Shallow Well Drilling

Well construction with small mud rotary rigs

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About Us

Lifewater International is a Christian nonprofit organization established in 1977 that demonstrates God's love by helping communities in Africa, Asia, and Latin America gain safe water, adequate sanitation, and effective hygiene practices that they will enjoy for generations. Focusing on sustainability, Lifewater and its qualified volunteer field trainers train and equip in-country partner organizations in the three crucial components of water development: water, sanitation, and hygiene (WASH). Lifewater's partner organizations then use the training and resources to help local communities meet their basic water and sanitation needs. Through this, both partners and local communities gain confidence in their ability to nurture the health and well-being of their people.

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Purpose of This Manual

Learning the art of well drilling requires hands-on experience. Book knowledge is not sufficient. Therefore, to make the most of the information provided here, we recommend that you attend our course in Shallow Well Drilling to acquire the skills, knowledge, and attitudes that are considered necessary to implement a successful water well drilling program using the LS200 or other small mud rotary rigs with a similar capacity. [See our web site, www.Lifewater.org, for details.] As used in this manual a "shallow" well is one designed to be used with a hand pump, the strongest of which can lift water about 80 meters from the water table to the surface.

Due to the limitations of these small drill rigs, some topics that would be necessary to cover in a well drilling manual intended for a broad range of drilling equipment are not addressed here. Furthermore, this manual is not a detailed technical reference for the LS100, LS200 or LS300 drill rigs; that information is available from the manufacturer, Little Beaver, Inc. in Livingston, Texas www.Littlebeaver.com, 800-227-7515.

The lessons in this manual are intended be taught in a participatory style, with a high level of student interaction and hands-on practice. Many of the lessons are also suitable for "distance learning" where students read the lesson, answer questions, and engage in remote group discussions. Ideally, this class will be taught over a period of approximately one month. Students need sufficient time working with the drill rig under supervision so they can develop good habits.

The upper-right corner of the first page of each lesson displays one or more icons that indicate the setting for which the lesson has been written:


Lessons that can be studied individually at home.


Lessons that will work best in a classroom setting.


Lessons that are best taught on the drill site.

Acknowledgements

Lifewater International is very fortunate to have as volunteers many distinguished well drillers and hydrogeologists. Their contributions to this manual have been immeasurable. In addition to the many friends too numerous to list who have offered useful suggestions and helpful advice, the following colleagues deserve specific recognition and appreciation: Peter Ball, Jim Clark, Timothy Cleath, Martin Hamann, Greg Hamer, Joe Haynes, Shawn Roberts, Glenn Stronks, and Joseph Troester.

Dedication



This manual is dedicated to the memory of Harry Westmoreland, who went home to his reward on February 16, 2007. As the founder of Lone Star Bits, Harry was the principal designer and the original manufacturer of the LS series of drill rigs. Almost everything I know about well drilling was learned from Harry. But Harry's mentoring went far beyond the techniques of well drilling. His passion to see the poor gain access to safe water and the knowledge of God's love was truly contagious. There is no way to know how many lives Harry touched for good, but the world is a much better place for him having been here. *FLP*

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Lesson 1.1 Welcome!

Purpose

To get to know one another and reflect on the purpose of taking this class.

Objectives

By the end of this lesson, participants will have

- Briefly shared an experience which inspired them to work in well drilling
- Become introduced to one another
- Illustrated and shared with one another their expectations for the class

Materials

- Name tags
- Paper and markers

Preparation

- Organize the class into teams based on working groups or other relationships
- If possible, include an experienced person in each team
- Name tags should be numbered or color-coded to identify team membership

Time

45 minutes

Steps

1. Introductions
2. Lifewater's Mission Statement
3. Express Your Expectations

1. Introductions - 15 minutes

In order to get to know one another in a new way, take a few minutes to think of one significant event that led you to become involved in well drilling.

Then use a blank sheet of paper to draw a simple representation of that event. Write your name on the top of the paper and a short sentence about your event below the drawing. When you're finished, you can share the event with the class, if you wish.

2. Lifewater's Mission Statement - 10 minutes

In groups of two, read Lifewater's Mission Statement below and discuss any element that stands out to you. Be prepared to share your thoughts with the rest of the class.

MISSION STATEMENT

"Compelled by God's call and the global water and sanitation crisis, Lifewater International equips partner organizations and works with them to empower communities in developing countries to gain safe water, adequate sanitation, effective hygiene, and the knowledge of Jesus' love."

3. Express Your Expectations - 20 minutes

Note the color of your name tag or number written on it; that is the team you will be working with throughout this class. Gather together with your team.

Working together with your team, draw an "expectations hand" similar to the one shown, and write on it some of your team's expectations for this class.

Post your team's hand on a wall with other teams' expectation hands. Read the other teams' expectations. We'll hear what stands out to you.

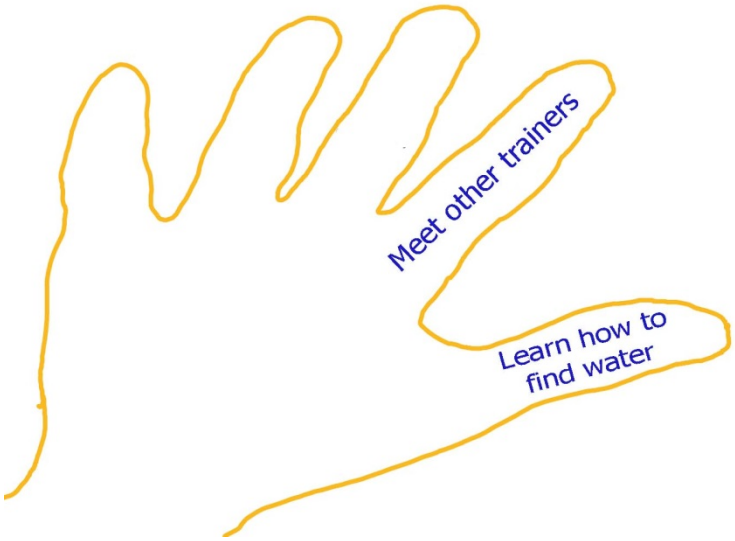


Figure 1 Expectations Hand

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Lesson 1.2 Class Objectives

Purpose

To share the objectives of the course.

Objectives

By the end of this lesson, participants will have

- Examined Lifewater's goals in the course

Materials

- Flip chart and markers

Preparation

- Study lesson ahead of time

Time

30 minutes

Steps

1. Course Objectives
2. Two Challenges
3. Review the Manual

1. Course Objectives - 5 minutes

This is an introductory course designed to give you the basic skills needed to get started in the process of learning how to construct a good well. (**Note:** Throughout this manual, the term "well" refers to a drilled well or borehole; a "tube well" in some countries. When the manual refers to a larger diameter well that has been dug by hand then the term "hand-dug well" is used.)

Well drilling is a combination of technique and "art" – you may quickly pick up the basic techniques, but it will take much experience to learn the art of well drilling. So never lose the sense that you are a "learner," even years after you have completed this course. A good well drilling crew works together like experienced performers in a complicated dance. When each one knows his steps and does them well, the result is very good.

In this class you will learn how to recognize a good drilling site, taking into account the occurrence and movement of groundwater as well as important cultural factors.

You will learn that a good well is much more than a hole in the ground. You will also learn – through experience - that well drilling is a problem-solving exercise!

We will spend a lot of time learning the mechanical details of constructing a good well and what it means to be a "professional" well driller.

But just making a good well is not enough, is it? Don't we also want people to gain knowledge of God's love?

So, in addition to being well drillers we are also ministers of the Gospel. That should make a difference in everything we do. Therefore, in this class we will consider the attitudes we have and the way in which we conduct ourselves when working on a well drilling problem. Our work, as well as our lives, should be a reflection of God's character.

Another very important objective of this course is to keep you safe. There are many ways to get hurt in this class and while you are in the field drilling a well. So we will pay close attention to safe practices.

2. Two Challenges - 5 minutes

Circumstances often exist that can be challenges for getting a job done. In well drilling, two common challenges are:

- **Equipment breakdown** - drill rigs take a beating so they often break and;
- **Sustainability** - keeping your drilling operation continuing for a long time.

You will face circumstances such as government policies, community attitudes, and lack of parts which will be hard to overcome. As difficult as these problems may seem in comparison to your abilities, you **can** have an influence. God selected you for this work for a reason! You are problem-solvers who can contribute to a change in circumstances. Let God use the creativity that He has given you.

3. Review the Manual - 20 minutes

Take a few minutes to get familiar with this well drilling manual, starting with the Table of Contents.

Section 1	Orientation
Section 2	Finding Safe Water
Section 3	Drilling a Water Well
Section 4	Completing the Well
Section 5	Hand Pump Installation
Section 6	Well Construction Skills
Section 7	Signs of a "Professional" Driller
Section 8	Preparing the Community

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Lesson 1.3 Roles and Attitudes

Purpose

To recognize the many roles of an effective well driller.

Objectives

By the end of this lesson, participants will have

- Considered and discussed the different roles and attitudes that a well driller can play

Materials

- None

Preparation

- Study lesson ahead of time

Time

30 minutes

Steps

1. Well drilling roles
2. Godly Well Drilling Ethics

1. Well Drilling Roles – 20 minutes

It is easy for a well driller to focus only on the task of bringing water out of the ground. That task does require a lot of attention. But a well driller who is doing this work as a *ministry* must take a wider view.

➢ In what ways do you think these words apply to well drilling?

Diplomat - _____

_____

_____

Detective - _____

_____

_____

Repairman - _____

_____

_____

Doctor -

Disciple -

Trainer -

Evangelist -

Businessman -

Friend -

2. Godly Well Drilling Ethics – 10 minutes

Well drilling, like any other work, involves handling money and items of value such as tools or pump parts. As representatives of Jesus Christ, we must be trustworthy and walk in the highest integrity. We all know that the world is corrupt, but with God's help we do not need to be corrupt ourselves.

It has been reported that some well drillers have cheated their customers by charging them for an 80-meter well when they only drilled to 50 meters. Or they have cheated their employers by selling tools or parts, keeping the money, and reporting that the tool had been stolen or the part had been installed in a well. May such dishonest ways never be found among you!

- If you find that a co-worker is being dishonest, what should you do about it?



Lesson 1.4 Daily Devotions and Safety Briefing

Purpose

Develop a habit of starting the day with God's Word and prayer and cultivate a culture of watching for – and correcting - safety problems.

Objectives

By the end of this lesson, participants will have

- Started their day considering a passage of Scripture.
- Reviewed safety considerations for each day's activities.

Materials

- Bible

Preparation

- On day 1, review Phil. 2:4. Assign subsequent days to each team and let the teams decide who will lead.
- Review upcoming activities to warn of safety hazards
- Observe and make note of any unsafe conditions to mention in next briefing

Time

15 minutes (each morning)

Steps

1. How and Why
2. Daily Scripture and Safety Briefing

1. How and Why - 5 minutes

It is easy to get focused on the details of well drilling and lose sight of the fact that we are servants of God and of one another. So it is helpful to take a few minutes at the beginning of the day to remind ourselves of these truths.

A daily devotion and safety briefing should not last more than 15 minutes. It is best conducted when the team arrives at the site, before any work begins. Share a verse or two of Scripture, but don't give an in-depth Bible study or sermon. The point is simply to focus our minds on the things of God. Finish with a brief prayer.

In the same way, the safety briefing should not be a lecture. Rather, just take a few moments to share any safe and unsafe actions noticed during the day before and to point out safety hazards that may come up during the current day's work. The Crew Chief is responsible to ensure that the devotion and safety briefing takes place every morning, but each team member can take turns leading it.

Day 1 – Scripture and Safety Briefing - 15 minutes

> Each of you should look not only to your own interests, but also to the interests of others.
>
> Philippians 2:4 NIV

- How does this passage relate to maintaining safety on the job site?

List below all of the ways that you can "look to the interests of others" and be prepared to share your thoughts with the rest of the class.

Use the spaces provided to take notes on each day's safety briefing. If you do not write it down, you will more likely forget it – and somebody could get hurt as a result.

Safety hazards to watch for today:



Figure 2 Head Injury

Head injuries can easily happen when working around a drill rig, so ALWAYS wear a hard hat! Please do not let something like this happen to you, to your team mates, or to a visitor.

Also wear gloves. There are many opportunities for a pinched finger and wrenches raise burrs on the pipe which can cut deeply.

It is important to have a simple first aid kit at the well drilling site. The Facilitator will point out the location of the first aid kit for this class.

Day 2 to Class End –Daily Scripture and Safety Briefing - 15 minutes

Space is provided at the end of the manual for taking notes.

Lesson 2.1 Water: God's Gift to Us

Purpose

To introduce the water cycle, consider the impact of our use of water, and our responsibilities associated with that use.

Objectives

By the end of this lesson, participants will have

- Reviewed a Biblical foundation for the need and provision of water in our lives
- Considered where the water we use ends up

Materials

- Poster of Water Cycle
- Flip chart and markers

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. Uses for Water
2. Water in the Bible
3. God's Gift
4. Loving our Neighbors

1. Uses for Water - 5 minutes

Working with your team, list some of the ways in which you use water, or activities you do for which water is needed. (We will come back to this later in the lesson.)

2. Water in the Bible - 20 minutes

In your teams, read the following Bible verses together.

Ecclesiastes 1:7
All streams run to the sea, but the sea is not full; to the place where the streams flow, there they continue to flow.

Isaiah 43:19-21
See, I am doing a new thing! Now it springs up; do you not perceive it? I am making a way in the desert and streams in the wasteland. The wild animals honor me, the jackals and the owls, because I provide water in the desert and streams in the wasteland, to give drink to my people, my chosen, the people I formed for myself that they may proclaim my praise.

Isaiah 55:10-11
For as the rain and the snow come down from heaven, and do not return there until they have watered the earth, making it bring forth and sprout, giving seed to the sower and bread to the eater, so shall my word be that goes out from my mouth; it shall not return to me empty, but it shall accomplish that which I purpose, and succeed in the thing for which I sent it.

Zechariah 10:1
Ask the LORD for rain in the springtime; it is the LORD who makes the storm clouds. He gives showers of rain to men, and plants of the field to everyone.

Jeremiah 14:22
Do any of the worthless idols of the nations bring rain? Do the skies themselves send down showers? No, it is you, O LORD our God. Therefore our hope is in you, for you are the one who does all this.



Matthew 5:44-45

But I tell you: Love your enemies and pray for those who persecute you, that you may be sons of your Father in heaven. He causes his sun to rise on the evil and the good, and sends rain on the righteous and the unrighteous.



John 4:13-14

Jesus answered, "Everyone who drinks this water will be thirsty again, but whoever drinks the water I give him will never thirst. Indeed, the water I give him will become in him a spring of water welling up to eternal life."

Connections - Now take a few minutes to consider together how these Bible verses might relate to the water uses or activities that you listed at the beginning of this lesson.

For example, because streams run to the sea (Ecclesiastes 1:7), we are able to use them for transportation.

Be prepared to share a few of the relationships you saw with the rest of the class.

3. God's Gift - 10 minutes

Without water, there can be no life.

As we review the water cycle, follow along with the drawing below. Each numbered arrow on the drawing corresponds to one of the terms listed below. Match each term with the corresponding arrow number.

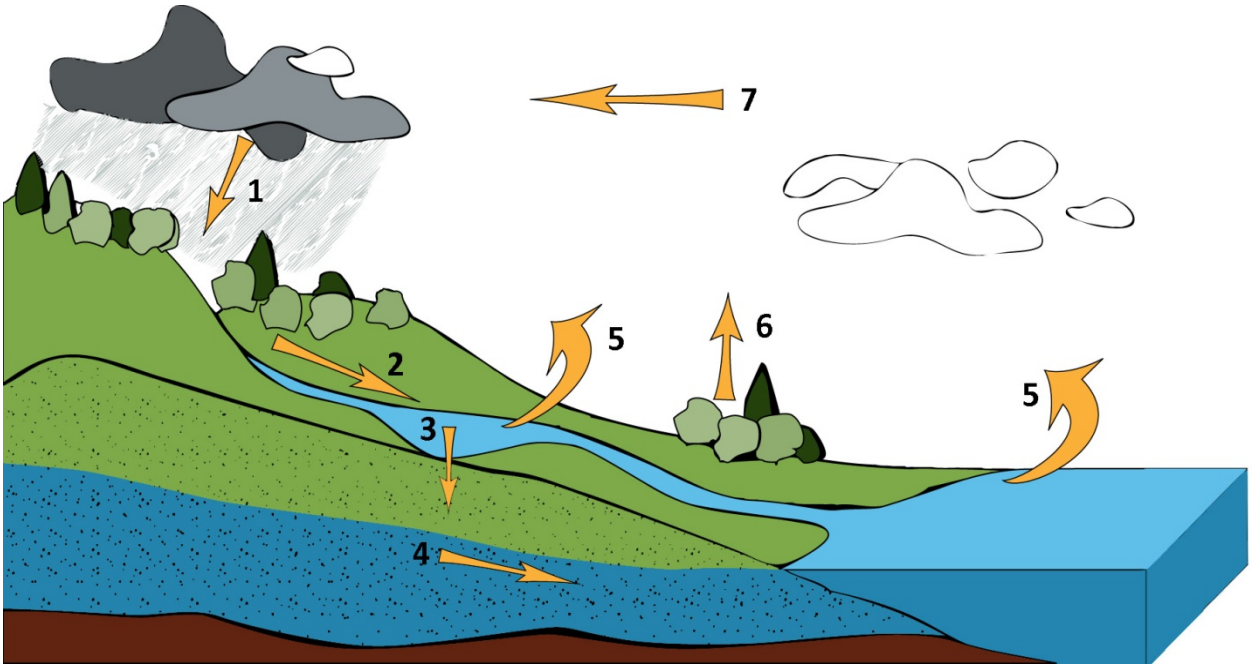


Figure 3 The Water Cycle

_____Precipitation (rain or snow)

_____Runoff

_____Infiltration

_____Groundwater

_____Evaporation

_____Transpiration

_____Clouds

4. Loving Our Neighbors - 25 minutes

- **Where does water come from?**
  When you are finished labeling the water cycle phases, circle all of the locations on the drawing where you directly receive from God the water that you need for the uses or activities that you listed at the start of this lesson.

- **Where does water go?**
  For a water use or activity that you listed, briefly share with the class where you think the water goes after you have finished with it.

- **Who is downstream from you? Who is upstream from you?**

Read the following Scriptures:



Galatians 5:13-14

You, my brothers, were called to be free. But do not use your freedom to indulge the sinful nature; rather, serve one another in love. The entire law is summed up in a single command: "Love your neighbor as yourself."



Ezekiel 34:18-19

Is it not enough for you to feed on the good pasture? Must you also trample the rest of your pasture with your feet? Is it not enough for you to drink clear water? Must you also muddy the rest with your feet? Must my flock feed on what you have trampled and drink what you have muddied with your feet?



Philippians 2:3-4

Do nothing out of selfish ambition or vain conceit, but in humility consider others better than yourselves. Each of you should look not only to your own interests, but also to the interests of others.

- **How then should we live?**
  In what ways do you think these passages relate to the ways in which we handle the water that we use?

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Lesson 2.2 Safe Water: What, Why, How?



Purpose

To. lay a foundation for the value of safe water and introduce methods of obtaining it.

Objectives

By the end of this lesson, participants will have

- Examined a definition of "safe" water
- Considered the importance of safe water to survival
- Reviewed different methods of obtaining safe water

Materials

- Flip chart and markers

Preparation

- Study lesson ahead of time

Time

30 minutes

Steps

1. What is "Safe" Water?
2. Why is Safe Water Important?
3. How Is Safe Water Obtained?

1. What is "Safe" Water? - 10 minutes

The World Health Organization considers water to be "safe" if it contains no disease-causing organisms or harmful chemicals.

Disease-causing organisms include many kinds of viruses, bacteria and parasites. Harmful chemicals include those used to kill weeds and insects, vehicle fuels, and the wastes from many industrial processes. Most harmful chemicals come from human activity, but some may occur naturally, like arsenic or fluoride. We call all of these things "contaminants."

Some contaminants in water are obvious: oil causes a sheen and a smell, too much iron produces a bad taste, and silt makes the water muddy. But many harmful things in water can't be detected in these ways. In fact, water may be clear and cold and yet contain chemicals or bacteria that are very harmful. Water might appear to be clean but actually be unsafe to drink. So we use the term "safe water" rather than "clean water" to avoid confusion.

Consider the water cycle (Figure 3): Rain – and most water underneath the ground - does not contain disease-causing organisms or harmful chemicals.

- So how does water become unsafe to drink - contaminated? Take a few minutes to list some ways that water is made unsafe to drink:

2. Why is Safe Water Important? - 15 minutes

It is common knowledge that we must have water to live. Our bodies are mostly made up of water and every process of life involves water. The basic functions of our body require about 1 to 3 liters (1-3 quarts) of water every day. We cannot live more than about 3 days without water.

But when we talk about "safe" water the issue is not as obvious. You may find that a stream does not meet the World Health Organization's definition of "safe water." But a man who grew up near that stream may say, "What is the problem? I have been drinking that water every day of my life – and I am strong!" So this man is not likely to agree that a safe water supply is a priority for his village.

- How would you respond to this man? What might change his opinion about the need for safe water?

- In your community, do most people consider traditional water sources to be safe or unsafe to drink?

