during the well installation. Even with hollow-stem auger drilling which uses no drilling fluids, clays from adjacent strata can be smeared along the borehole walls during drilling. A fine layer of clay smeared along the well screen will decrease the permeability of that region and alter the hydraulic response of the well.

The purpose of well development in wells used for water resources is to alter the physical characteristics of the aquifer near the borehole in order to allow water to flow more freely toward the well.



Well development removes fine sediments along the well screen-aquifer contact and some distance into the formation.

In terms of the apparatus used and the type of water motion created across the well screen, the methods may differ. A back and forth flow (alternating inflow and outflow across the well screen) is preferred.

Fines are removed from spaces between larger sand grains causing open spaces “bridged” by the sand grains. This unstable condition can later collapse causing fines to enter the well.

There are different types of well development methods which include:

Overpumping

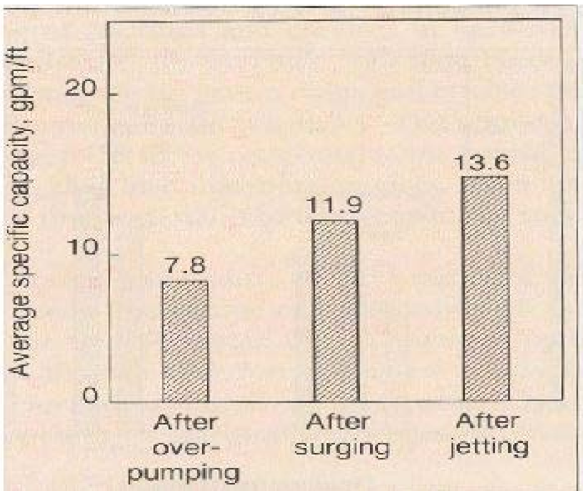
- Pump the well at a higher rate than expected for its future use
- Must use a pump that will not be damaged by sand in water

- Only results in inflow across screen – can produce sand bridging
- Preferential development can occur – removal of fines from only the high permeability zones and/or upper section of well screen

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



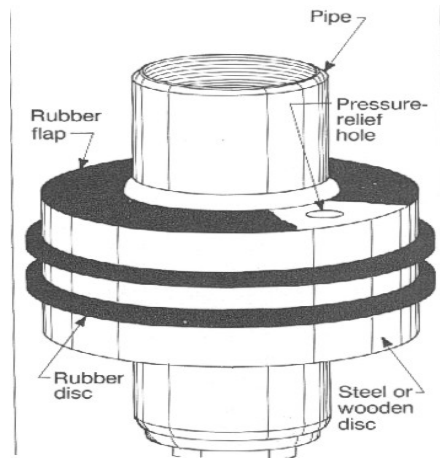
The graph above shows clearly the impact on specific capacity when overpumping was followed by surging, and then surging was followed by jetting. Specific capacities of the wells involved in this controlled test were improved 74% when a 3-step development approach was employed. The results shown above are for screen wells rotary drilled with bentonite fluid additives.

Mechanical Surging

Mechanical surging is the first of two methods of well development that removes particles and clogging materials by the force of water impinging on them. A development method such as mechanical surging is a vigorous development method not suited to all aquifer types.
Mechanical surging has less potential for aquifer damage if a continuous flow of water into the well from the aquifer is maintained.
Mechanical plungers may be fitted with one-way valves allowing them to lift water and fine sand out of the hole. Solid plungers do exist but have more potential to damage the aquifer. The results of mechanical surging should be measured by checking the well yield periodically, every

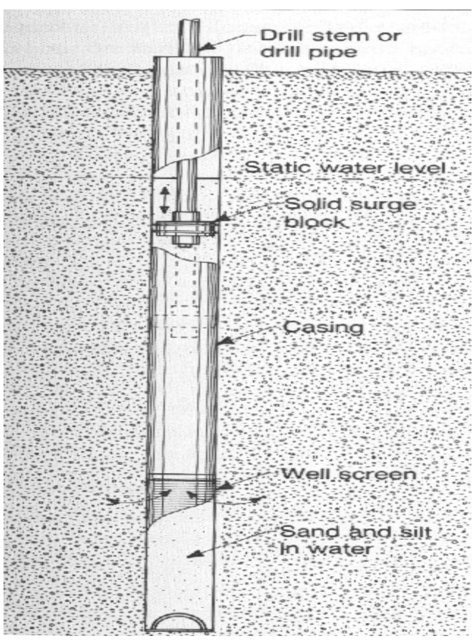
hour after the process begins. Surge plunger should be a good fit in the casing. The plunger may be attached directly to the drill stem or operated by hand depending on well depth.

Water is forced to flow in and out of a screen by raising and lowering a plunger apparatus within the well casing.
Apparatus called a surge block
The surge block is attached to PVC pipe and raised and lowered causing water flow through the well screen.
Sediment must be removed from the well by bailers, other pumps or air lifting



Air Lifting or Surging

Compressed air is injected into the well and lifts water and sediment to the surface



For removal of the sediment, the water/sediment mixture is allowed to exit the well at the ground surface
For surging action, the air injection is stopped before the water reaches the surface and the water is allowed to fall down the borehole.
Need to be careful of rupturing the well screen with the compressed air.

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

Well development is 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 before the well is placed in service.

By boring fewer boreholes, it will ensure that wells are developed to the best possible technical standards. The well 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

Well development methods are based on establishing velocities of flow greater than those produced by the expected rate of pumping from the completed well. This is combined with vigorous reversal of flow (surging) to prevent sand grains from bridging against each other. Movement is 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.

Whatever the method used in developing the well, the ultimate purpose is the same. Well development is carried out to maximize well yield. All new wells should be developed before being put into production to achieve sand free flows and maximum yield.

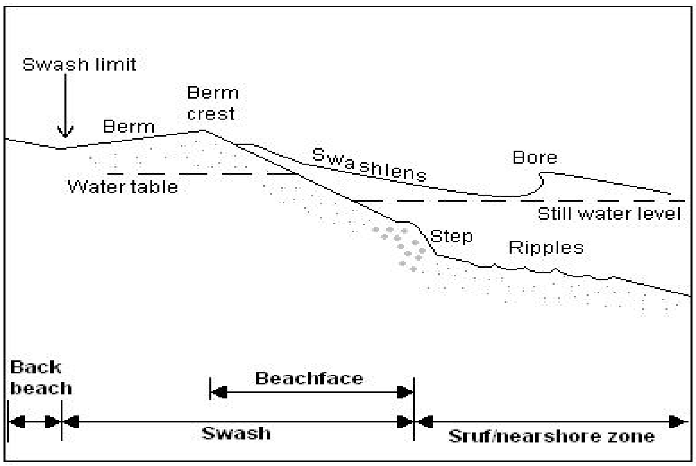
There are two main objectives to be achieved through well development. Better well yield will be accomplished whichever method is used.

1. Repair any damage done to the formation surrounding the borehole by the physical operation of drilling. Repairing the damage to the formation involves:
    - Removing any “clay smear” or “mud cake” covering the aquifer surface
    - Flushing out of the borehole drilling fluids, which were introduced during the drilling process.
    - Reverse any chemical or physical changes to the formation surrounding the borehole, which was brought on by the drilling activities and or drilling fluids.
2. Improve near-well permeability and stability. By improving the permeability and stability of the area immediately adjacent to production zones, water flow into the well is maximized.

To improve near-well permeability and stability the smallest size particles in the areas surrounding the production zones must be removed. By removing the sediments and fine particles from the near-well area, a high permeability zone is created. Thus, more water can be obtained from the well.

Backwashing

This is also 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.

Development by Surging

Surging is another, less common method used for developing well yields in bedrock wells. This development method uses a cable tool drill machine. Cable tool machines were commonly used for drilling water wells up until the 1960s, when rotary drill machines replaced them. The cable tool method of drilling employs the principal of free falling weight to deliver rhythmic blows against the bottom of a drill hole. A drill bit is attached at the bottom of a string of tools, which is suspended by a cable and systematically raised and dropped within the well. When used for well development, the drill operator surges the well using the same method of raising and dropping the drill string, either with the standard drill bit, or by attaching a surge block in place of the bit. The rhythmic action of the drill string pushes water into bedrock fractures and then pulls water out of the fractures. This surging action flushes and removes fine particles and rock fragments from existing bedrock fractures, resulting in an increased flow of water to the well.

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.

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. 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.

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.

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. Bailing is hard work and can take all day.

Well Development by Hydro-fracturing

Hydro-fracturing, commonly referred to as hydro-fracking, is a well development process that involves injecting water under high pressure into a bedrock formation through the well. By using this process, it is intended to flush and remove fine particles and rock fragments from existing bedrock fractures and/or increase the size and extent of existing fractures which results in an increased flow of water.

The procedure is often used to increase well yields of new deep drilled wells with marginal or inadequate production rates. It may also be applied to older existing wells that have progressively diminished recovery rates over time, which is usually caused by mineralization and incrustation of rock fractures.

History

Hydrofracturing was originally developed in the oil fields to increase production volumes and is a relative newcomer to the drinking water well industry. It is now the method preferred by most contractors for developing bedrock wells because it is a controlled process. Older methods included blasting with dynamite and, more recently, the application of dry ice to a capped well. These methods were somewhat uncontrolled and sometimes resulted in well failure.