The World Health Organization's definition of "safe water" does not take into account the fact that there can be degrees of contamination. Some bacteria or parasites are more dangerous than others and some chemicals are more harmful than others. With some things, just a little contamination is serious; with other things it takes more to cause a problem.

Also, the people who are most sensitive to contaminated water are children, the elderly, and those with weakened resistance as a result of malnutrition or sickness. The most common result of drinking water that contains disease-causing organisms is a case of diarrhea. If not treated properly, diarrhea can cause a person to lose so much water that they die from dehydration. The tragedy is that in many communities diarrhea is considered to be a normal condition of childhood. Those who survive tend to forget that many of their generation died before the age of 5.

Many diseases are very closely linked to unsafe water. If a community does not have enough water for adequate washing then people become susceptible to other health problems such as eye or skin conditions. "Stomach problems" among adults, even strong ones, are such a common thing that people tend to think nothing of being sick for a few days every month, or even more frequently. So our strong friend who thinks his village water supply is adequate may not realize that the health problems that kill children and cripple his village can be prevented and the health of the entire community can be improved.

3. How Is Safe Water Obtained? - 5 minutes

Safe water for drinking can come from three sources:

- Rainwater
- Surface Water
- Groundwater

As the water cycle lesson shows, all water at some time falls as rain or snow. And, except for some areas with severe air pollution, rain water is completely safe to drink. Depending on how a village's roofs are made, it can be fairly simple to collect and store rain that runs off a roof. If rain is the only source of water, then enough storage must be provided to last through the dry season. It is also necessary to keep the collection areas and the storage vessels clean or the rainwater can become contaminated.

Surface water is the most obvious water source and the easiest to use. But it is also the most easily contaminated. Rainwater that flows over the land picks up any contamination that is on the land, like feces or harmful chemicals, and carries it to streams and lakes of all sizes. As discussed in the water cycle lesson, if a village that is upstream dumps its wastes into a stream, then the people who are downstream suffer. As a result, surface water is often not safe to drink so it must first be treated to remove contaminants.

Good methods have been developed for collecting and storing rainwater. And there are many different ways to treat surface water to make it safe to drink. It is wise to consider these options when deciding how to help people get safe water. However, this manual deals only with water that is found below the surface of the earth, called groundwater.

Groundwater, in most cases, is safe to drink without any treatment. This is because the soil normally filters out disease-causing organisms and harmful chemicals as the groundwater flows through it.

If groundwater is found to be unsafe to drink it may be because the filtering capacity of the soil sediments has been exceeded or (less commonly) because the water has picked up naturally-occurring harmful chemicals, such as arsenic, from the rocks or sediments through which it flows. The filtering capacity of the soil, sediment, or rock can be exceeded where large quantities of contaminants have been deposited such as from a latrine, animal pen, trash dump, or industrial site. And if the groundwater is close to the surface, say less than 10 meters, then it is easier for surface contaminants to reach it. These concerns must be taken into account when selecting a well site, as will be discussed in another lesson.

Lesson 2.3 Groundwater

Purpose

To introduce basic principles of groundwater occurrence and movement.

Objectives

By the end of this lesson, participants will have

- Studied key groundwater terms
- Examined different types of aquifers

Materials

- Poster of groundwater diagram with wells
- Flip chart and markers

Preparation

- Study lesson ahead of time

Time

90 minutes

Steps

1. Basic Hydrogeology
2. Aquifers
3. Groundwater Levels

1. Basic Hydrogeology - 40 minutes

To be a successful well driller, it is not enough to know how to operate a drill rig. You must also know how to find groundwater.

A group of men who had been drilling wells for about a year told a Lifewater trainer, "When we drill down here in this valley it is easy to find water. But when we drill on that hill over there we just get dry holes. Why is that?"

➢ How would you answer these men?

_____

_____

_____

In this lesson we will learn some of the basic ideas of hydrogeology. "Hydro" refers to water and "geology" is the study of the earth. So hydrogeology is the study of water under the ground. (Hydrogeologists can't agree if "groundwater" or "ground water" is the proper term.)

It is useful for a well driller to have a broad knowledge of hydrogeology, but to get started as a well driller with a LS200 drill rig it is enough to know that there are materials that these rigs can drill through and materials that they cannot drill through. Most sediment – except for cobbles and boulders – can be drilled with these rigs. Most bedrock – except for very soft types – cannot be drilled.

This drawing represents what you might see if you could take a slice of the earth and look at it sideways. The words on the drawing are used by hydrogeologists to describe how groundwater is found. The goal of this lesson is to understand these words and the ideas behind them. With this understanding, a well driller can have better success at finding water.

The drawing shows aquifers that are unconfined, perched, and confined. Dashed lines indicate the potential water levels of each aquifer. The source of the confined aquifer is the recharge area, which is at a high elevation. Each of the terms shown on this drawing is defined in the following pages.

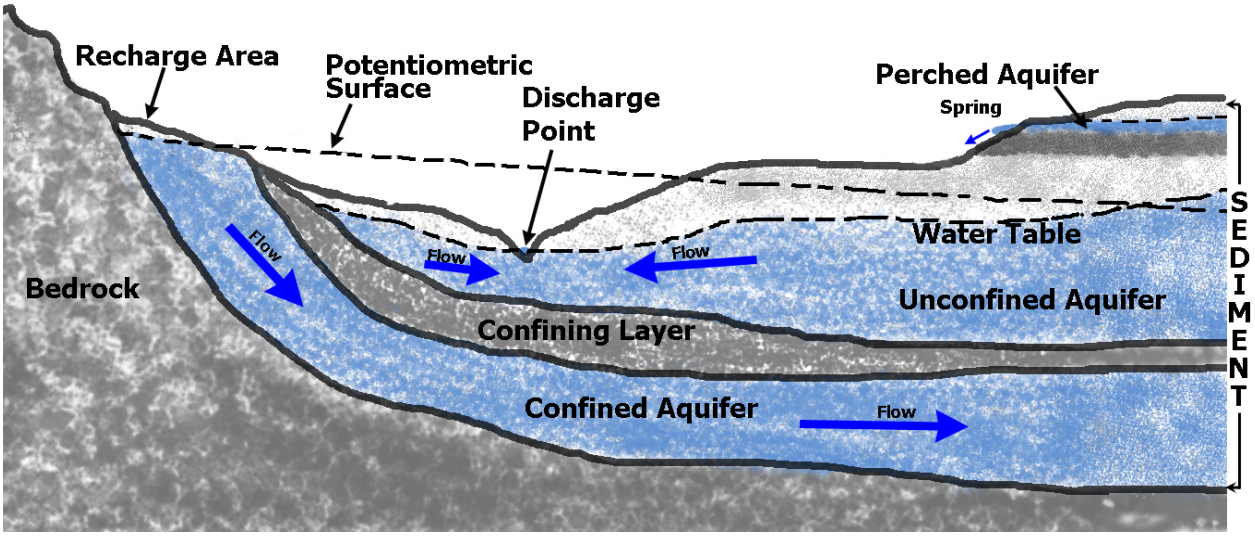


Figure 4 Groundwater Diagram

Sediment includes clay, silt, sand, gravel, cobbles, and boulders. These different types of sediment are listed in order of increasing grain size. Sediment has usually been moved by water, wind, or gravity from one location to another and is typically deposited in layers. These are called sedimentary layers or strata. [In lesson 3.9 we will spend time getting to know the different kinds of sediment.]

Bedrock refers to solid rock that has not been broken down into sediment, or sediment that has been cemented together. It is often found below layers of sediment, but can also be found on the surface. There are many, many different kinds of rock. Some soft types of rock can be drilled with the LS200 drill rigs, but most rock is too hard.

A **Recharge Area** is a region where rainfall or surface water soaks into the ground to become groundwater.

A **Discharge Area** is a place where groundwater comes to the ground surface. This is usually a **spring** or the bed of a stream or pond. (A spring is defined as a point where the water table intersects the ground surface.) Groundwater can also discharge along the shore or beneath a lake or the ocean. Groundwater flows from a recharge area to a discharge point. Groundwater near a discharge point is closer to the surface than groundwater in a recharge area. So the area near a discharge point is usually a good place to drill a well.

Groundwater flows through open spaces in sediment or rock. The following terms are key to understanding where to find groundwater that will flow into a water well.

Porosity refers to the spaces – or **pores** - between the grains of soil, sediment, or rock. When those pores are filled with water, the material is said to be **saturated**.

Permeability refers to the degree that these pores are connected to one another. A permeable sediment is one in which water may easily move from one pore to another. The easier water can move, the more water can be pumped out of a well. (This is also called hydraulic conductivity.)

An **Aquifer** is a layer of earth material that will yield water to a well in a useable quantity. One of the most productive aquifer materials are coarse sand and gravel because these sediments have both high porosity and high permeability.

The porosity and permeability of an aquifer are important characteristics to understand. Clay has high porosity, but the pores in clay are so small that water cannot easily move through them. As a result, clay is not a good aquifer material, even if it is saturated, since it has low permeability. Because sand and gravel have large pores that are well connected these sediments make the best aquifer material.

A layer of bedrock that has a very low porosity could be an aquifer if there are enough cracks in it and those cracks are connected so that water flows through them enough to supply water to a well.

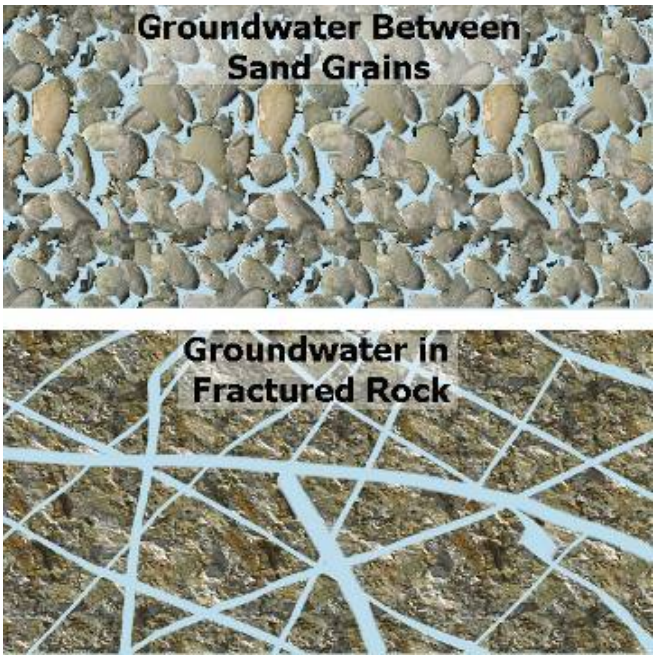


Figure 5 Sand and Rock Aquifers

A **Confining Layer** is sediment such as clay, or a layer of rock, that has a low permeability and therefore does not allow water to easily pass through it. A confining layer covers or is on top of an aquifer and may protect the confined groundwater from contamination.

Figure 6 shows different layers that a driller might find under the ground. These layers can be any thickness, occur at any depth, and the different types of sediment can be in any order. Study this drawing and then answer the questions below. Assume that each layer, except for the soil at the top, is saturated with water.

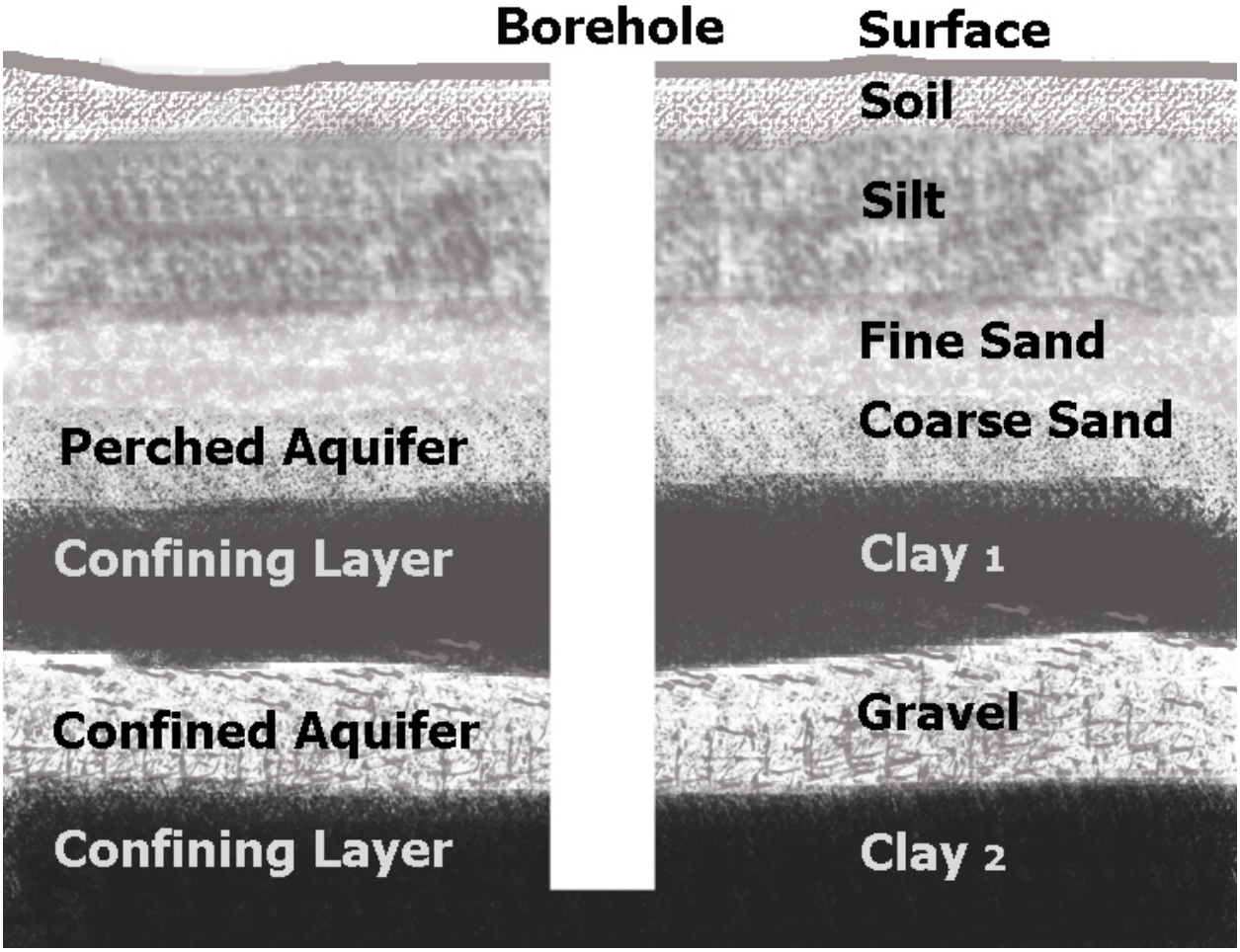


Figure 6 Sediment Layers

- Which sediment layer is likely to be the best aquifer? Explain why: _____

_____

- Which sediment layer is likely to be the second-best aquifer? Explain why: _____

_____

2. Aquifer Types - 20 minutes

When people think about groundwater, they sometimes imagine a lake or a river flowing under the ground. Some areas around the world do have water-filled caves with underground rivers. However, in the great majority of places groundwater occurs in the small pores between soil and sediment particles and in small cracks in rocks.

As mentioned above, groundwater flows naturally from a recharge area to a discharge area. This is usually from a higher elevation to a lower elevation. The speed of groundwater flow depends on the permeability of the sediment the water flows through. In general, 90% of groundwater is flowing at rates between 2 m/day, which is fast for groundwater, and 2 m/year which is slow.

There are different types of aquifers so it is useful for a well driller to be able to know and be able to recognize aquifer types.

An **Unconfined Aquifer** is an aquifer that does not have a confining layer of clay or silt above it. The top of the saturated portion of the aquifer is called the **Water Table.** (This ▼ is a symbol used to indicate the water table on a drawing.) Pores below the water table are filled with water**.** The elevation of water in a shallow well is the same as the water table outside the well. The water table will probably be the same as the water level in nearby hand-dug wells. Because the water table tends to roughly follow the shape of the ground, the direction of groundwater flow is usually "downhill." Unconfined aquifers are found near the earth's surface; they are easily recharged and can also be easily contaminated.

In most places the water table rises in the wet season and drops in the dry season. The depth to the water table will vary during the year and from year to year.

A **Perched Aquifer** is a small unconfined aquifer that has a confining layer below it. The sediment immediately below the confining layer has no groundwater. There may be a larger, regional aquifer at a greater depth. Perched aquifers generally do not provide much water, are easily contaminated, may be quickly pumped dry, and often go dry in dry seasons.

A **Confined aquifer** is an aquifer with a confining layer above and below it. When a confined aquifer is tapped by a well, water is under sufficient pressure such that it rises above the top of the aquifer and sometimes to the land surface. This is how a flowing or **artesian well** is formed, as shown on the groundwater diagram (Figure 7).

3. Groundwater Levels - 30 minutes

"How deep is it to groundwater?" is a very important question that a well driller always wants to know. The answer can get complicated because it depends on the type of aquifer (unconfined or confined) and many other factors. The following terms are used by hydrogeologists to describe different water levels:

The **Potentiometric Surface** is the surface (as shown on a map or cross-section) showing the elevation to which groundwater will rise in a well. For an unconfined aquifer, the potentiometric surface is a level often taken to be the **water table**. For a confined aquifer, it is the level of water measured in a well.

Static water level has two meanings: (1) The level or elevation of the water table in a well when the pump is not operating. (2) The level or elevation to which water would rise in a well penetrating a confined aquifer that is not being pumped.

Seasonal fluctuation. The water table in an unconfined aquifer tends to rise during the rainy season and drop during the dry season. The seasonal difference in water level can range from less than a meter to as much as 5 or 6 meters, depending on the amount of rainfall and how many trees draw water out of the aquifer. An unconfined aquifer with a water table less than 20 meters below ground will likely have a greater seasonal fluctuation than a deeper aquifer.

Take some time to study Figure 7, Groundwater Diagram with Wells. The drawing shows a well in each aquifer. Answer the following questions based on what has been taught so far.

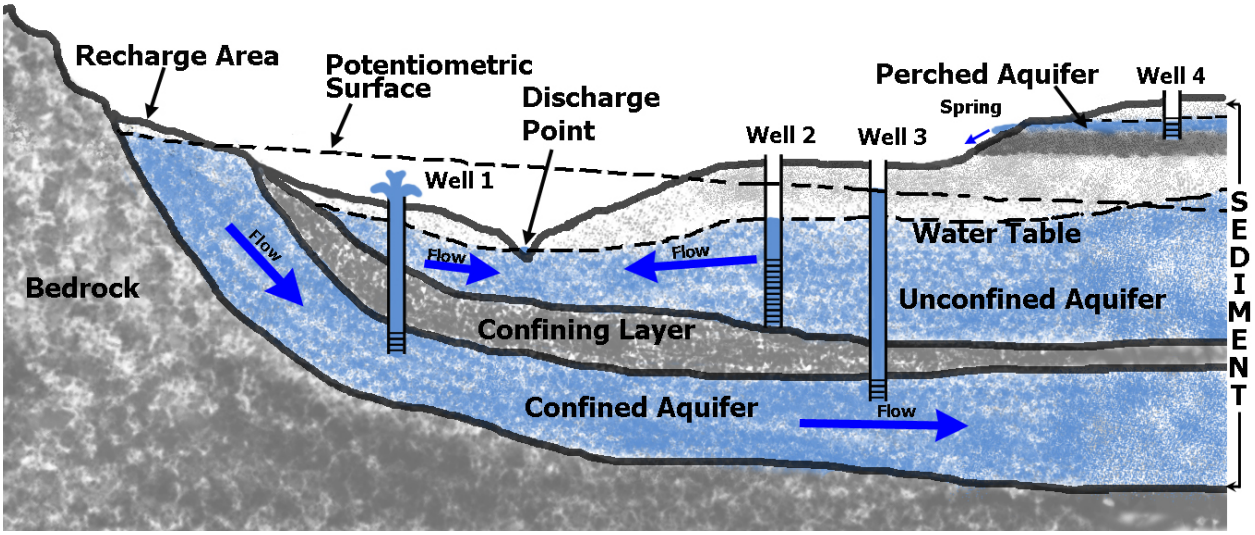


Figure 7 Groundwater Diagram with Wells

- Examine the directions of groundwater flow indicated by the blue arrows. Why is groundwater in the unconfined aquifer moving in two opposite directions? _____

_____

- Of the four wells shown in this drawing, which one do you think is likely to produce the greatest amount of water? Which one the least amount of water?

  Explain why: _____

_____

- Well number 1 is flowing; why is that? _____

_____

- Why do wells 2 and 3 have different static water levels? _____

_____

- Which wells are likely to show seasonal fluctuation? Explain why: _____

_____

- A spring is discharging from the perched aquifer. Mark another location on the drawing where it might be possible to find a spring. Why might that area be a good place to drill? _

_____

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Lesson 2.4 Deciding Where to Drill – Part 1

Purpose

To introduce methods of prospecting for groundwater.

Objectives

By the end of this lesson, participants will have

- Examined geological factors that influence where groundwater can be reached with the LS200.
- Reviewed advanced geophysical methods.
- Explored the surface geology features of the training area.

Materials

- Geology map or topography map of the training area

Preparation

- Study lesson ahead of time
- Obtain local geologic and topographic maps
- Scout the area around the class location for a place to conduct a geology field trip: look for topography, outcrops, road cuts that expose formations, surface water, springs & seeps, wells, and other water prospecting clues.

Time

2-1/2 hours; 30 minutes for steps 1 and 2 plus several hours for field trip

Steps

1. Simple Ways to Find Groundwater
2. Geophysical Methods
3. Groundwater in the Project Area

1. Simple Ways to Find Groundwater - 20 minutes

Selecting a good place to drill a well requires a basic understanding of hydrogeology and experience. In the previous lesson we introduced the key ideas that describe the occurrence and movement of groundwater. In this lesson we will apply those ideas to finding a likely place to drill. Keep careful notes on each well that you drill because your experience will enable you to be more confident about your choice of a well site.

Groundwater occurs at some depth below most of the world's land surface. The hard part is finding it within a depth that can be reached with the LS200 drill rig and in sediment that those rigs can drill into. Following are some very simple questions to ask and clues to look for when searching for a good spot to drill.

Clues to look for and questions to ask:

- Where are people presently getting their water?
- Hand dug wells will show the depth to groundwater and the type of sediment near the surface.
- Are there drilled wells in the area? Perhaps the village or the responsible government agency has useful information on the well, such as its depth and the sediment or rock types encountered when the well was drilled.
- Groundwater can often be found in sand or gravel layers in the bottom of a valley, even if those layers are covered by layers of clay or silt.
- Groundwater in valleys or low-lying areas is often closer to the surface than in steep or relatively high areas.
- Are there springs in the area? Groundwater can usually be found nearby. If a spring flows all year it is likely to come from a productive aquifer. If the spring dries up, then it might be overflow from a perched aquifer, but it is still worth exploring.
- Are there streams in the area? Carefully observe stream flow, looking for sections where the flow is greater and sections where the flow is less. Where it is greater, groundwater is likely discharging into the stream, indicating a good place to drill. Even dry stream beds often have shallow groundwater underneath.
- Trees or shrubs that remain green in the dry season may have roots that reach into the groundwater at a relatively shallow depth. Greener patches of grass may reveal places where groundwater is close to the surface.
- Pay attention to where animals go to find water. Bees and pigs are very good at finding water.
- Look for deposits of salt or other minerals – usually visible as a white “crust” on the surface of the ground. These may be caused by the evaporation of groundwater, which leaves the minerals behind. A large surface deposit might indicate that the groundwater has a very high mineral content.
- Look for "outcrops" of tilted layers of rock on hills or ridges; groundwater will flow downhill along the direction of trend. (But remember that the LS200 cannot drill in hard rock or through layers of boulders or coarse gravel.)
- Some rock layers, like sandstone or limestone, have many cracks. These may produce acceptable quantities of water. Examine any outcrops of marble or limestone that are being used for building materials; some can be good aquifers. With patience, the LS200 can drill in some kinds of softer rock.
- Are there large boulders on the surface in the area where you hope to drill a well? If so, they probably extend into the ground. The LS200 will not be able to drill past them.
- Do not limit your investigation to a small area. It is desirable for a well to be as close as possible to a village, but it is more important that the well produce a sufficient amount of water.

- Don't overlook or discount local knowledge. Ask the men who dig wells in the area how they locate a good site.

➢ What are some other clues for finding groundwater that you can think of?

_____

_____

_____

_____

_____

2. Geophysical Methods - 10 minutes

A "geophysical" survey or technique refers to a way of finding out about conditions beneath the ground surface without actually drilling a borehole. Geophysical techniques can be used to help select more promising drilling locations and depths, avoid less promising locations, and help in selecting a suitable drilling method. Although geophysical surveys are more commonly used in groundwater exploration in hard crystalline rock areas, they can also assist in exploring unconsolidated sediments.

Each geophysical technique measures a specific physical property of the rock or sediment. Many different properties can be measured, depending on the type of instrument that is used. Examples include the earth's electrical resistance, electrical conductance, density, and magnetic properties. Changes in these properties can be related to changes in the type of sediment or rock, potential for aquifers, and in some cases groundwater quality. However, not all strata or aquifers have enough contrast in one of these physical properties to be able to be detected by a geophysical technique.

Geophysical methods can allow you to "look into the ground" – but the view is not always very clear. Each technique has strengths, weaknesses, and assumptions that must be evaluated to determine if a particular technique will work in a specific situation. So no geophysical technique is "one size fits all."

No geophysical method can, by itself, determine that an aquifer exists or doesn't exist at a specific site or at a specific depth. But if used correctly, and if compared with a nearby site of known geology, a geophysical survey can give indications of a more promising area or a less promising area or depths where one may find an adequate aquifer. Furthermore, the use of geophysical techniques will be more successful if the data is gathered and interpreted by an experienced geologist or geophysicist.

How a geophysical survey can be useful:

A driller is working in an area where there is a layer of hard bedrock through which the LS200 can't penetrate. The sediment just above that bedrock is often a good aquifer. But the depth to the bedrock varies greatly from place to place. By conducting a geophysical survey in a spot where a well has already been drilled, the "signature" of that bedrock can be identified. So another survey conducted at a new location can indicate the depth where the bedrock occurs. If this is beyond the limit of the LS200, then the driller knows not to attempt drilling at that location.

Examples of geophysical methods are electrical resistivity, seismic refraction, ground penetrating radar, and electromagnetic surveys. It is beyond the scope of this course to teach how to use the different types of geophysical methods. However, since these methods are becoming more common around the world, it is helpful to know what they are, what they can do and what limitations they have.

Electrical resistivity and seismic refraction are commonly used in groundwater investigations so only these are summarized below. Using both methods at the same site can give improved results. Commercial resistivity and seismic instruments are readily available but also very expensive, in the range of USD $10,000 - $20,000 each. Much less expensive instruments can be constructed (USD $150 - $250) and these are currently being tested under field conditions.

Electrical Resistivity

A resistivity survey measures the electrical resistance to current induced into the ground. Two pairs of electrodes at defined spacing along a line are pounded into the ground. Electrical current is applied to the outer pair of electrodes while the voltage drop is measured with a voltmeter attached to the inner pair of electrodes. Wider spacing of the outer current electrodes results in a greater depth of investigation.

The electrical resistance of sediment or rock depends on many factors such as particle size, porosity, density, mineral and chemical composition, and moisture level. Different combinations of these factors can produce very similar resistivity readings. For example, a layer of dry volcanic ash can look to a resistivity meter exactly like a gravel aquifer that is full of water. From resistivity data alone it would be difficult to know which type of layer the instrument was "seeing."

Seismic Refraction

A seismic refraction survey measures how fast a "shockwave" travels through the ground. The shockwave is induced by hitting a metal plate with a sledge hammer or by setting off a small explosive charge. A very sensitive microphone, called a geophone, records the initial shockwave and the timing of subsequent waves that are generated as the initial wave is bent by

(refracted by) or bounces off (is reflected by) different layers of sediment or rock. Because the waves travel at different speeds depending on the density of the material they pass through, the timing of their arrival at the geophone can be interpreted to show the density at different depths.

Considering the electrical resistivity example given above, a volcanic ash layer would probably have a lower density than a saturated gravel aquifer so a seismic survey would be able to determine what the layer might be. If, based on well drilling and other geologic explorations, it was known that there were no volcanic deposits in the area then the layer could be interpreted as an aquifer. But that would not be certain until an actual borehole was drilled.

2. Groundwater in the Project Area - 120 minutes

Take a walking tour near the classroom and see if you can find the groundwater "clues" mentioned in step 1 of this lesson. Identify as many of these geology features as you can:

- Hills
- Valleys
- Bedrock outcrop
- Road cuts, stream banks, or other places exposing sediment or rock layers.
- Trees that may have roots reaching to the water table
- Groundwater recharge areas
- Groundwater discharge; streams, seeps, springs, streams, rivers, lakes, ocean

➢ Within the area you explored, where does the geology indicate might be a good place to drill a well? Give your reasons for selecting it: _____

_____

_____

_____

_____

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Lesson 2.5 Deciding Where to Drill – Part 2

Purpose

To identify factors other than geology that influence the decision on where to drill.

Objectives

By the end of this lesson, participants will have

- Examined cultural and environmental factors that guide well placement.

Materials

- Flip chart and markers
- Posters: Latrine and High-Low Water table
- Copies of Figure 10, Case Studies for Well Location

Preparation

- Study lesson ahead of time.
- Using the full-page versions in Appendix 13, copy sets of Figure 10 for each team

Time

75 minutes

Steps

1. "We Want the Well Here!"
2. Wells and Latrines
3. Environmental Factors
4. Cultural Factors
5. Property Ownership
6. Make a Site Map

1. "We Want the Well Here!" - 5 minutes

A well driller is often told where the village leaders or property owner want their well to be located. That spot is usually based on convenience; perhaps close to the center of the village or near the owner's house. But it often happens that the people who select a well location do not consider other concerns. To pick the best site, the drill crew must consider many factors. This process requires diplomacy and patience, because there may be reasons why the location selected by the village leaders or property owner is not the best one. In many cases, drill site selection requires compromises.

As discussed in the previous lesson, the hydrogeology of the site must be the first consideration when selecting a well location. The drill rig must be able to penetrate the formations in the area and reach groundwater within the depth limit of the rig. If the drill rig can work in the area, there is usually a wide range of sites where a well could be drilled. This lesson examines the other factors that must be considered in selecting a good well site.

2. Wells and Latrines - 40 minutes

Latrines and other places where human or animal waste is concentrated can introduce disease-causing organisms into the groundwater. But if the well is located far enough away from these sources, then the soil is able to filter out harmful organisms before they reach the well. To determine the minimum safe separation distance between a well and a family latrine we need to know these three things (listed in order of their importance):

1. Distance between the bottom of the latrine and the water table
2. Type of soil between the bottom of the latrine and the water table
3. Direction the groundwater is moving (usually difficult to know with certainty)

Following the guidelines described below will not ensure that a well will be free from bacterial contamination. The well must be properly constructed (Section 4) and the well water should be tested as required by the government agency responsible for monitoring water quality.

Groundwater Flow Direction

If flow direction is known, it is best to place the well up-gradient from a latrine, so that contamination moves away from the well. Groundwater flow direction can be estimated. Groundwater in an unconfined aquifer tends to flow in the direction that the ground slopes and it flows from a recharge area to a discharge point. So it usually is better to locate a well uphill from a latrine than downhill from one.

Deep Water Table

If the water table is at least 5 meters below the bottom of the latrine, then a silty or fine sandy soil can remove most contamination before it reaches the groundwater. If the soil is medium sand or gravel, then the water table should be more than 10 meters below the bottom of the latrine. If these minimum distances can't be met for the soil type, then choose a minimum safe separation distance as if it were a high water table.

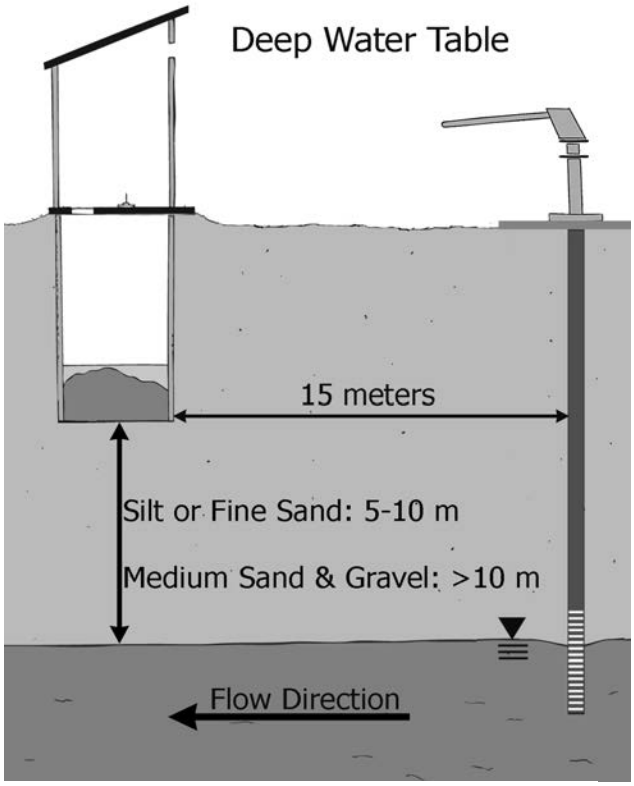


Figure 8 Latrine With Deep Water Table

Note: The World Health Organization has recommended that a well be no closer than 30 meters from a latrine. This does not account for soil type or distance to groundwater from the bottom of the latrine. The safe distances presented in this lesson are adapted from more recent research by the Water, Engineering and Development Centre; Reed, Bob. 2003. *Low-Cost Sanitation*. WEDC, UK.

High Water Table

If the bottom of the latrine is at the water table, or close to it, then disease-causing organisms can get into the groundwater. If the soil at the bottom of the latrine is fine-grained like clay, silt or fine sand, then it has a better filtering action than coarse sand or gravel. So the safe distance from a latrine is shorter for fine soils than for coarse soils. In any case, if flow direction is known, it is best to put the well up-gradient from a latrine.

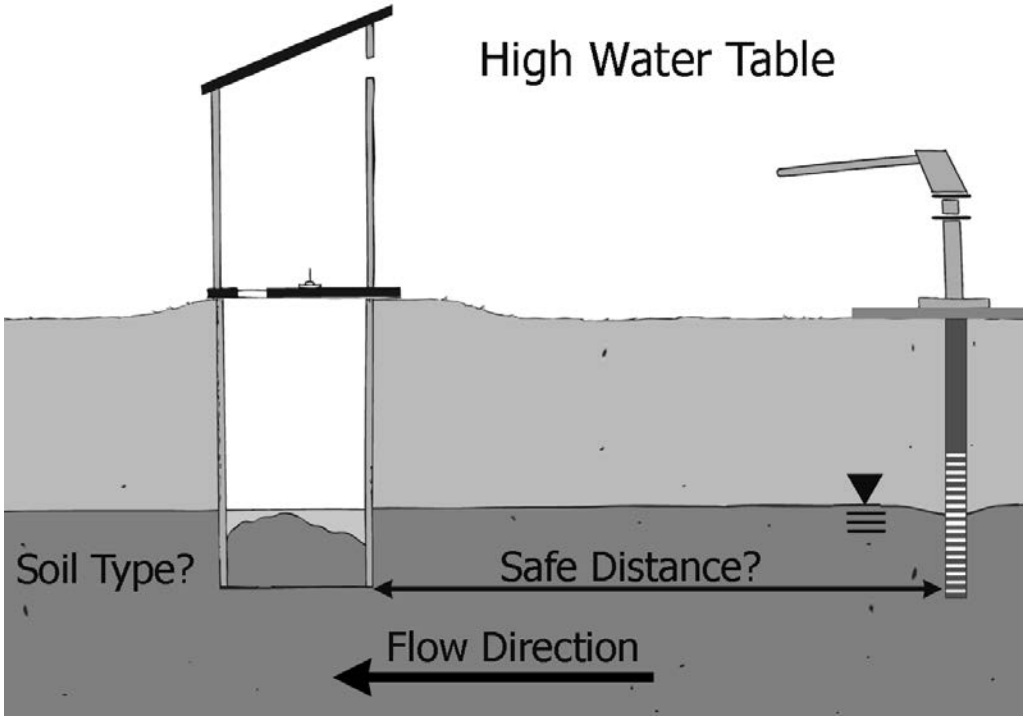


Figure 9 Latrine With High Water Table

Sediment Type	Safe Distance
Clay, silt, or fine sand	15 meters
Medium sand	50 meters
Coarse sand or gravel	500 meters
Fractured rock	500 meters

- How can you find out the depth to the water table? _____

_____

- How would you determine the distance between the bottom of a latrine and the water table? _____

_____

- How can you find out the soil type below the latrine? _____

_____

Carefully study the six different cases of well location in Figure 10, paying attention to distances between a latrine and proposed well, soil types, and groundwater flow directions.

- Which cases meet the minimum "safe distance" criteria? _____
- Which do you think is the best well location? List them in order from best to worst. Be prepared to give reasons for your choices.

Case # _____ _____ _____ _____ _____ _____

Best **Worst**

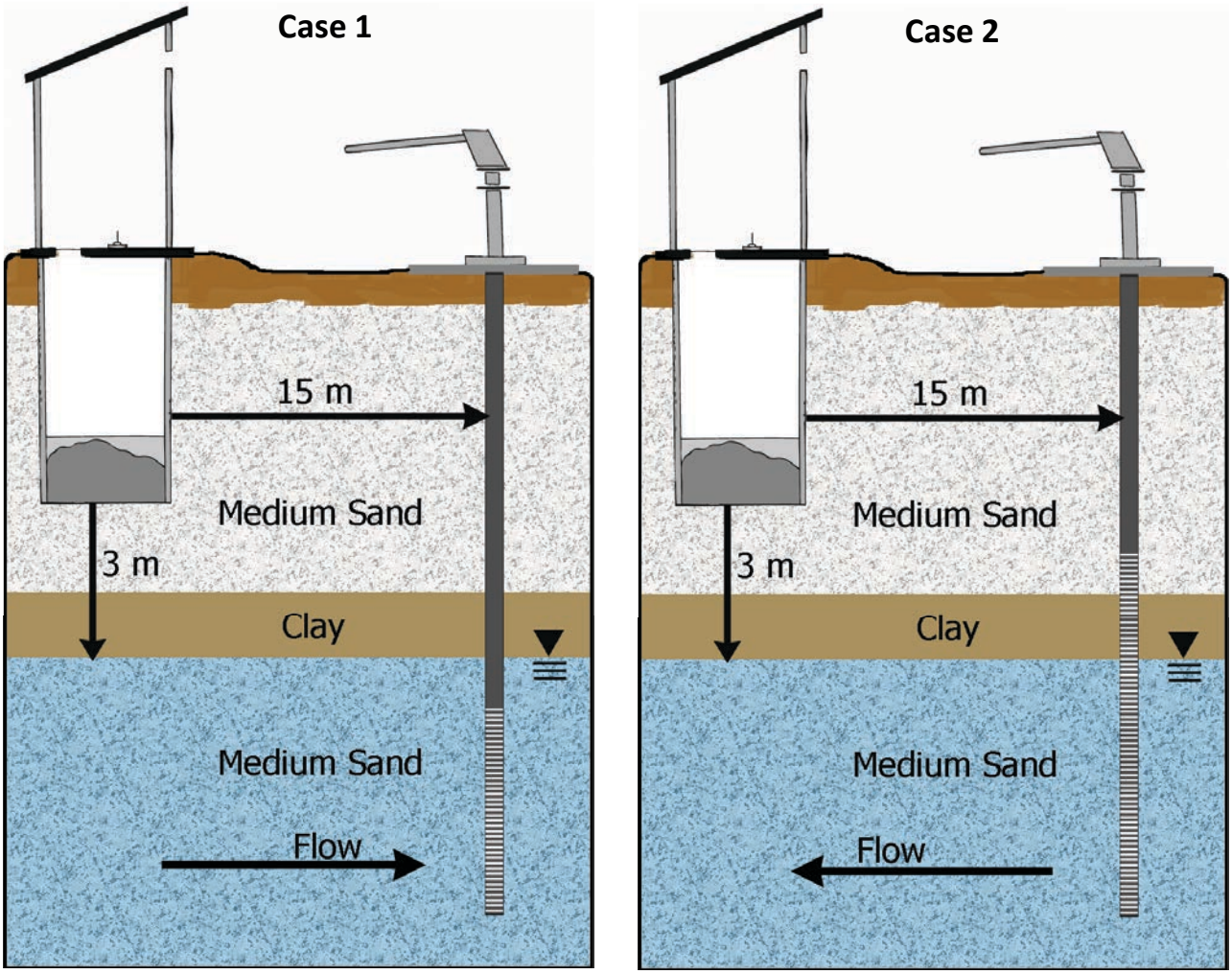


Figure 10 Case Studies for Well Location

There are full-page versions of these figures in Appendix 13. Copy these and give a set to each team for them to lay out in order from best to worst case.