The use of dynamite frequently caused wells to collapse from the force of the blast, rendering the well useless. The use of dry ice was common only a few years ago and was a much less violent approach to applying high pressure to the bedrock formation. The resulting phase change of water to ice from melting of solid carbon dioxide (CO_2) to gaseous CO_2resulted in a 5 percent increase in volume of the water/ice and an increase in the volume of CO_2 gas. The well was capped immediately after the introduction of dry ice into the well. The CO_2 gas was trapped in the well as it expanded, resulting in a significant increase in pressure. The pressure generated theoretically had the same effect on bedrock fractures as the hydrofracturing process does today. Unfortunately, in some wells the increased pressure on the well casing forced the casing in the upward direction causing the drive shoe seal to lift, consequently breaking the seal and allowing surface water, or near surface groundwater, to enter the well. In one reported instance the well casing actually shot out of the ground into the air. The hydrofracturing process eliminates this problem by controlling the pressure with packers below the well casing.

The Hydrofracturing Process

The procedure involves the installation of an inflatable or mechanical packer that is placed in the

well bore at least 40 feet below the well casing and drive shoe seal, and at least 60 feet below the ground surface to ensure that the process does not "break" the seal or allow surface water contaminants to enter the well. The packer is inflated or locked into position and water is pumped through the packer under pressure. Most applications require between 500 and 2,000 pounds per square inch (psi) pressure and in some cases 3,000 psi pressure may be needed in tight rock formations.

If successful, pressure will steadily rise to a maximum level as the rock formation resists flow, then pressure will suddenly drop off and stabilize at a lower level. The drop in pressure indicates that the formation is accepting water and the resistance to flow is diminished. Water is then pumped into the formation for 5 to 30 minutes. Injection pump delivery rates of 50 to 75 gallons per minute (gpm) have proven successful. Generally, 1,500 to 2,000 gallons of water or more are pumped into the bedrock formation.

It is extremely important that only potable water, or clear disinfected water, is used for injection water because of the high pressures involved and potential for forcing contaminants deep into the bedrock fractures.

One or two packers may be used for hydrofracturing. When utilizing one packer, the packer is set near the top of the well but at a safe distance below the drive shoe seal. After the initial pressurization sequence, the packer is released and lowered further into the hole, and the process is repeated as many times as necessary. Commonly, two pressure sequences are performed.

Zone isolation hydrofracturing uses a two packer system where the packers are placed in series and water is pumped into the isolated zone between the packers. This system can be more effective because it concentrates hydraulic pressure within a small area, typically 30 to 60 foot intervals, and individual fractures can be isolated and hydraulically developed. With this method, approximately eight zones are isolated within the well starting within a specified section of the well targeted by the water well contractor. Each successive pressure sequence stresses one interval higher than the last. In this way, all potential water bearing fractures, or fracture zones, are worked independently within the section of the well bore being developed. This differs from, the single packer, one or two sequence method, which probably only affects the weakest, least resistant point(s) in the well.

The single packer method is generally used for private wells serving individual households and commonly produces adequate results. Zone isolation hydrofracturing is a much more expensive and time consuming procedure, and is generally used only on very difficult wells or public supply wells where a larger flow of water is desired.

Testing Well Yield

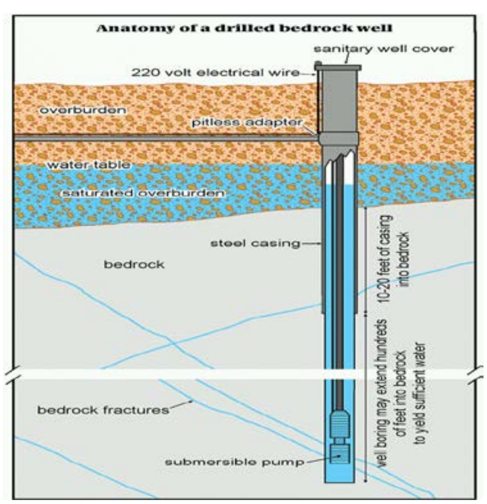
Well yield is the volume of water that can be pumped during a specific period of time (it is expressed as litres or gallons per minute). Sometimes the yield of existing wells will be tested to determine if it is worthwhile to drill in the same area. If a submersible pump is installed, a full pump test can be done. 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.

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.. 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.



Well yield increases, if successful, are generally modest but may constitute a significant increase if the original well yield was very low. Occasionally, large increases in well recovery rates are realized. A typical well yield after hydrofracturing is 0.5 to 5 gpm. Water well contractors report a high success rate. However, in some instances due to geologic conditions hydrofracturing will not increase well yield. If initial pressure continues to build and reaches the operator's maximum equipment capacity, the formation will not accept water and the procedure may not be successful.

Many water well contractors do not include yield testing as part of their hydrofracturing Contract because injection water volumes are large enough that it may require an extended period of time to allow the bedrock aquifer to reach equilibrium. If the yield test is conducted immediately after the well is hydrofractured, the amount of water injected into the bedrock formation must be a consideration to avoid an over estimation of the increased well yield.

Safety Issues on the Job

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.
- 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;

- 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;
- 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..

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

Heat stroke

Gastro-intestinal illness

Traffic accident

Injury on the Job and/or transfusion with tainted blood

Being mugged or attacked