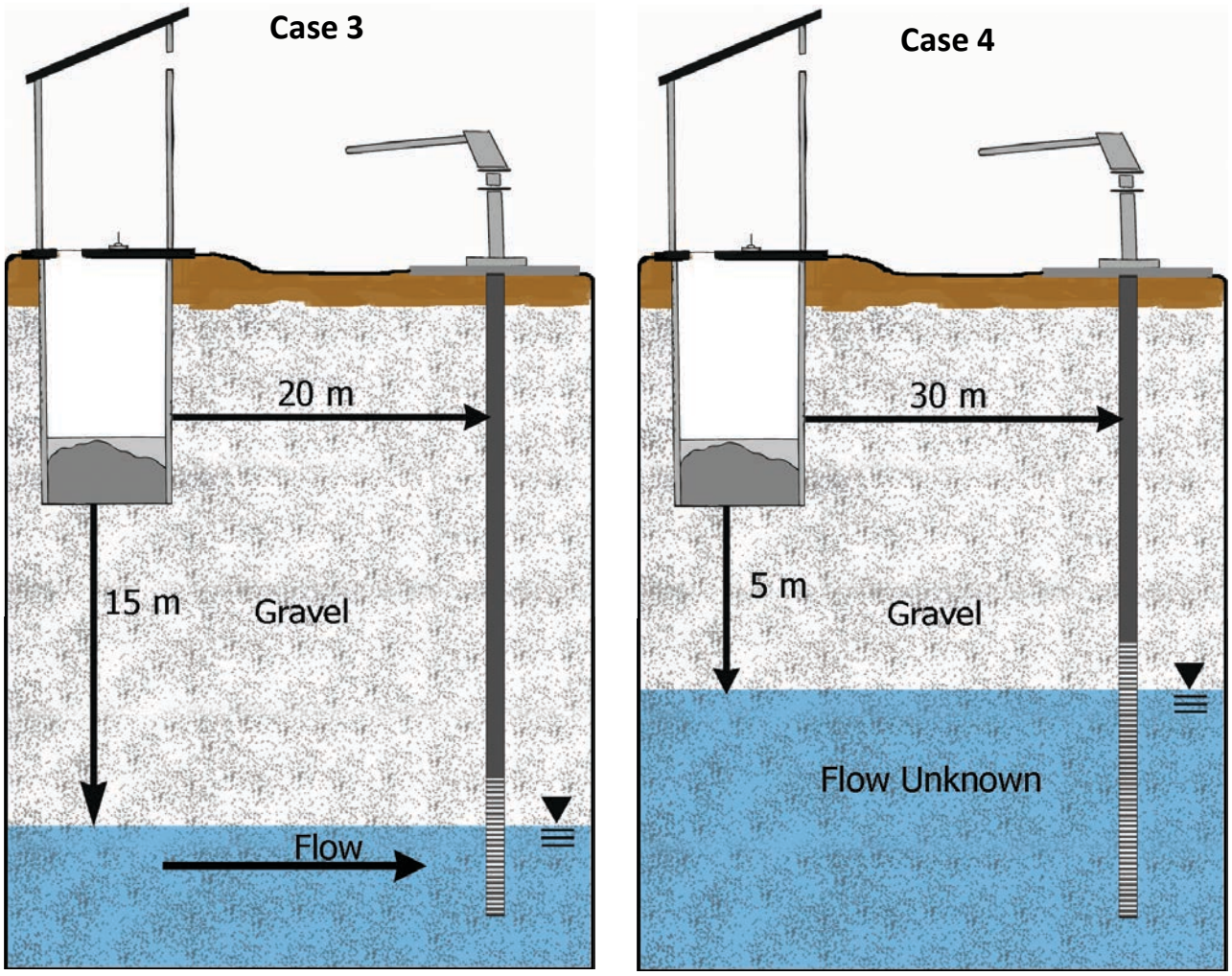


Figure 10 Case Studies (continued)

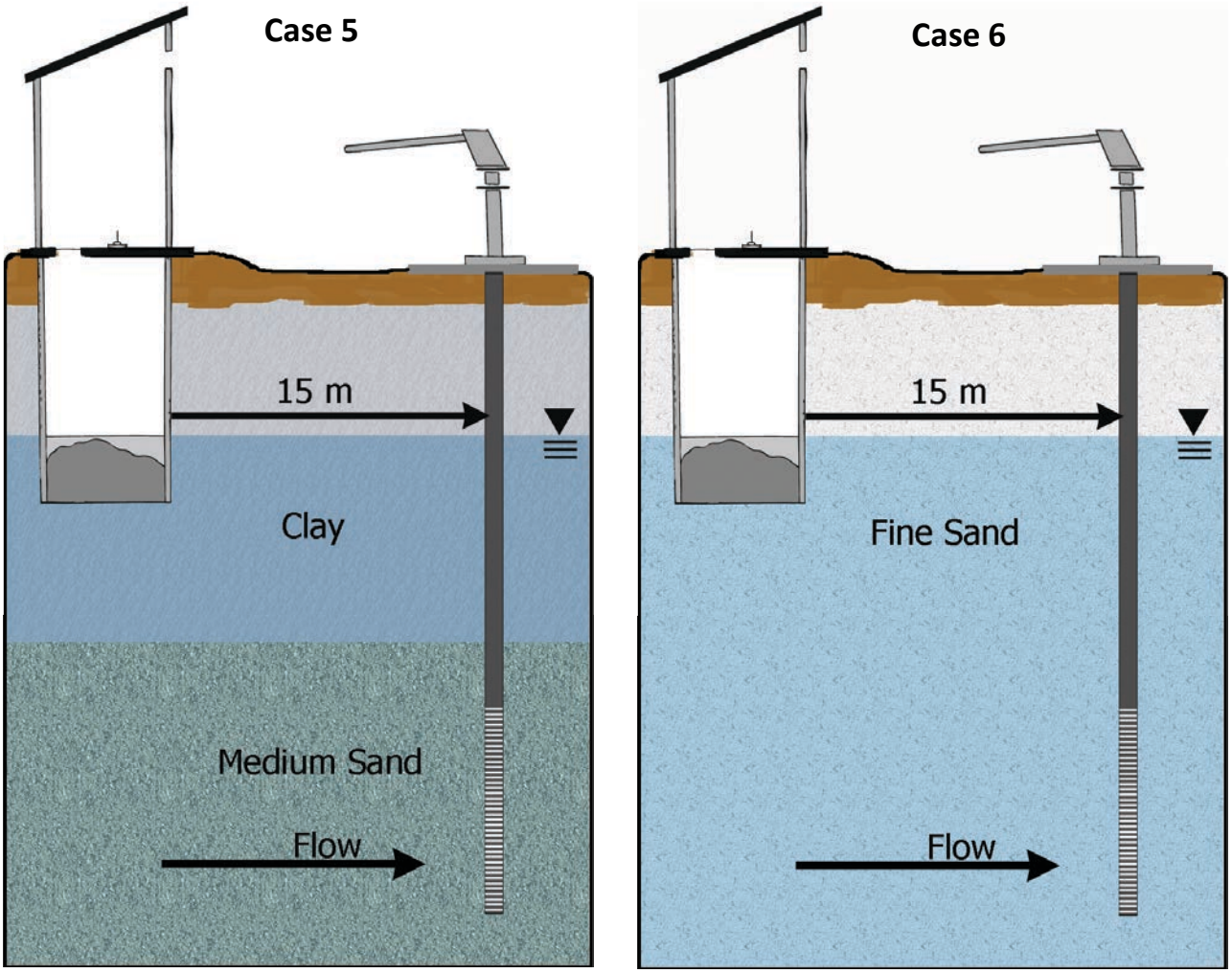


Figure 10 Case Studies (continued)

3. Environmental Factors - 10 minutes

"Environmental factors" are parts of the natural world and are not the result of human activity. For example, a stream that runs near the village is an environmental factor.

- The direction in which groundwater moves is a very important environmental factor to know, because a well should be placed so contamination from a latrine or other source ("cultural factors") moves away from the well, not toward it.
- The type of soil near the surface is also important. Clay, silt, and fine sand can keep contaminants from reaching the groundwater.
- Surface waters – streams, rivers, or ponds - may contain biological, agricultural or industrial contamination so wells should be located at least 15 meters away from them.
- Avoid areas that get flooded, since people cannot get to the well during high water and the well may be contaminated by floodwaters overflowing and seeping into the well.
- The well site should be elevated enough to direct all surface runoff away from it.
- Saltwater intrusion can affect shallow groundwater near the coast, so wells should be placed away from shore or drilled into a deep aquifer.
- Naturally-occurring chemicals may affect groundwater quality, so water should be tested in areas where this may be a problem.

➢ What other environmental factors can you think of that might affect well location?

_____

_____

4. Cultural Factors - 10 minutes

"Cultural factors" can be thought of as anything related to human activity that should be considered when locating a well. For example, an animal pen is a cultural factor. It takes time and effort to identify the relevant cultural factors in a community. But these must not be overlooked because the long-term success of a well depends on the community accepting it.

The following paragraphs give examples of some cultural factors to consider in locating a good well drilling site:

- Proximity to where people live. In the introduction to this lesson a situation was described where the village selected a well location based on convenience. This is a very

important cultural factor to consider. Studies have shown that when a water point is located less than 200 meters from a home, people tend to use more water than when the source is farther away. They drink more water and wash more often, which contributes to better health.

- If there are more people who want to use the well than the well can support, people will not have enough water for good health. One well for every 300 people is an appropriate goal. A large village may need several wells in order to experience all of the health benefits of safe water.

- Are there areas in or around the community that are considered sacred? It is wise to respect the "spiritual landscape" of the area as viewed by those who live there. You may not share the communities' beliefs, but it is a demonstration of love to be sensitive to theirs. Asking about these things with gentleness can help build good relationships.

- A cemetery is an especially sensitive cultural issue. In some places, people have refused to drink water that comes from the ground because people are buried in the ground. There is no real risk of groundwater contamination if a well is located a safe distance upgradient from a cemetery. However, the perception that people have is a more important consideration when choosing a drilling site.

- Even a small village may have a well thought-out plan for growth. So consider what future development may take place in the village and locate the well in a site that will not conflict with that growth.

- Some communities have cesspools or large seepage pits that receive much more human waste than a family latrine. A well should be placed at least 50 meters from such a concentrated contamination source.

- Animal pens concentrate waste in a small space and are similar to a latrine in their potential for contaminating groundwater. Use the "safe separation distance" criteria as you would for a latrine.

- Industrial facilities or garbage dumps may discharge harmful chemicals into the soil and groundwater so wells should be located at least 100 meters up-gradient.

- A well should be no closer than 7 meters from overhead power lines, because the lines could be touched when installing or repairing the hand pump.

- Before drilling, identify any underground pipes that might run near the well site.

- If a new well is placed too close to another well that is still being used, they may interfere with each other. This can reduce the amount of water that each well is able to produce. The appropriate separation distance depends on the pumping rate of the wells and the characteristics of the aquifer.

- An abandoned well may be filled with trash. Since it probably reaches to the water table, this can be a very serious source of groundwater contamination. Use the "safe separation distance" criteria for a latrine that contacts the groundwater.

➢ What other cultural factors can you think of that might influence well location?

_____

_____

_____

_____

5. Property Ownership - 20 minutes

Property ownership is a cultural factor that deserves special consideration. Wherever there are people living and working there will be some sense of property. Ownership might be individual, collective, a mix of these, or something entirely different. In any case, it is not likely that property ownership will be evident to an outsider, even an outsider from another community within that culture. For this reason, it is very important to always ask permission before walking around and looking at things. It is best to be accompanied by a local leader so no suspicion will arise among villagers who may not know the purpose of your visit.

➢ In your home culture, how do people react when they see a stranger walking around their houses and fields? Do they not care or do they get concerned?

_____

Who owns the well?

An essential part of the process of selecting a well location is determining property ownership of the well site and access to the well. There are four arrangements that tend to be successful, as described below. But these are not the only ones that will work; the key is for the community to discuss the issue and agree on a solution before the well is drilled.

- **A publically-owned well on public property for public purposes.**

  In this arrangement the involvement of the community leaders is essential. Typically, a Village Water Committee is elected by the community to administer all aspects of the

well. The things that the water committee takes responsibility for include; collecting fees, establishing operating times (especially important if the well has limited yield), keeping the pump pad clean, and maintaining or repairing the pump. The Lifewater Partner that constructs the well may need to advise the water committee, but the policies are determined by the community.

In a variation of this approach, the Lifewater Partner and the community agree on a service contract where the Partner provides maintenance and repair of the pump for a monthly fee. The water committee collects this fee from the users of the well. This arrangement guarantees the community a fixed cost for their water supply and gives the Partner a regular income. The Partner has a strong incentive to perform routine maintenance of the pump, since that will reduce the need for expensive repairs.

- **A privately-owned well on private property for public purposes.**

  In this case the community contracts the responsibility for well maintenance to the property owner, who charges for that service. He keeps the pump working and the people pay a reasonable fee for the water. If he doesn't maintain the pump, or if he cuts off access, then he doesn't earn any money. He is running a small-scale water utility. Any contractual arrangements are between the owner of the well and the community. In some communities, it may be difficult for the leaders to impose fees for anything, so this arrangement gets around that problem. The people of the community are given a choice; they can either pay for safe water or get contaminated water for free. If the fee is based on water usage, then people will tend to use the safe water for drinking and cooking, and use other sources for washing and activities where water quality is not as critical.

- **A privately-owned well on private property for private purposes.**

  This is the commercial side of a well drilling operation, where the Lifewater Partner is paid as a contractor to construct a well. The manner in which the well is used is entirely up to the owner. Contractual arrangements deal primarily with well construction, but the Partner might also offer a service contract for well maintenance.



A case study in ownership

The local church that provided the well said that it should be for everyone's use. But the well was actually drilled on one family's property, next to a common path. Because the well was considered to be "public" the property owner did not feel personally responsible for maintaining it. Since no fees were being collected for using the water, the owner was without resources to repair the pump even if he wanted to as a goodwill gesture. At one point, a dispute arose between the property owner and the community, so he locked up the pump. A mob came and battered the pump with big sticks, claiming that if they couldn't have the water then he wasn't going to get any, either.

- What went wrong in this community? _____

_____

_____

_____

- What could the church that gave this well to the community have done to avoid these problems?

_____

_____

_____

6. Make a Site Map - 10 minutes

There may be a large number of latrines in a village, plus many other environmental and cultural factors to consider. Selecting a good well site can be very difficult. It often involves making a trade-off between conflicting goals. In these cases, making a simple site map helps identify the most important factors to consider.

Start from the preferred well location; this is usually suggested by the village leaders or property owner. Walk around the well site looking for possible contamination sources within 10 meters of the well. Then go farther out, looking for sources within 20 meters of the well. Repeat the search in a 30-meter circle. If the soil is gravel and the water table high, you may need to search for latrines as far as 500 meters away.

As you go around, make a simple sketch of what you find. The drawing on the next page is an example. Your map does not need to be exact. When you locate a contamination source near the well, measure the distance to it from the well. (A long step is just about one meter.) For a more precise map, it is helpful to use a GPS receiver or a compass and a measuring tape.

Remember to take topography into account because it influences the direction of groundwater flow.

If you find contamination sources too close to the preferred well location, then discuss the problem with the village leaders or property owner. Help them select a better well site. Moving a latrine or an animal pen is not a solution that will work, since contamination from these sources will remain in the ground for a long time.

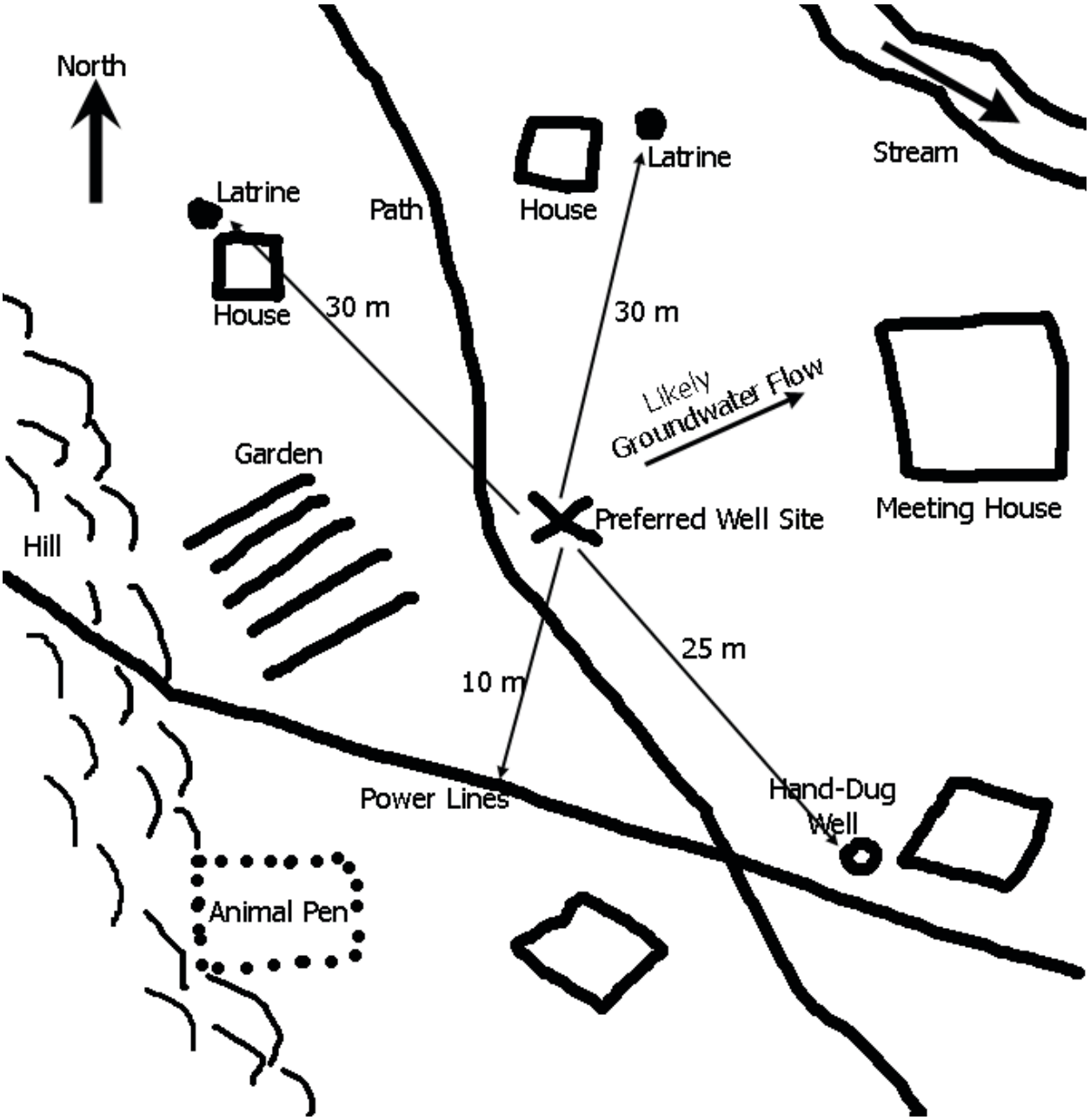


Figure 11 Sample Well Location Map

Lesson 3.1 Drilling Methods

Purpose

To survey different methods of making a borehole.

Objectives

By the end of this lesson, participants will have

- Examined different drilling methods

Materials

- None

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. Introduction
2. Manual Methods
3. Powered Methods

1. Introduction - 5 minutes

This manual is about drilling boreholes with small mud rotary drill rigs like the LS200. However, there are many other ways to reach groundwater. This lesson is a very brief survey of well drilling methods.

The first rule for choosing a drilling method is: **The method must match the geology.**

It does no good to try to drill rock with a rig that is not designed for rock drilling. Likewise, it is unwise to use an expensive, high-power rig in a location where simpler methods would be adequate.

The second rule for choosing a drilling method is: **Know what it costs.**

Although costs are only mentioned in general terms in this lesson, it is important when selecting a drilling method to take into account the purchase price of the drilling rig, the tools and support equipment it requires, the cost to maintain all of that equipment, and the cost to operate it. Operating costs include labor, transporting the equipment to and from the drill site, fuel to run the equipment, and drilling supplies consumed. These cost elements vary greatly. (Lesson 7.6, “Counting the Cost” considers the cost factors of well drilling in detail.)

2. Manual Methods - 30 minutes

People have been making wells without the use of power equipment for thousands of years. Each of the methods described in this section involve hard work, but most can be carried out using locally-available materials and skills.

Hand-Digging. Digging a well by hand, using simple tools like a pick and shovel, with a bucket on a rope to remove cuttings, is the oldest and probably the most frequently-used method of getting access to groundwater.

Advantages: Making a hand-dug well requires only common tools and skills, so it can be done by anyone. In many areas men have specialized in this trade as a business. Where labor costs are low, this is usually the least costly method of well construction. In an aquifer with low permeability, a large diameter hand-dug well may produce more water than a borehole in the same aquifer.

Disadvantages: Very dangerous to dig due to high potential for cave-ins and lack of oxygen. Digging a well is very hard work for one person. Because it is difficult to dig very deep, hand-dug wells more than 30 meters are uncommon. Unless the groundwater seeps in very slowly, it is not possible to dig more than about a meter below the water table. Digging into rock is extremely slow. A hand-dug well is very difficult to protect from contamination. There are many ways for surface water to seep in, and the typical bucket on a rope used to fetch water easily transmits bacteria to the groundwater. A hand-dug well can be protected by sealing the walls, pouring a concrete apron, putting a lid over the top, and installing a hand pump. But these measures increase the cost of the well.

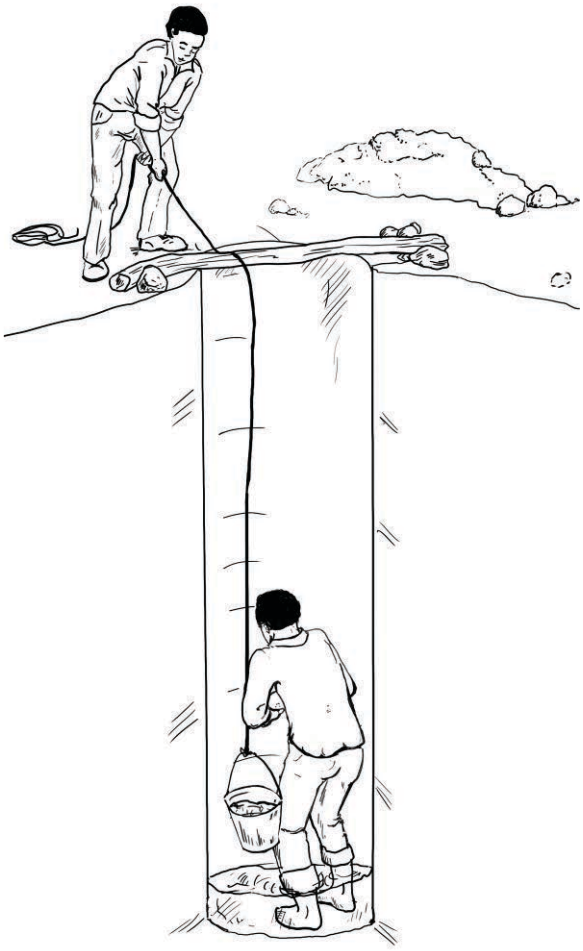


Figure 12 Hand Digging

Sludging. This ancient drilling method consists of raising and lowering an open pipe in a water-filled hole. During the up stroke, the operator holds his hand over the top of the pipe. Just as the pipe reaches the top of the stroke and is starting down, the operator uncovers the pipe. As the pipe is rapidly pushed down, water and cuttings are forced out the top. The pipe can be as simple as hollowed-out bamboo or joints of PVC pipe with a sharpened bit at the end. With a suitable drilling pipe, a borehole can be advanced to at least 70 meters. Beyond about 10 meters, it is necessary to raise the pipe using a rope and a tripod.

Advantages: Sludging is much easier and safer than manual digging. The materials required are very simple and can be adapted from whatever is locally available.

Disadvantages: Sludging is very tiring and requires a crew of people taking turns. It can only drill in soft materials such as silt and sand. Hard clay can be slowly penetrated but rock can't be drilled. Large gravel can't be lifted out of the borehole. The borehole diameter is typically only slightly larger than the diameter of the well casing, so it is hard to install an adequate sanitary seal to prevent contamination from surface water. (See Section 4 - Completing the Well for definitions of these well construction terms.)



Figure 13 Sludging

Manual Percussion Drilling. This form of drilling is said to have been used by the Chinese more than 4,000 years ago. It is still commonly practiced around the world today. It consists of repeatedly dropping a heavy drill bit connected to a rope or cable in a hole partially filled with water. The bit loosens the soil, or chips off pieces of rock. Once enough cuttings have collected in the hole, the bit is pulled out and a bailer is lowered to collect the cuttings. The bailer is a pipe with a one-way valve or flap at the bottom that lets cuttings into the pipe but not out. When brought to the surface, the bailer is tipped up to empty the cuttings. There are many different ways to raise and lower the drill bit and bailer, such as pulling on a rope (illustrated below) or using a flexible pole called a "spring pole."

By adding a sharpened bit and a one-way valve at the bottom of the drill pipe, manual percussion and sludging techniques can be combined to get better penetration than sludging and more efficient cuttings removal than percussion drilling.

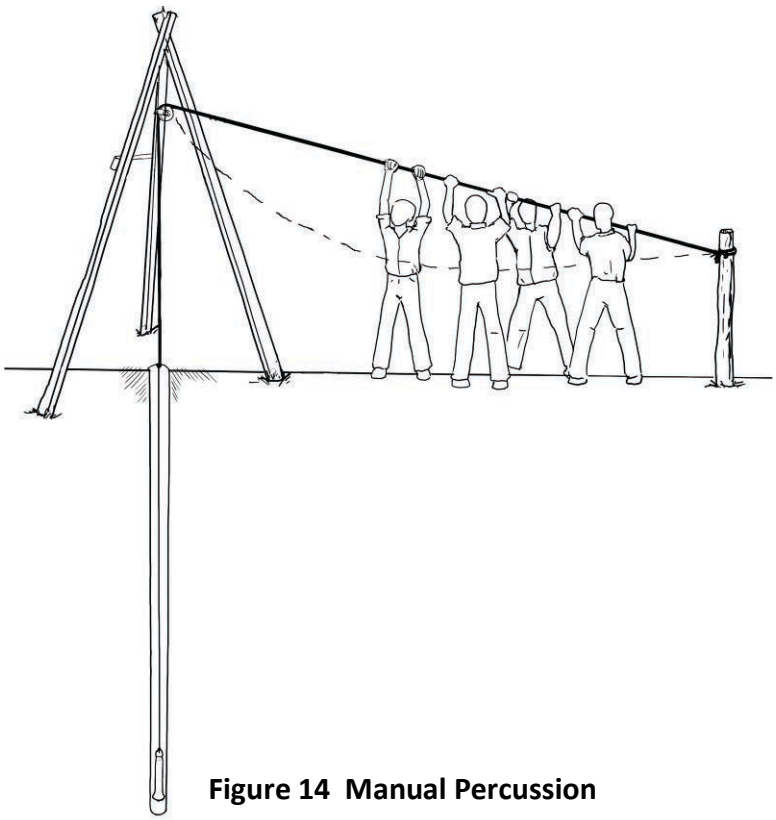


Figure 14 Manual Percussion

Advantages: Although manual percussion drilling requires more specialized tools and more skill than hand-digging, it is a method that anyone can employ and perfect. It is faster and much safer than hand-digging and is capable of reaching 70 meters or deeper. With a proper bit design, percussion drilling can also penetrate boulders or solid rock (very slowly). The borehole can be sealed to prevent surface water from entering the well and with a hand pump installed can provide a good supply of safe water.

Disadvantages: Starting the borehole usually requires digging a small-diameter starter hole more than a meter deep. Lifting the drill bit and bailer is hard, but a group of people can pull together to share the work.

Drive Point. Also called a "sand point" this method employs a sharpened hard steel point at the end of a short (less than 1 meter) section of perforated pipe. A strong steel pipe is screwed onto the drive point and the assembly is driven into the ground using a heavy sledge hammer.

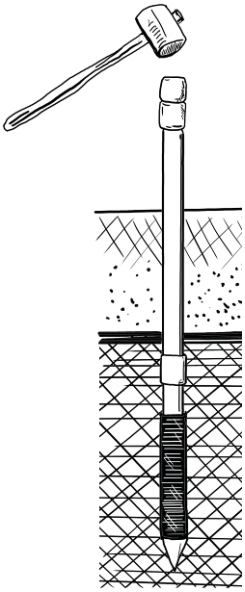


Figure 15 Drive Point

Advantages: This is a very simple, one-man operation that can install a shallow well in only a few hours.

Disadvantages: A drive point is only effective in loose sand where there is a high water table, such as close to a river or lake. It is very difficult to drive more than about 5 meters. It is not possible to install an adequate sanitary seal so a well made with this method is easily contaminated.

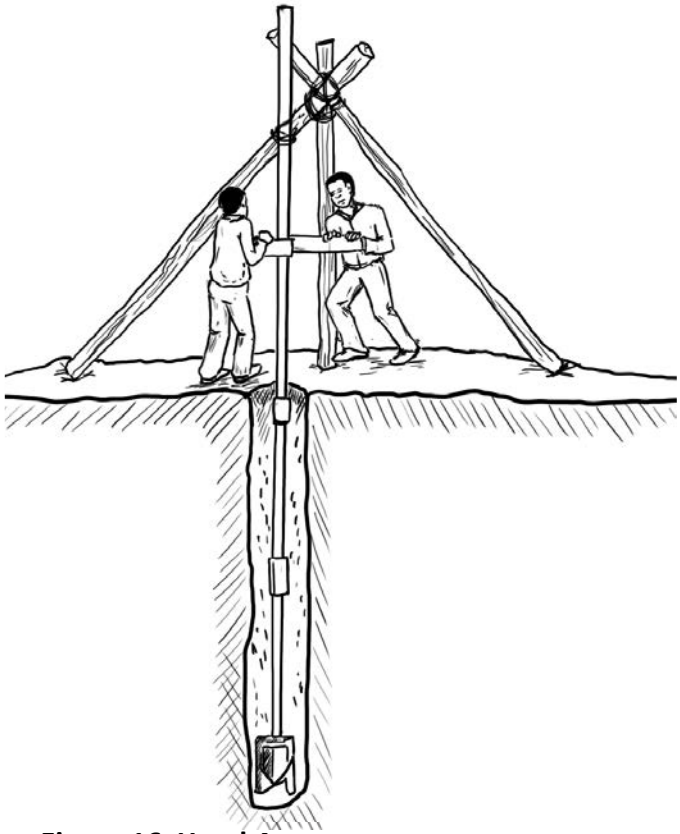


Figure 16 Hand Auger

Hand Auger. This manual drilling method uses a small-diameter open-bottom bucket with angled teeth at the end to cut into the soil. The bucket is attached by a series of steel rods to a T-shaped handle at the top by which the bucket is rotated. As the bucket fills, it is lifted out and emptied. Additional rods are added as the hole gets deeper. Auguring is normally used for taking soil samples, but is has been marketed for use in shallow well construction.

Advantages: The tools are very light and compact and can easily be carried by one person.

Disadvantages: Hand auguring requires specialized tools with heat-treated steel for the teeth. The method is very limited in the diameter of hole it can produce (less than 8 cm) and the depth it can reach. In loose silt or sand it may be possible to auger to 10 meters, but it would be very difficult to make that depth in a compact soil or in gravel. Once below the water table, it is very difficult to keep the hole from collapsing.

- Of the different manual drilling methods described above, which one seems like it would work best under most geology conditions? Explain your answer: _____

_____

_____

_____

- Please describe any manual drilling methods you are familiar with that have not been mentioned. _____

_____

_____

_____

2. Powered Methods - 25 minutes

Most manual well drilling methods have been adapted to use machinery instead of human power. And new methods have been developed that can drill larger diameter boreholes much deeper and faster than any manual method. A well drilling machine is typically called a "drill rig" or just a "rig."

Jetting. This method employs a pump to force a flow of water down a drill pipe and out a narrow nozzle to make a "jet" of water that loosens the sediment. The return flow of water outside the drill pipe carries cuttings up to the surface and into a settling pit. The pump then returns the water back down the pipe. The drill pipe is suspended from a tripod and rotated by hand to keep the borehole straight.

Advantages: This method only requires a water pump that can generate sufficient pressure and lengths of pipe. The pipe is often left in the ground to serve as the well casing. In fine sand, a 5 cm diameter PVC pipe can be rapidly advanced to more than 60 meters. It only takes two people to jet a well.

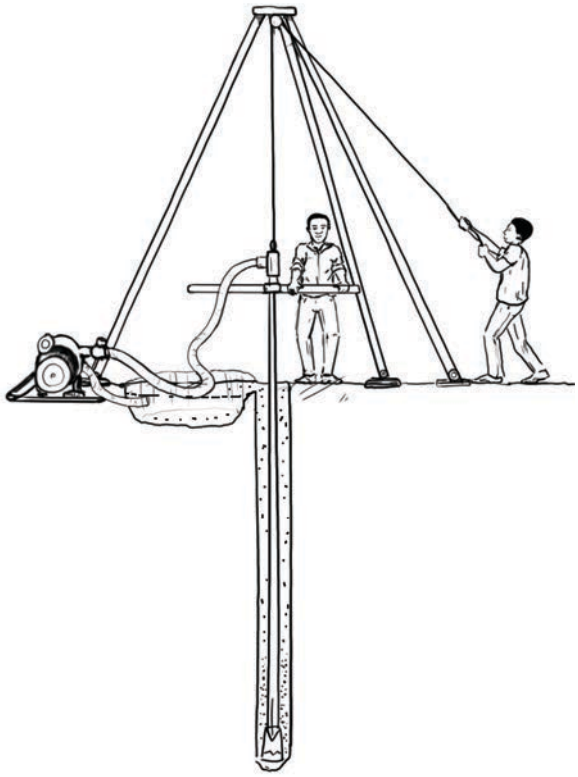


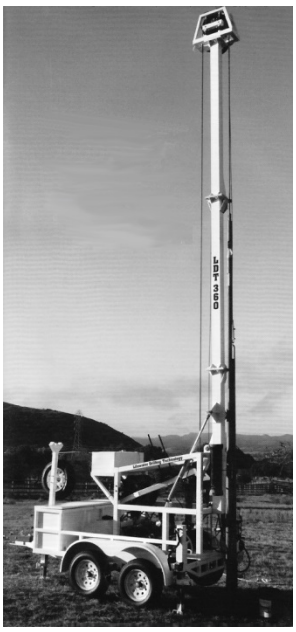
Figure 17 Jetting

Disadvantages: Jetting is only suitable for soft, fine-grained sediments. Gravel is too heavy for the return water to bring it to the surface. The diameter of the borehole is only slightly larger than the drill pipe/casing. Therefore, it is difficult to install a sufficient gravel pack or an adequate sanitary seal to protect the well from surface water contamination.

Cable Tool. This is a mechanized version of manual percussion drilling. The heavy drill bit and related parts are called the "tools" and they are raised and dropped on a steel cable. Cuttings are removed with a bailer. Several meters of water must be maintained in the borehole to keep the cuttings suspended. The machinery ranges from a basic skid-mounted powered winch with a tripod to a complex set of pulleys and drums with a large mast. The larger cable tool rigs are mounted on a trailer or the bed of a truck and use hydraulic motors to raise and lower the mast and rotate the drums of cable. Few cable tool rigs are being made today since most commercial drillers prefer faster drilling methods. However, an economical and compact trailer-mounted cable tool rig has recently come on the market (Figure 18). The LDT360 by Lifewater Drilling Technology[1] can drill to 120 meters (400') in rock or sediments. Bits are available for borehole diameters from 10 cm to 25 cm (4"-10"). Two rigs will fit into a 20-foot shipping container.



Truck-Mounted



Trailer-Mounted

Figure 18 Cable Tool Rigs

Advantages: A cable tool rig can drill through anything. The larger versions can drill hundreds of meters deep. Compared with other powered drill rigs, the machinery is simple and has a relatively low rate of fuel consumption.

Disadvantages: Compared to other drill rigs of a similar size, a cable tool rig drills very slowly. (This is actually an advantage in situations where the drillers are educating the community on principles of hygiene and sanitation and ways to ensure the sustainability of their well.) When drilling in loose sediments, it is necessary to drive steel pipe behind the drill bit to keep the borehole from collapsing. The sections of this "drive casing" must be welded together going in and cut apart coming out. So an arc welder and a cutting torch are needed. The tools on a medium to large sized rig are very heavy and require a cable and winch to move around.

[1] Not commercially affiliated with Lifewater International, although Lifewater volunteers participated in the design and testing of the rig. See *LifewaterDrillingTechnology.com* for more information.

Mud Rotary. This method of drilling starts with the basic concept of well jetting described above. Add a larger cutting bit, lengths of steel drill pipe with threaded joints, a motor to turn and lift the drill pipe, and a sturdy mast to support the pipe and you have the elements of a mud rotary drill rig. A further refinement is mixing bentonite clay or other materials in the water to improve its ability to lift cuttings out of the hole; this fluid is called "drilling mud" or just "mud." (See lessons 3.6, 3.7, and 3.8 later in this section.) There are many kinds of mud rotary drill rigs, but they fall in two basic categories; table drive, where the drill pipe is turned by a rotating mechanism near the base of the rig, and top-head drive, where the drill pipe is turned by a motor attached to the upper end of the pipe. In both types, the upper end of the drill pipe is attached to a lifting mechanism that raises and lowers it along the mast. Both types of mud rotary rigs also have a swivel attached to the upper end of the drill pipe that allows drilling mud to be pumped down the drill pipe while the pipe is rotating. The larger the rig, the faster and deeper it can drill. The LS100 and LS200 drill rigs are mud rotary rigs at the small end of the range of drill rig sizes.

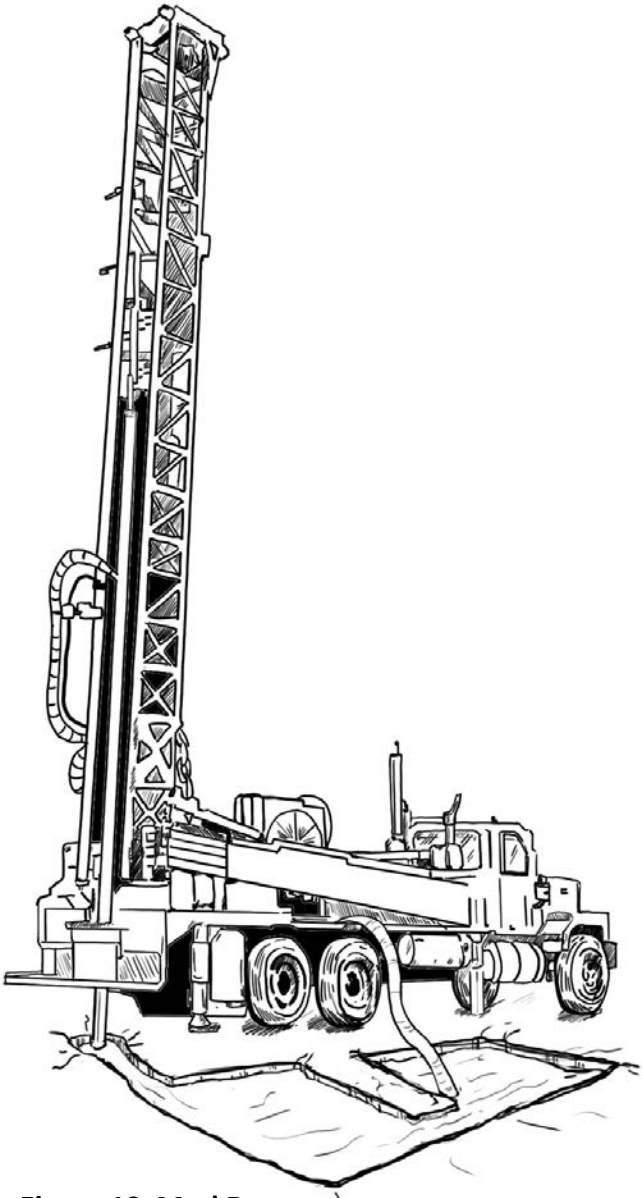


Figure 19 Mud Rotary

Advantages: Because the borehole is kept open by the pressure of the drilling mud, it is not necessary to use a drive casing as with cable tool drilling. Mud rotary drilling is also much faster than cable tool. A large mud rotary rig can drill a borehole 60 cm in diameter to 1,000 meters or more. Even a small rig like the LS200 can drill a 20 cm borehole to a depth of 60 meters.

Disadvantages: Drilling through rock requires a great amount of weight on the drill bit, so only the larger mud rotary rigs can effectively drill in rock. Most mud rotary rigs have a motor to rotate and lift the drill pipe and a motor to operate the mud pump. As a result, mud rotary rigs use more fuel per hour than a comparable cable tool rig. Most drilling operations that use a large mud rotary rig also require support vehicles to haul water and drill pipe.

Air Rotary. The mechanical elements of an air rotary drill rig are similar to a mud rotary rig; table drive and top-head drive are the two basic options for rotating the drill pipe. The principal difference is an air rotary rig uses compressed air to remove cuttings rather than drilling mud. A type of "foam" can be added to the air stream to improve cuttings removal and provide some borehole stability. An air rotary rig can use the same type of drill bits as a mud rig, but it can also drill with a down-the-hole hammer. This type of bit uses compressed air to break up rock and it can drill very fast. A large air rotary rig can drill a borehole 60 cm in diameter to 500 meters or more.



Figure 20 Air Rotary

Advantages: Because there is no drilling mud to mix or settling pits to dig, an air rotary rig can be set up very quickly. An air rotary rig also drills much faster than any other rig of a comparable size.

Disadvantages: An air rotary drill rig requires a very large air compressor, especially if a down-hole hammer is used. This adds significantly to the cost of the rig, its maintenance needs, and its fuel use. A large air rotary rig will consume 40-60 liters per hour of fuel, making it one of the most expensive types of drill rig to operate. Large air rotary rigs also require support vehicles.

- What is one of the most important things to consider when selecting a drilling method?

  _____

  _____

- Please describe any powered drilling methods you are familiar with that have not been mentioned. _____

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Lesson 3.2 Small Mud Rotary Drill Rigs

Purpose

To study the parts of an LS200 drill rig and learn how the rig operates.

Objectives

By the end of this lesson, participants will have

- Studied the terminology of the LS200 rig parts
- Inspected the packing checklist of an LS200
- Assembled an LS200 rig
- Examined how the parts function together to drill a borehole

Materials

- Poster of LS200 parts
- Drill rig and tools.
- Shipping packing list.
- Fuel and oil if the rig will be started up during this lesson.

Preparation

- Study lesson ahead of time.
- Arrange for a place outside in which to assemble the rig.

Time

90 minutes

Steps

1. Introduction
2. Parts of the LS200
3. Assemble the LS200

1. Introduction - 5 minutes

This manual is primarily written for two groups of small well drilling equipment; low-powered free-standing rigs and hydraulic trailer-mounted rigs (Figure 21). All of these rigs employ the principles of mud rotary drilling in a scaled-down package and can work in remote areas where large truck-mounted rigs cannot reach.

Low-Powered Free-Standing Rigs. There is a variety of designs and specifications within this class of drill rig. In their basic configuration, these small rigs are not able to penetrate rock or drill deeper than about 60 meters (200 feet). The typical characteristics of these rigs include:

- Top-head drive powered by a small (5 HP) internal combustion engine;
- Transmission employing a centrifugal clutch;
- Manual winch to raise and lower the bit;
- High-flow/low pressure centrifugal mud pump;
- Drag bit attached to light weight drill pipe in 5-foot (1.5m) lengths.

Low-Powered Free-Standing Rigs



Lone Star LS200



DeepRock Hydra-Drill 77



PAT-Drill 201

Trailer-Mounted Hydraulic Rigs



Lone Star LS300T



DeepRock M60



PAT-Drill 300Tp

Figure 21 Small Mud Rotary Rigs (images adapted from manufactures' web sites)

The inability of the small low-powered free-standing rigs to drill through hard rock is primarily due to their light weight. A tri-cone rock bit works best with several thousand pounds of force, which these rigs are not capable of delivering. The rigs' limited power and centrifugal clutch are contributing factors. Their depth limit is primarily determined by the low pressure and low up-hole velocity generated by the mud pump (see lesson 3.6, Drilling Mud Part 1 – The Role of Mud). The lift capacity of a manual winch also contributes to their depth limit.

The disadvantages of this class of drill rig are balanced by their portability, ease of use, and low cost. Most of these small rigs can be broken down into man-portable components and are easily transported in the back of a pickup truck. These rigs are routinely carried into remote areas by canoe, donkey cart, or small airplane. Because the components are very simple, these rigs can be successfully operated with a minimum of training. The cost (and quality) of these small rigs varies widely, but most sell for less than $20,000 USD.

Examples of low-powered free-standing drill rigs include the following: [2]

- Lone Star LS100/200 (manufactured by Little Beaver in Livingston, Texas)
  http://www.lonestardrills.com/water-well-drills/mechanical-series/ls200/
- DeepRock Hydra-Drill (manufactured in Marquez, Texas)
  http://www.deeprock.com/HD/Default.aspx
- PAT-Drill 201 (manufactured in Bangkok, Thailand)
  http://www.patdrill.com/products01_201.asp

Some manufacturers offer a version of their free-standing rig in which the internal combustion engine is replaced by a direct-drive hydraulic motor and the manual winch replaced with a hydraulic winch. These modifications make the rigs easier to operate. However, without a larger mud pump, they are not able to drill much deeper than the low-powered versions. The hydraulic versions are also more expensive.

Trailer-Mounted Hydraulic Rigs. These rigs typically employ a hydraulic direct drive motor, hydraulic winch, stronger and taller mast, and a more powerful mud pump. Being trailer-mounted provides for drill pipe and tool storage and makes these rigs easier to move and set up. They cost considerably more than the free-standing rigs, with prices starting around $30,000 USD. The improvements allow drilling to a depth of at least 100 meters (300 feet) and some rock drilling with a tri-cone bit. The basic principles of mud rotary drilling with a hydraulic rig are the same as with the smaller non-hydraulic group of rigs. However, the addition of hydraulics involves operation and maintenance concerns that are not covered in this manual.

[2] There are other models that fit into this class of drill rig (eg. http://hydra-jett.com). Being listed here does not imply endorsement by Lifewater International. Lifewater International does not sell or have any financial interest in any of these drill rigs. However, Lifewater staff and volunteers were involved in the initial concept and design of the LS100 by Harry Westmoreland of Lone Star Bits, its original manufacturer.

A significant difference between the low-power free-standing and the trailer-mounted hydraulic rigs is the latter can be converted for air-rotary drilling with the addition of a high-powered air compressor and a down-hole air hammer bit. This enables these rigs to drill rapidly through even hard rock. However, this modification adds roughly $40,000 USD to the cost of the rig; $30,000 for the air compressor and $10,000 for the down-hole hammer bit and associated equipment. Even so, the cost is much less than a new truck-mounted air-rotary drill rig and these small rigs are able to drill in areas that a truck-mounted rig can't reach. Drilling with a down-hole hammer bit is beyond the scope of this manual. Several references are provided in Appendix 15.

In this manual, the Lone Star LS200 drill rig manufactured by Little Beaver will be used as being representative of a "small mud rotary drill rig". There are operational differences between the various models of small drill rig. Therefore, it is important to always consult the owner's manual before operating any of these rigs. This training guide is not a substitute for the operation and maintenance manual from the rig manufacturer.

2. Parts of the LS200 - 25 minutes

The LS200 drill rig can be thought of as having three "systems" of parts that work together. Locate each of these systems and parts on the following drawing:

Support system - mast, shuttle, winch, drill table, slips

*** Drilling system** - drill motor, transmission, drill pipe, bit.

& Circulation system - mud pump, suction hose with strainer, discharge hose, bypass hose, three-way valve, swivel and quill.

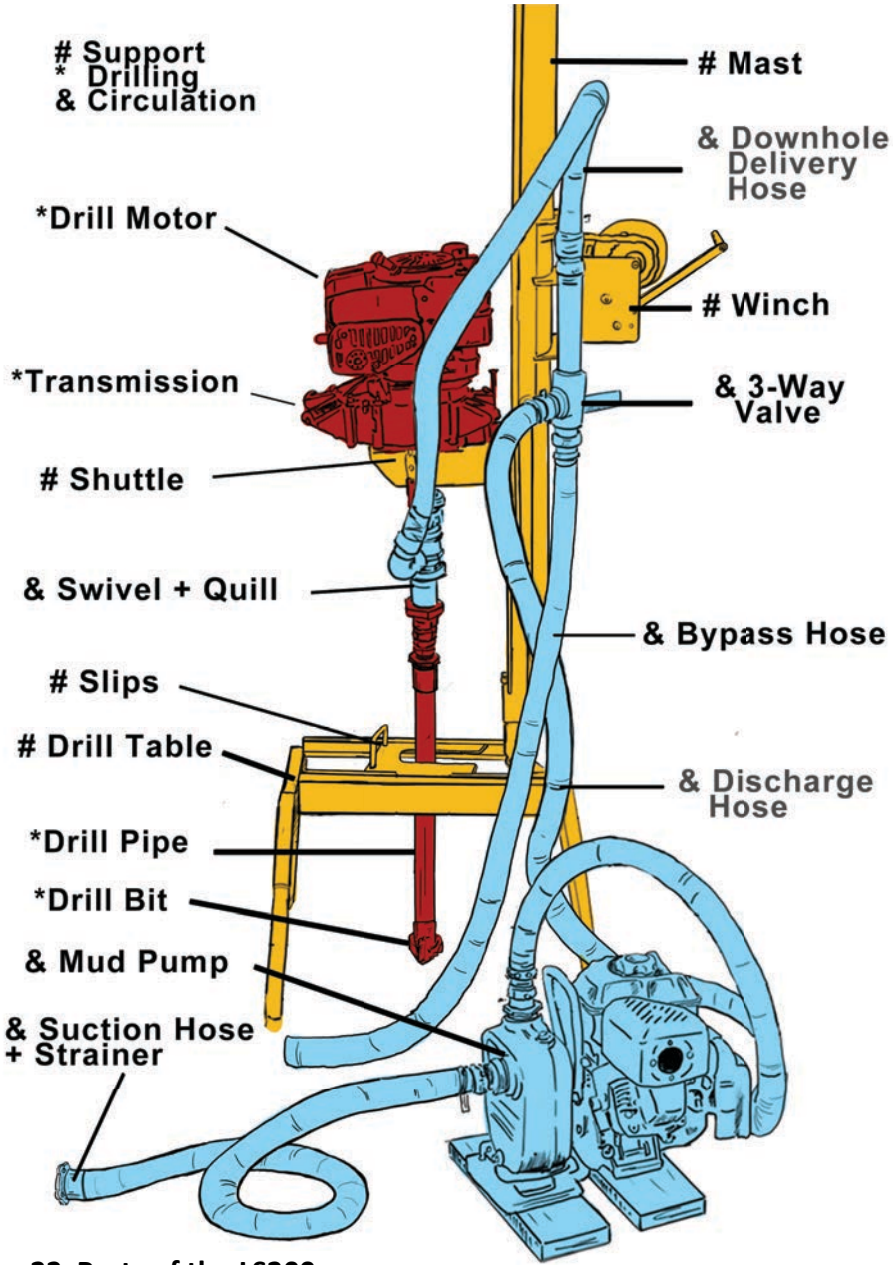


Figure 22 Parts of the LS200

2. Assemble the LS200 - 60 minutes

Now open the LS200 crate and remove each part of the rig. As it comes out, call out the name of the part. Someone needs to check off each part on the shipping packing list (Appendix 1).

Assemble the drill rig in this order:

1. Insert the stabilizer tubes into the feet of the drill table.
2. Attach the top handle to the mast and then tie three ropes to the handle.
3. Bolt the mast onto the drill table.
4. Inspect the drill motor and transmission to make sure they both have a proper amount of oil and the drill motor has fuel.
5. With the shuttle at a low position on the mast attach the drill motor and transmission to the shuttle.
6. Take apart and inspect the swivel to ensure that the seals are in good condition and the bearing surface is free from sand and well greased. Attach the swivel and quill to the transmission.
7. Level the rig so that the table is horizontal and the mast is vertical. If the rig is crooked the borehole will be crooked so a hand pump will not work properly.
8. Tie down the rig using the three ropes attached to the handle. Arrange the ropes evenly around the rig. Raise the drill motor to make sure that the ropes do not interfere with it.
9. Grease the chain idler sprocket bearings using the grease nipples.
10. Lubricate the winch, chain and sprockets, mast shuttle, and slip area with light oil.
11. Attach the short down-hole delivery hose between the three-way valve and the swivel. When attaching hoses, always make sure that a gasket is in place.
12. Attach the bypass hose between the three-way valve and the mud mixer.
13. Inspect the mud pump to make sure it has fuel and oil.
14. Attach the suction hose to the front of the mud pump.
15. Fill the mud pump chamber and suction hose with water or drilling mud.
    Important: Never operate the mud pump without first filling the pump chamber with water or drilling mud. Running it dry will quickly ruin the shaft seal. With a damaged shaft seal, the pump is unable to generate adequate suction.
    Attach the discharge hose between the three-way valve the top of the mud pump.
16. Lightly apply pipe dope to the male threads on a section of drill pipe and attach a drill bit.
17. Raise the drill motor to the top of the mast, lightly apply pipe dope to the quill, then attach the section of drill pipe with the bit.

If the rig is being assembled for an actual drilling operation, rather than a classroom demonstration, one of the crew members will be directing a group of helpers to dig mud pits as described in lessons 3.5 and 3.7. For a classroom demonstration, outline mud pits with tape or chalk.

There are two mud pits; the first is the settling pit and the second is the suction pit. The suction pit must be located on the left-hand side of the drill rig. This is because the hoses from the mud pump attach to the three-way valve, which is on the left side of the mast (as viewed from the back of the rig where the driller stands).

It is very important for each member of the drilling crew to know the names of each part. So take time to memorize the parts and test each other until you can name them without hesitation.

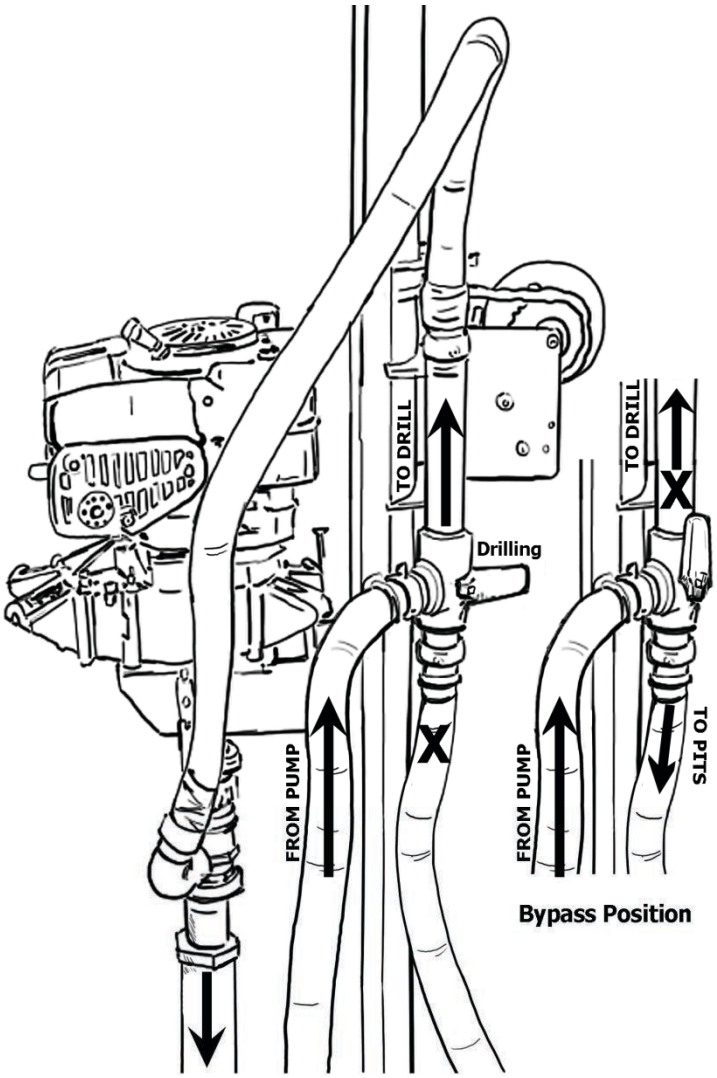


Figure 23 LS200 Hose Connections

With the LS200 rig assembled, review the principles by which it works:

- The drill motor mounted on the mast turns the drill pipe and bit.
- The mud pump forces drilling mud through the swivel, down drill pipe, and out the bit, which loosens the sediment and generates “cuttings.”
- The drilling mud returns to the surface bringing the cuttings with it.
- The cuttings drop out in the settling pit and the drilling mud is picked up by the pump from the suction pit and re-circulated through the drill pipe back into the borehole.

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Lesson 3.3 Drill Site Set-up

Purpose

To learn how to lay out an efficient and safe drilling site.

Objectives

By the end of this lesson, participants will have

- Experimented with alternate ways to lay out a drilling site.
- Set up a working drilling site.

Materials

- Sets of drill site components, cut out for each team (Appendix 13).
- Tape to mark mud pits (classroom setting)
- Poster of Drill Site Setup
- Drill rig and tools.

Preparation

- Study lesson ahead of time.
- Cut out sets of drilling site elements to re-arrange.

Time

60 minutes

Steps

1. Elements of a Drilling Site.
2. Alternative Drilling Site Arrangements.

1. Elements of a Drilling Site - 10 minutes

Drilling with the LS200 involves a lot of tools, equipment, and supplies. Following are the main items that need to be set up at a well drilling site:

Drill rig	Settling channel
Drill pipe	Suction pit
Tools	Suction hose
Mud pump	Cuttings samples
Mud mixing / water drums	Well casing
Bentonite storage	Hand pump
Mud mixer / bypass hose	Sand & gravel
Return channel	Cement

In addition to all of this drilling equipment, it is also necessary to park vehicles and perhaps an equipment trailer. Without a good plan, a drilling site can very quickly become disorganized. A disorganized site is unsafe and makes every task harder.

2. Alternative Drilling Site Arrangements - 50 minutes

There can be some flexibility in the way the elements of a drilling site are arranged. Often, features of the site such as a tree or a fence will affect where things can be placed. In whatever way the drilling site is organized, it must be **SAFE** and **EFFICIENT**:

SAFE

- A safety perimeter is established with a rope on stakes to keep visitors away from the drilling site. If important visitors arrive, the Crew Chief steps outside the safety perimeter to talk with them.
- Everyone within the safety perimeter wears a hard hat.
- The drill rig is placed on level ground and away from overhead power lines, low tree branches and traffic.
- Tripping hazards such as hoses and the rig tie-down ropes are placed where people are not constantly walking.
- The return channel and mud pits are kept from overflowing so the area does not become muddy and slippery.
- There is a first aid kit on hand and at least one drilling crew member has had basic first aid training.
- Engines are always shut off before adding fuel.

EFFICIENT

- The suction pit and mud pump are close enough to the drill rig so the discharge hose easily reaches the left-hand side of the rig where the hose connections are located.
- The settling channel and the suction pit are at least 1 meter (3 feet) from the borehole so they will not end up under the pump pad.
- Frequently-used tools are placed where the crew members who use them do not have to walk far.
- Tools are laid on a board or a tarp to keep them clean and after a tool has been used, it is always put back in the same place.
- Arrangements have been made in advance for an adequate supply of water to be available at the drilling site. An efficient mud pit will have a volume of about 650 liters (170 gallons) of water (see lessons 3.6 and 3.8). Additional water will be needed as drilling progresses so it is wise to plan on using as much as 3,000 Liters (790 gallons) of water.
- The different drilling crew members have well-defined working areas that do not interfere with each other. The Drill Helper has clear access to the front and side of the rig.
- Each crew member knows his job and does it properly and in the right sequence. For example, mixing mud takes at least 30 minutes, so this task is started right away, as the rig is being assembled.

- All equipment, tools, and supplies that will be needed for drilling and pump installation have been purchased and brought to the drill site. (See lesson 7.2 Planning and Mobilization and the Well Construction Checklist in Appendix 2.)
-

➢ Study the two examples of drilling site layouts in the following drawings.

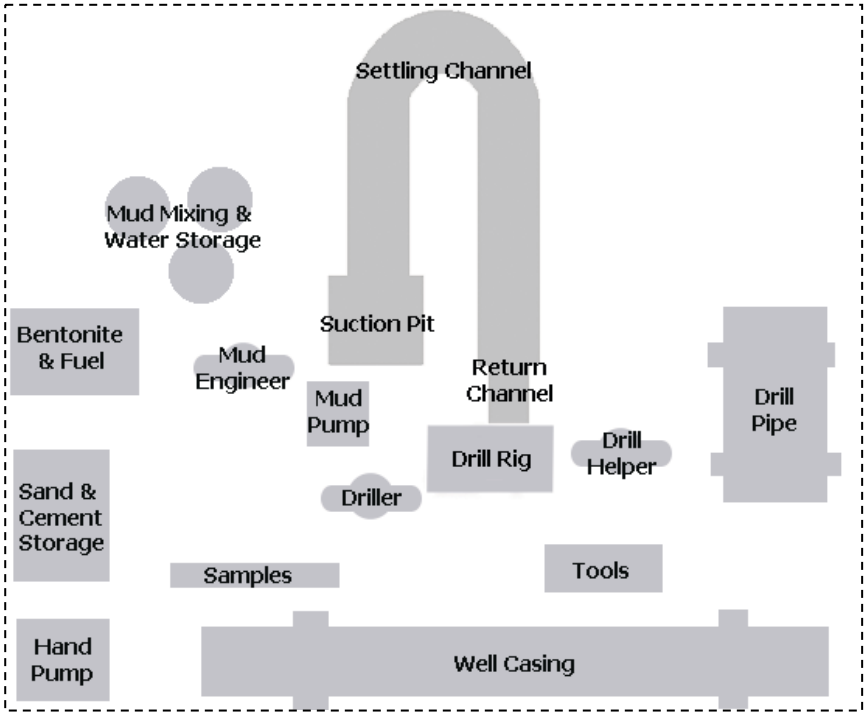


Figure 24 Efficient Drilling Site

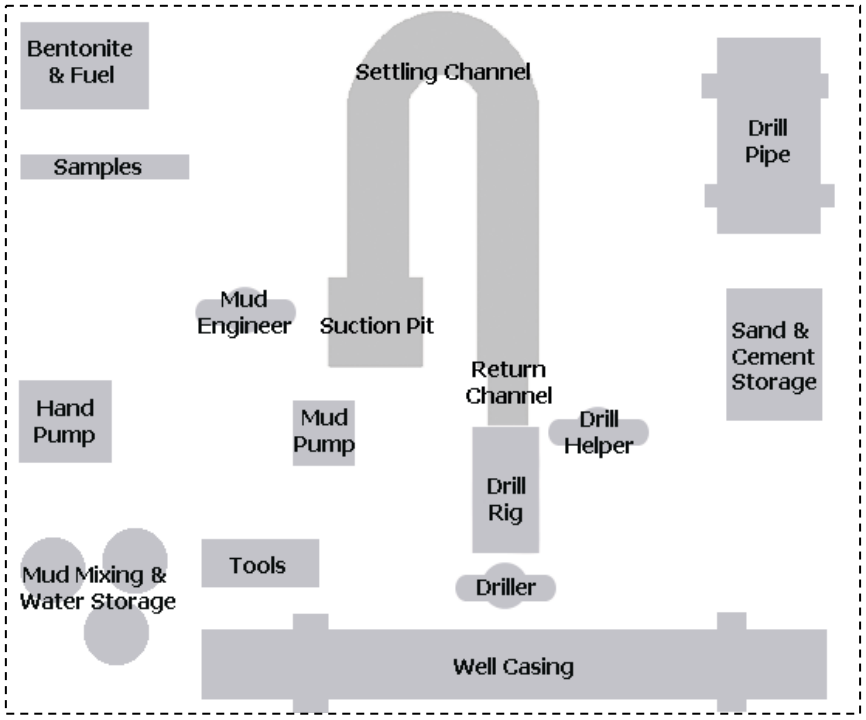


Figure 25 Inefficient Drilling Site

- For each drilling site layout, draw a line around the main working area for the Driller, the Drill Helper, and the Mud Engineer.

- Compared to Figure 24, why is Figure 25 an "inefficient" drilling site set-up?

_____

_____

- Using cut-outs of each element of a drilling site (see Appendix 13), experiment with different ways to arrange them. Discuss the advantages and disadvantages of each different layout.



Lesson 3.4 Drill Crew Duties

Purpose

To recognize the different jobs on a well drilling site and learn what each job involves.

Objectives

By the end of this lesson, participants will have

- Identified the different duties (positions) on a well drilling crew
- Studied the responsibilities of each position

Materials

- Poster of Drill Site Setup.

Preparation

- Study lesson ahead of time
- If an actual drill site isn't available, lay out a mock-up

Time

45 minutes

Steps

1. Drilling Site Jobs
2. Other Important Jobs

1. Drilling Site Jobs - 30 minutes

Have you ever learned a difficult dance? Some dances are simple, but others have many different steps which must be performed in sequence. And different people in the dance may have different steps. When everyone knows the dance and performs it well, then it is a delight to participate in or to just watch. Well drilling can be like that when everyone knows their job and does it correctly.

Think of this next lesson as "Well Drilling Dance School." We will learn and practice the steps without the distraction of the drilling equipment. Then, when you get on the equipment and the "music starts" you will have a better idea of what you are supposed to be doing.

The LS200 can be operated by two people. But this is not safe, even for experienced drillers, because there are many things to watch and things can go wrong very quickly. An ideal crew size is five or six people, including one whose primary role is driving the vehicle. Each drilling crew member should clearly understand his (or her) job. An untrained person should never be allowed to operate the drill rig.

When a well drilling crew is just getting started, each member is usually at the same level of experience. It may not be obvious who will be best suited for each job. So it is a good idea to

trade the jobs around so that everybody has a chance to practice each role and find where they are most comfortable.

Crew Chief. The Crew Chief is in charge of the drilling operation. But this is not a "supervisor" role – the Crew Chief will get dirty. He must know each job on the site, be constantly watching what is happening, and be able to step in to help or give direction whenever there is a need. (In oil well drilling this person is called the Tool Pusher.) If the Driller or the Mud Engineer is unable to work, then the Crew Chief does their job. The Crew Chief is responsible for preparing the boring log (see lesson 3.9), but other crew members will also help collect and interpret cuttings samples. The Crew Chief, working with the Driller, will determine how the well should be designed (see lesson 4.1). When there is a need to speak with community leaders and the Project Manager is not on site, then the Crew Chief makes sure their questions are answered. The Crew Chief should also be aware of children and adults who want to get past the perimeter rope and gently remind them to stay back for their safety.

Driller. The Driller operates the drill rig, controls mud circulation, and monitors the cuttings coming up the borehole. The Driller is very sensitive to the sounds and movements of the drill rig, because these are important clues to the type of sediment that is being drilled. He is always looking for signs of problems so they can be corrected before becoming serious. For example, if the return flow from the borehole slows down, he will ask the Mud Engineer to check the suction strainer. The Driller counts how many sections of drill pipe are in the borehole, so at any time he is able to give the exact depth of the drill bit. When there is any change in drilling conditions the Driller notes the depth and reports this to the Crew Chief for logging the borehole.

Assistant Driller. The Assistant Driller works very closely with the Driller, adding or removing pipe sections as directed, greasing and adjusting the swivel, collecting cuttings to show to the driller, and helping the Crew Chief maintain the cuttings samples. The Assistant Driller is responsible to make sure that tools are kept clean and in their proper place; but everyone on the drilling site shares that job, as well.

Mud Engineer. The Mud Engineer decides on the best placement of the mud pits, directs community helpers in digging the pits, mixes the drilling mud, keeps the mud pump running, and monitors the properties of the mud. When the Driller needs the mud to be thicker or thinner to match a change in drilling conditions, the Mud Engineer must be ready to respond quickly.

Helper / Driver. The Helper works primarily with the Mud Engineer, assisting him with mud mixing, refueling the mud pump, removing grass and sticks from the suction strainer, and shoveling out cuttings from the mud pits. When needed, the Helper also assists the Driller. It is good for the Helper to be the crew's driver, because he will often need to drive the truck carrying water drums to get more water for drilling.

Ambassador. For safety reasons, the crew members who are operating the drill rig should not be distracted by questions from the spectators that gather to watch the drilling operation. So it is helpful for one crew member to have primary responsibility for interacting with spectators. He can answer their questions about the drilling, explain the purpose and motivation for the project, and ensure that spectators stay out of danger.



2. Other Important Jobs – 15 minutes

It takes more than a well drilling crew to have a productive well drilling operation. Depending on the amount of work, it might be more efficient to have a separate pump installation crew so the drilling crew can move to another site once the borehole has been completed. Large professional drilling companies also have a maintenance crew that keeps the equipment in good condition so the drilling crew can rest between jobs.

Regardless of the size of the program, the following roles are essential for success. Unless only one or two wells are being drilled in a month, these support jobs need to be done by people other than the well drilling crew.

Director. The Director is the primary representative of the organization. He or she has more responsibilities than can be described here. When an organization is just starting, the Director may do nearly every job. As more people join the organization, the Director's role shifts to supporting those people.

Project Manager. It takes a lot of time to meet with community leaders to reach agreement on where a well should be located, who will pay for the well, and who will be responsible for maintaining it. In many places, government agencies are also involved in the decisions about a well. Therefore, to keep the drilling crew occupied constructing wells, these meetings are the responsibility of the Project Manager. He or she will be negotiating with the community at least several months in advance of the drilling crew arriving to start work. In a small organization, the Project Manager's job can be done by the Director, but as the number of projects and the number of employees increases, the Director will have too many other responsibilities to be spending all of his time in the field.

Financial Manager. An organization that does not properly manage its finances will eventually fail. It does not matter whether it is a charitable organization operating with donated funds or a business trying to operate at a profit. If more money is being spent than is being received, the organization cannot function. Financial management requires bookkeeping and accounting skills. These roles may be held by one person or by several, including outside consultants. In general, the more money that an organization handles the more people are required to manage it. Lessons 7.3 Record Keeping, and 7.6 Counting the Cost describe some of the tasks that are the responsibility of the Financial Manager.

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Lesson 3.5 Well Construction Stages

Purpose

To study the stages involved in constructing a well.

Objectives

By the end of this lesson, participants will have

- Considered how well drilling is like a complex dance.
- Rehearsed the steps prior to getting on the dance floor.

Materials

- Drill rig and tools. Alternate: tape and other props to represent a drill site.
- Poster of Well Construction Stages.

Preparation

- Study lesson ahead of time.
- The lesson can either be done at a "real" drill site or indoors, if necessary.
- Set up the rig, mud pump, and all other tools, water drums, etc. (lesson 3.2 & 3.3).
- Dig mud pits or just outline them if this is not a drill site.

Time

90 minutes

Steps

1. Well Construction in 20 Stages.
2. What to Watch For.

1. Well Construction in 20 Stages- 60 minutes

Every well drilling project is unique - that's why well drilling is so interesting! But there are common patterns and procedures to follow that help to reduce avoidable problems. Following are 20 stages to well construction. Detailed step-by-step instructions for the drilling operation are described in Appendix 3.

1. Mobilize

To mobilize means "to prepare for action." When the action is drilling a well, much preparation is needed before arriving at the drilling site. Lesson 7.2 is all about planning and mobilizing, so all that will be said at this point is that a checklist (see Appendix 2) should be used to make sure that everything needed for the drilling is brought to the site and is in good condition.



Figure 26 Mobilization Checklist

2. Meet with the Water Committee

Arrangements with local leaders should have been made before the crew arrives at the drilling site. Even so, it is important to meet with the water committee to review agreements and make sure everyone understands who will do what.



Figure 27 Water Committee

3. Select a drilling site

A geology survey to select the drilling site may have been made before the crew arrives to start work. If not, then it is important to review the geology of the area and consider cultural and environmental factors when selecting the drilling site (lessons 2.4 and 2.5). It is always wise to explain that the drilling crew will do the best they can to reach good groundwater, but they can never "guarantee" that water will be found.



Figure 28 Geology Survey

4. Set up the drilling site

Once a site has been agreed on, begin unloading the equipment and setting up the drill site as described in lesson 3.3. (Where appropriate, this is a good time to pray together.)

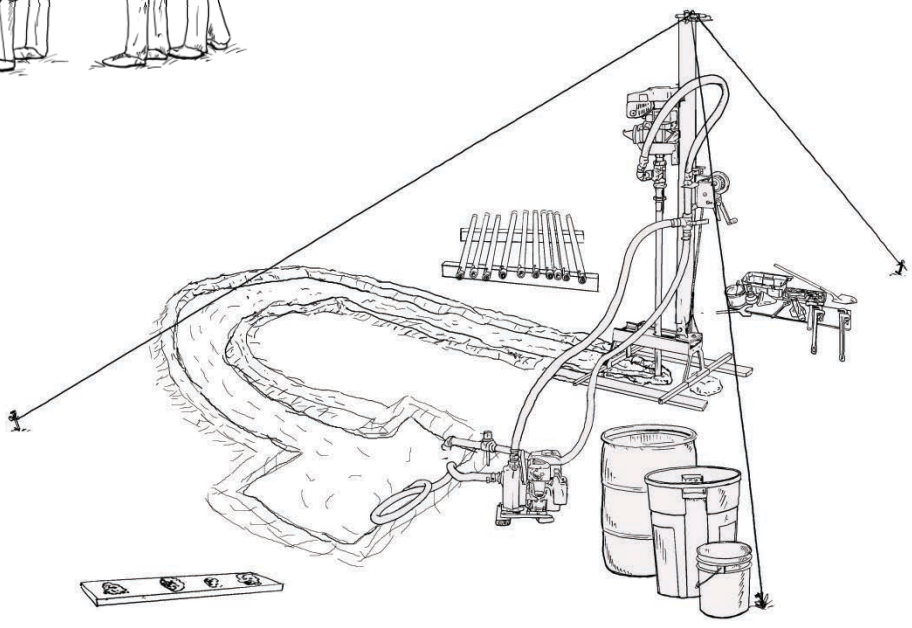


Figure 29 Drill Site Setup

5. Drill a pilot hole

Drilling should begin with the small pilot bit. This will drill faster than the large reaming bit and will produce fewer cuttings. Very carefully collect and record cuttings samples to develop an accurate boring log (lesson 3.9). If the immediate area has already been drilled before, the sediment is easy to drill, and the water table depth and aquifer thickness are known, then it will save some time to start drilling with the reaming bit attached.

The drilling steps detailed in Appendix 3 should be reviewed before operating the rig.

To know when to stop drilling, these are clues that an aquifer has been reached:

- The mud gets thinner.
- "Streams" of clear water appear in the drilling mud as it exits the borehole.
- The mud temperature changes.
- The mud level in the suction pit rapidly increases or decreases.
- Drill cuttings show sand or gravel.
- If drilling in clay, the chips of clay are no longer dry inside when broken open.

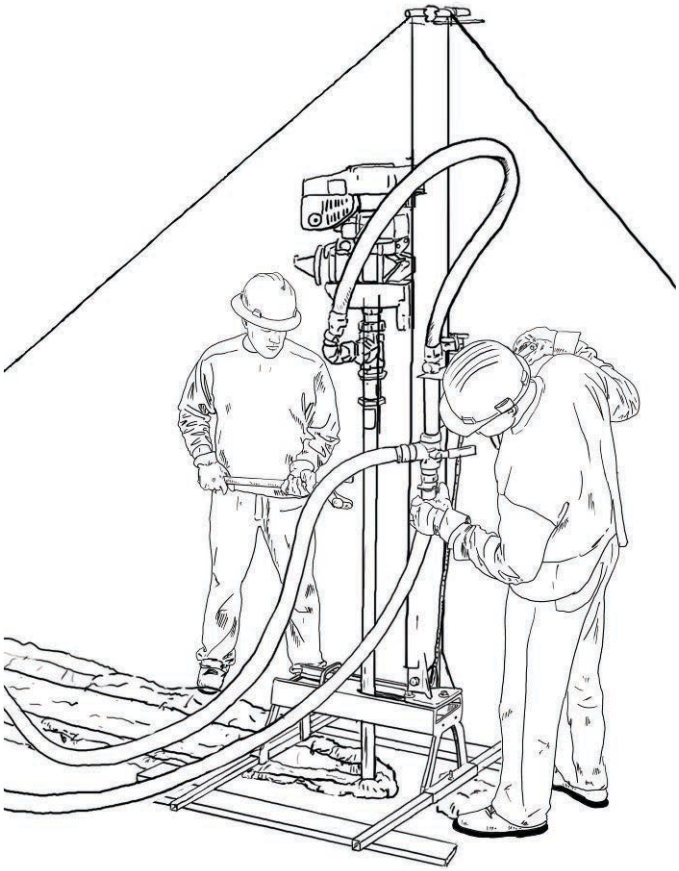


Figure 30 Drill Rig Operation

6. Making and breaking pipe joints

To "make up" a drill pipe connection means to attach a drill pipe to the quill and to another section of drill pipe already in the borehole. To "break" a joint is to disconnect the drill pipe. When drilling down (advancing the borehole) you will make joints and when removing pipe from the borehole ("tripping out") you will break joints. When first learning to drill with the LS200, this process will go slowly but with practice the driller and assistant driller will get very good at it.

It is easier to demonstrate the procedure for making up a pipe joint than it is to describe it (see Appendix 3). The trainer will show how it is done and will give everyone time to practice it.

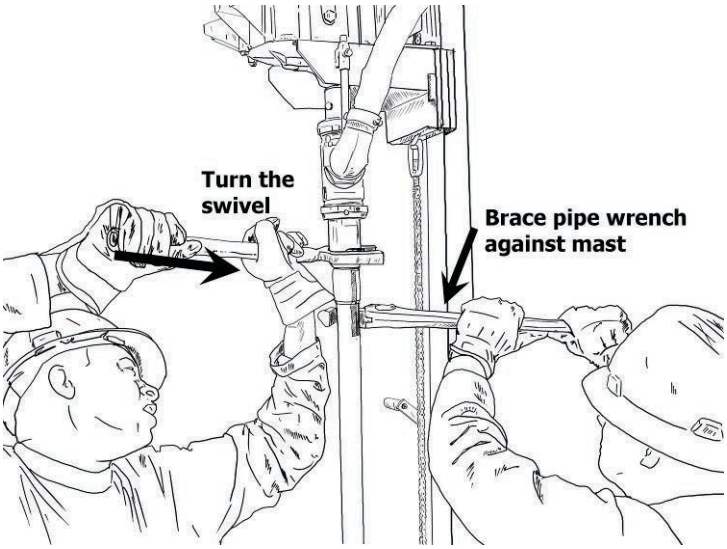
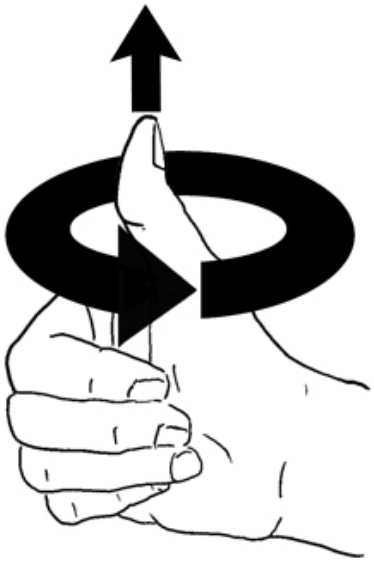


Figure 31 Disconnecting Pipe

The proper way to place and hold the wrenches when breaking a connection is shown in the drawing to the left. Since the drill pipe is resting on the slip and can't go down, the drill motor must move up. So, following the "right-hand rule" (see below) the swivel must be turned to the right when facing the drill table. The Driller must slowly raise the drill motor while the swivel is being unscrewed from the drill pipe.

The person holding the pipe wrench should stand to the side so he is not hit in case the swivel wrench slips.

"***What direction do I turn it?***" is the question we ask every time we want to tighten or loosen a pipe connection or a nut and bolt. The "Right-Hand Rule" is an easy way to remember. Point your right thumb in the direction you want the object to move; the direction in which your fingers curl is the way it needs to be turned.



The pipe wrench is one of the most frequently used tools in well drilling. Although it is a simple tool, it can be difficult to master. Practice using two pipe wrenches to disconnect and reconnect a section of pipe joined to a coupling. Work at it until you are comfortable using pipe wrenches.

When using two pipe wrenches, pull them toward each other, rather than pushing away. Use the ridges on a pipe joint or coupling to get a better grip. Keep the wrenches close to each other, leaving enough room for your hands. Fingers can get smashed if a tight fitting releases suddenly, so be careful where you put your hands.

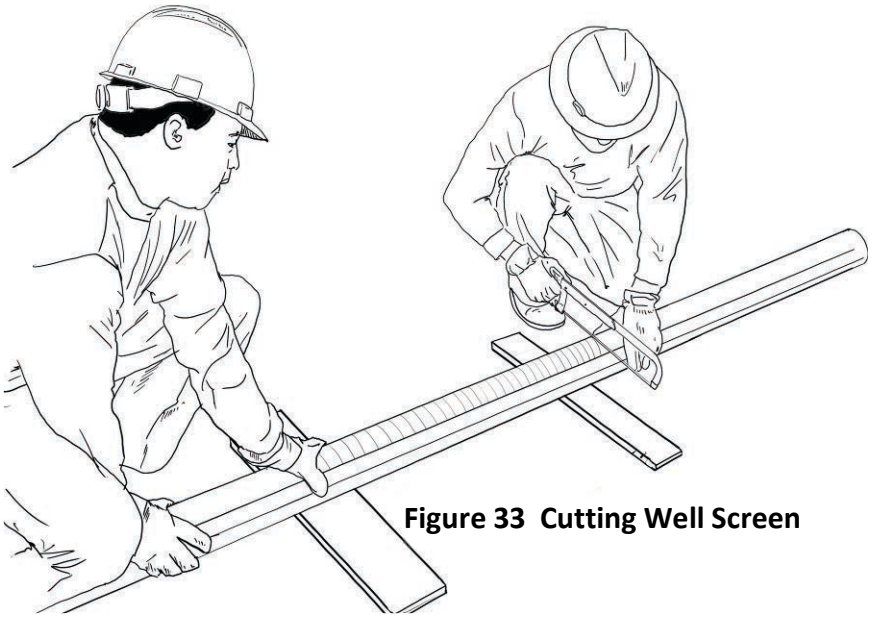


Figure 33 Cutting Well Screen

7. Design the well

Study the cuttings from the pilot hole (lesson 3.9) to determine the best depth for placing the well screen (lesson 4.1). This will be based on the water level and the aquifer depth and thickness.

Once the amount of well screen needed is known, the crew can begin cutting screen with a hack saw.

8. Ream the borehole

After the exploration borehole with the pilot bit has been completed, and the final well depth determined, pull out the drill pipe and add a reaming bit to increase the borehole diameter. If it is late in the day, it is best to stop at this point and resume early the next morning. Once reaming has begun, it should be completed, the casing installed, and the gravel pack placed in one continuous operation. Otherwise, there is a risk that the borehole will collapse. The small pilot hole is less likely to collapse.

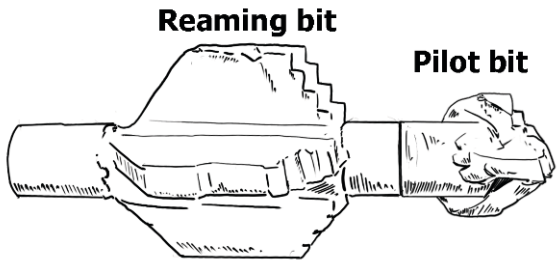


Figure 34 Drill Bits

Reaming will generate a large amount of cuttings, so it is necessary to frequently shovel out the mud pits. Prepare the well casing while the borehole is being reamed so it is ready to install as soon as reaming is finished. If the aquifer is fine sand then bentonite drilling mud could plug the pores. In this case it may be necessary when the aquifer is reached to switch from drilling with bentonite to drilling with polymer (see lesson 3.6).

Reaming and casing installation must be a continuous operation, especially in soft sediments where the borehole is subject to collapse. Keeping the borehole filled with drilling mud helps prevent collapse (see lesson 3.6). Plan ahead to have enough fuel and drilling water on site and be prepared to work into the night if necessary.

9. Install casing

To reduce the risk of a borehole collapse, especially when the aquifer is coarse sand or gravel, remove the drill pipe swiftly and install the casing as soon as the drill pipe has been removed. See lessons 4.1 and 4.2 for details on casing and well screen design and installation.

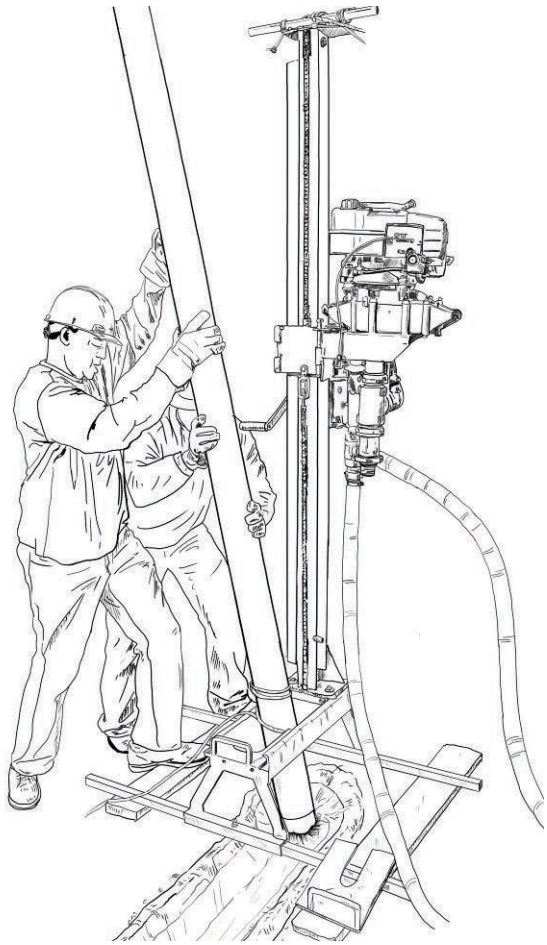


Figure 35 Installing Casing

10. Flush out drilling mud

The LS200 drill rig is provided with a casing flushing tool that is used to clean out the drilling mud as described in lesson 4.3.

11. Float in gravel pack

With the clear flushing water still flowing very slowly, gradually add the gravel pack to the borehole by hand as described in lesson 4.3

When the gravel pack is in place, the danger of borehole collapse has passed. If it is late, as it often will be at this point, cover the borehole so nothing can fall in and put away all tools before leaving the site.

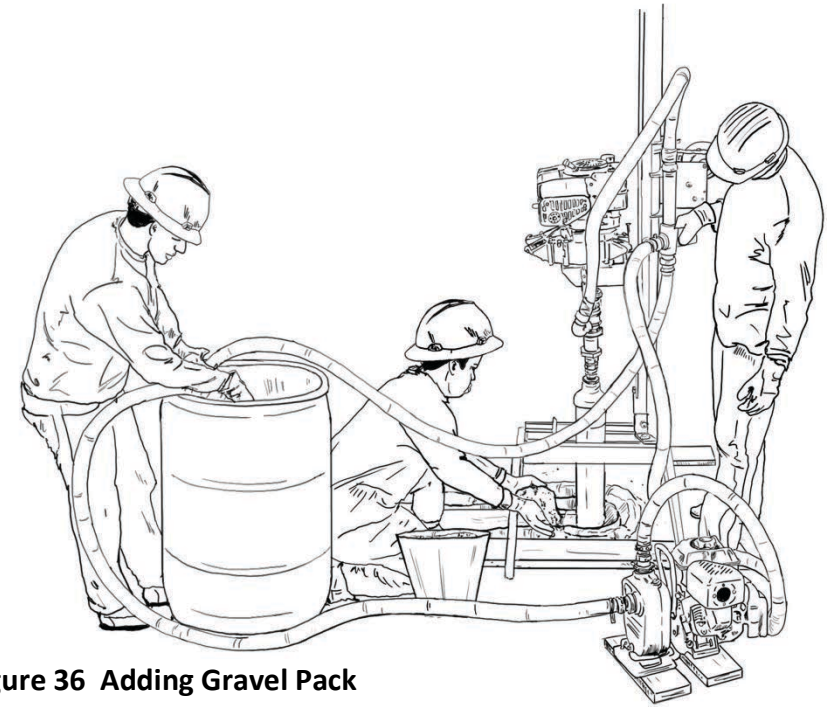


Figure 36 Adding Gravel Pack

12. Test well yield

Using a bailer, draw water out of the well as described in lesson 4.4 to determine if the well is likely to produce enough water to supply a hand pump. This is not a full well yield test, just a preliminary look. The well will not reach its full potential until it has been developed (lesson 4.6). It is not unusual for a well to produce little or no water until it has been thoroughly developed, which can take several days of work. If the well produces relatively clear water at this point then a field test for water quality (see Appendix 14) could be useful in deciding whether or not to complete the well



Figure 37 Bailing a Well

13. Commitment point

Based on the results of the initial well yield test, decide whether to install a pump in the well or close the borehole and try another spot. If the well can't be developed so that it will produce enough water (see lessons 4.4 and 4.6) then it must be closed as described in lesson 4.8.

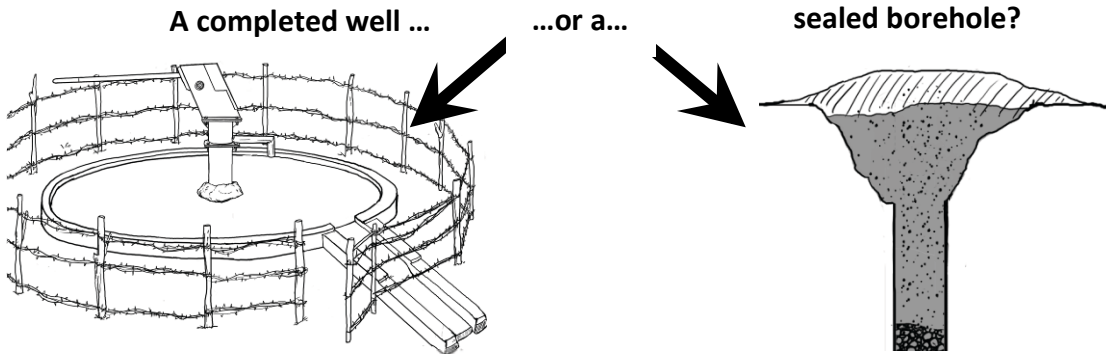


Figure 38 Commitment point.

14. Install sanitary seal

This is one of the most important steps in constructing a well. Without a good sanitary seal installed as described in lesson 4.5 then contaminated surface water can seep through the loose soil in the borehole and reach the water table. People will still be able to draw water from the well, but there is no guarantee that it will be safe to drink.

15. Develop the well

Developing the well as described in lesson 4.6 removes any remaining drilling mud and opens up flow paths through the aquifer into the well. Proper development can make the difference between a well that produces a small volume of muddy water and a well that produces a large volume of clear water.

16. Pour cement pad and set pump base

The pump pad, described in lesson 4.7, works with the sanitary seal to keep the well water safe. It also prevents formation of a mud puddle around the well, which can be a place of disease transmission. The well number, depth, and date of construction should be written on the pump pad.

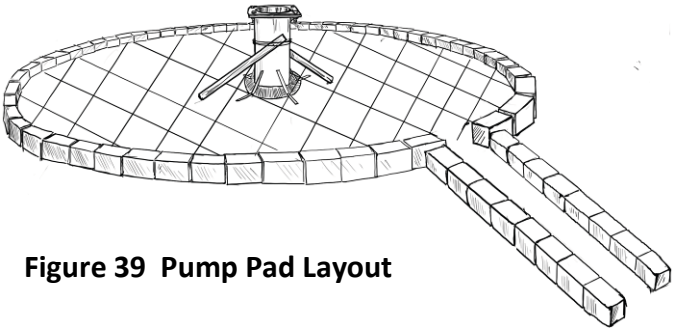


Figure 39 Pump Pad Layout

17. Install pump

Basic installation procedures for the Afridev and the India Mark II hand pumps are described in sections 5 and 6 of this manual. Specific manufacturers' instructions should be consulted when installing an unfamiliar type of pump.

18. Disinfect well

The well has been drilled with unsafe water and the well casing and pump parts have probably been laid on the ground. So the water in the well has been contaminated. Follow the procedure described in lesson 5.5 to kill bacteria that may have been introduced during well construction.

19. Well completion report

After installing the pump and disinfecting the well, complete a well construction report as described in lesson 7.3. Keep good notes during drilling and well construction so this report can be accurately filled out. Give a clean copy to the Village Water Committee, any government representatives, and keep a copy for your records. It is also useful to place a copy of the well report in a plastic bag taped inside the pump head.

20. Instruct the water committee

Section 8 of this manual gives suggestions on things that a village water committee can do to keep their well working properly. And before using the water, the chlorine must be pumped out, so instructions need to be given on when to do this.



Figure 40 Instructing the Water Committee

2. What to Watch For - 30 minutes

Well drilling takes concentration. Things can go wrong quickly and if everyone on the drilling crew is not paying attention, then serious problems can develop.

So **watch** for these things:

All of the Time

- Visitors. Both children and adults will want to see what you are doing. This is reasonable and should not be discouraged. But they need to be kept outside of the safety perimeter.
- Your crew members. Be aware of what the others are doing – or not doing. Be ready to help, but do not neglect you own job.
- Your tools. Tools have a bad habit of dropping down the borehole, walking away in the hands of a visitor, or just being misplaced – often in a crew member's pocket. Take good care of your tools! Keep them in a secure place where they are out of reach of visitors and can always be found.

While Drilling

- The rate of drilling must match the rate of cuttings removal. Drilling too fast will cause cuttings to build up in the hole and the bit will become stuck. Keep circulating drilling mud through the drill pipe until cuttings have been removed from the borehole. If the volume of sand cuttings is greater than the rate at which the bit is advancing then a cavern might be forming around the bit (see lesson 3.10).
- Rate of circulation. If the rate of drilling mud coming out of the borehole slows down or stops, then cuttings will drop back around the bit. Check to see if the suction hose strainer is clogged. If not, fluid is being lost to the formation. Pull up the drill bit a meter or so and make the drilling mud thicker.
- Maintain a proper drilling mud viscosity (lessons 3.6, 3.7 and 3.8). Keep mud pits full of fluid. If the level in the suction pit drops it could mean that drilling fluid is being lost down the hole. Thicker mud may be needed.
- Pay close attention to the feel of the drill rig and the cuttings, note the depth of any changes, and match cutting samples with drilling conditions. When the rate of advance stops and the bit begins to bounce around, it has hit rock or gravel. You probably won't be able to drill any deeper with the LS100 or LS200, so don't force

the bit down since this will damage the clutch of these rigs. If drilling with the LS300 or a similar trailer-mounted hydraulic rig, this may be an appropriate time to switch from using a drag bit to a rock drilling bit (either a roller cone bit or a down-hole hammer).



Ensure that cuttings are settling out before they reach the suction pit. If not, then the drilling mud may be too thick or the mud pit may be too small.



If the mud pit fills up with cuttings, new cuttings can't drop out and they will circulate back through the mud pump instead. This will wear out the pump. Routinely shovel out cuttings, especially when the drilling mud is not circulating while more drill pipe is being added.



Watch the engines. Check fuel levels while circulation has been stopped to add a pipe section. Always shut off engines before adding fuel.



Speed of rotation of the drill. If the drill motor becomes labored or starts to slow down then pull up on the drill pipe. Forcing the drill pipe down too hard causes friction, reduces speed of rotation and can damage the centrifugal clutch.



Never let the mud pump run without water or drilling mud in the pump chamber. Always prime it before starting.



Look for signs that indicate an aquifer has been reached:

- The mud gets thinner.
- “Streams” of clear water appear in the drilling mud as it exits the borehole.
- The mud temperature changes.
- The mud level in the suction pit rapidly increases or decreases.
- Drill cuttings show sand or gravel.
- If drilling in clay, the chips of clay are no longer dry inside when broken open.

Lesson 3.6 Drilling Mud Part 1 - The Role of Mud

Purpose

To introduce the importance of drilling with a properly engineered drilling fluid.

Objectives

By the end of this lesson, participants will have

- Considered the roles that bentonite plays in forming a good drilling fluid
- Observed a demonstration of viscosity and density
- Discovered where to obtain bentonite locally

Materials

- Posters of viscosity examples and mud thickness chart
- Samples of bentonite, soda ash and polymer to pass around.

Preparation

- Study lesson ahead of time.

Time

90 minutes

Steps

1. Introduction
2. Functions of Drilling Mud
3. How Drilling Mud Works
4. Ingredients of Drilling Mud
5. How Much?

1. Introduction - 5 minutes

The word "mud" – in common everyday usage – simply means wet dirt. But in well drilling, the term "drilling mud" means a carefully engineered drilling fluid. Do not think that any old dirt will do the job.

Your skill in forming and maintaining a proper drilling mud will determine your long-term success at completing good water wells with a mud-rotary drill rig. This is especially true when working with a low-power drilling rig like the LS200.

Drilling without proper mud may limit the depth that can be achieved, greatly increase the risk of getting the drill bit stuck, make it difficult to properly develop the well, and reduce the yield of the well.

There are three lessons on drilling mud:

Part 1 - "The Role of Mud" explains why drilling mud is important;
Part 2 – "Mixing Mud" guides you through the steps to make good drilling mud;
Part 3 – "Using Mud" gives practical advice on how to properly use drilling mud.

2. Functions of Drilling Mud - 15 minutes

Good drilling mud does four important things:

1. Drilling mud helps remove cuttings from the borehole.
This is important because otherwise cuttings will collect at the bottom of the borehole and lock up the drill bit. It does this by increasing the viscosity of the drilling fluid (we'll discuss this in more detail later in the lesson).

2. Drilling mud maintains hydrostatic pressure against the borehole wall, keeping it from collapsing.
The height of the column of drilling mud above the water table is called the "hydrostatic head." When drilling in sand and other soft sediments below the water table ("flowing sand") a hydrostatic head of at least 3 meters (10') is needed to guard against borehole collapse. (Lesson 3.10)

3. Drilling mud seals the borehole wall with a thin "wall cake."
This is important because the wall cake formed by good drilling mud helps stabilize the borehole wall, keeping it from collapsing. Also, the wall cake keeps the drilling mud from migrating into the aquifer where it is hard to remove during well development and can reduce water flow into the well.

4. Drilling mud lubricates and cools the drill bit.
This is important because a stuck bit puts an end to drilling and a hot bit wears out faster.

3. How Drilling Mud Works- 20 minutes

Good drilling mud can remove cuttings from the borehole because it has a high viscosity. Viscosity is a fluid's resistance to flow; the greater the resistance, the higher the viscosity. The viscosity of drilling mud is measured with a Marsh Funnel (described in the next lesson) and is expressed as the number of seconds that it takes for a quart of drilling mud to pass through the funnel.

The following illustration helps to see how increasing the viscosity of our drilling fluid helps to remove cuttings.

Picture a tube filled with water. Drop a small stone in the tube and think how fast it will drop to the bottom.

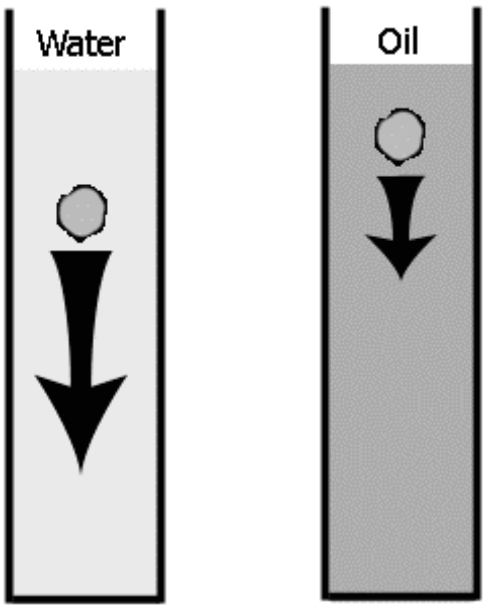


Figure 41 Viscosity Example 1

Now picture a tube filled with oil.

- Would the same stone drop faster or slower in oil than in water?

It drops slower in oil, because oil has a higher viscosity than water.

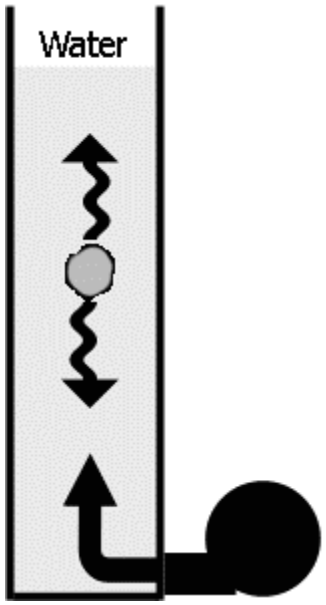


Figure 42
Viscosity Example 2

Now imagine that the tube has a pump at the bottom that is pumping water up the tube. What happens now when you drop a rock in the tube? Depending on the weight of the rock and how fast the water is moving up, the rock will either drop slower than it did in the still water or it might be pushed up out of the tube. It is easy to see that by increasing the pumping rate we can keep the stone from dropping to the bottom of the tube.

Consider if our pump is at its highest speed but the stone is so heavy that it still drops to the bottom.

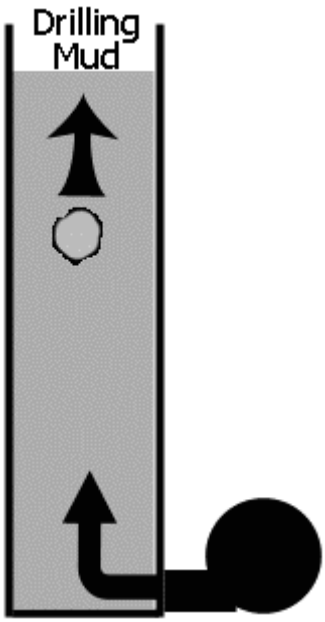


Figure 43
Viscosity Example 3

- What would happen if we replace the water in the tube with a fluid that has a higher viscosity than water – like drilling mud?

The fluid with a higher viscosity pushes harder against the stone so that without increasing the speed of the pump we are now able to lift the stone.

This is what happens when drilling with a low-powered rig like the LS100 or LS200 rig. The mud pumps on these rigs do not have a large range of speed. We will usually be running the pump at or near its top speed. So if the cuttings are not being lifted out of the borehole we can not increase the upward speed of our drilling fluid. But we can increase the viscosity of the drilling fluid. This makes it possible to lift even large gravel out of the borehole.

But lifting cuttings out of the borehole is only half of the job. The drilling mud is circulated back into the borehole, so the cuttings need to settle out in the mud pit. Otherwise, cuttings will be pumped back into the borehole and that wears out the mud pump and swivel, and can clog the bit. Good mud pit design plus proper mud viscosity equals successful drilling.

Traditionally, mud rotary drillers have dug mud pits with a volume that is three times the final borehole volume.[3] Starting with a large mud pit provides enough volume so that cuttings can drop out during the final stages of drilling. Cuttings are not removed from these pits during drilling. These pits are usually dug out with a bulldozer or backhoe.

The main problem with this traditional approach to mud pit design is that it requires a very large volume of water and bentonite. For example, a borehole 60 meters (200') deep with a diameter of 20 centimeters (8") has a volume of approximately 1,900 liters (500 gallons). Three times this volume would be 5,700 liters (1,500 gallons).

The water wells for which this manual is written are typically located in the rural districts of a developing country. Water is not readily available in these areas. So it may take many women and children carrying their buckets several kilometers to the nearest river to fill the mud pit. It would take 285, 20 liter (5 gallon) buckets to fill a mud pit with a volume of 5,700 liters. And it is normal for a portion of the drilling mud to be absorbed by the soil around the mud pit and in the borehole, so it is necessary to add water to the pit every day.

For this reason, drillers using these small mud rotary rigs rarely dig mud pits that meet the "three times borehole volume" rule. What has commonly been taught is to dig a settling pit that is about a meter square and a meter deep and a suction pit that is about half that size. A wall of soil is left between the pits with a gap that the drilling mud flows over. These pits usually have a total volume 1,500 liters (400 gallons) or less. Because digging by hand in hard baked soil is difficult, it has been observed that a drilling crew's mud pits tend to get smaller over time. The result is premature failure of the mud pump due to pumping too much sand.

Cuttings need time to settle out. And the farther they have to travel to reach the bottom of the mud pit, the longer they will stay in suspension. The two mud pits shown in Figure 44 have the same volume but cuttings will settle to the bottom faster in the shallow pit. So a channel, rather than a pit, will give better settling of cuttings. This is described in more detail in Lesson 3.8.

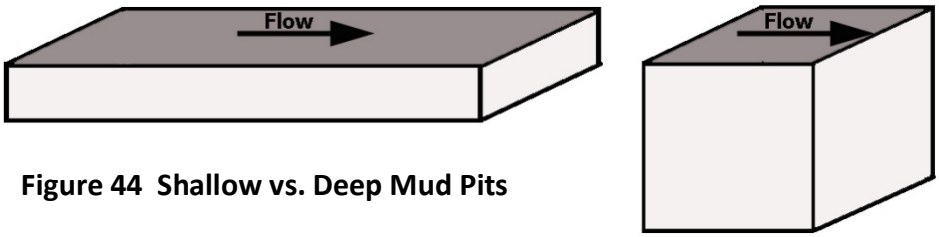


Figure 44 Shallow vs. Deep Mud Pits

[3] Many well drilling guides refer to this rule of thumb. However, instead of digging a large mud pit, which takes up space and is hard to remove, most modern big rig mud rotary drillers now use a trailer-mounted "shale shaker" with "sand cones" to separate cuttings and sand from the drilling mud.

The drilling mud needs to be thick enough to lift the cuttings, but not so thick that the cuttings can't settle out when the mud slows down in the mud pits. Achieving this balance takes practice and is the key to successful mud rotary drilling.

4. Ingredients of Drilling Mud - 45 minutes

The goal of mixing drilling mud is getting the right viscosity for the drilling conditions. Making good drilling mud is like baking a cake. It will only come out right if you use the right ingredients in the right amounts.

Water

Water is the starting point for making good drilling mud. It should be fairly clear and fresh; salty or brackish water will not work well. The water should not have a high mineral content (termed "hard" water) and it must have a **pH in the range of 8.5 to 9.5** (slightly alkaline). The water used to make drilling mud should always be checked using pH test strips (often available at a pharmacy) or a pH meter. See lesson 3.7 for more information on pH.

As noted in lesson 3.3 on setting up the drill site, an efficient mud pit will have a volume of about 650 liters (170 gallons) of water. A recommended size and shape for the mud pit is shown in lesson 3.8. In addition, the borehole must be kept full of drilling mud. A 60 meter (200') deep borehole has a volume of 1,900 Liters (500 gallons).

While drilling, it is necessary to keep a supply of make-up water – at least one 55-gallon drum - ready in case there is sudden fluid loss. It takes a lot of water to drill a well with the mud rotary method, so careful planning is needed to ensure that enough water is available before drilling is started. Expect to use as much as 3,000 Liters (790 gallons) of water to complete a 60 meter (200') deep well.

Many drill crews keep a small gas-powered pump that can lift water from a stream or pond. They use this to fill 55-gallon drums in the back of a truck. This way, one crew member with the help of a few villagers can get more water without having to stop drilling. Some drilling crews use a large portable "bladder tank" to store their water so they do not need to make refill runs.

Bentonite

It is sometimes said that when drilling in clay the borehole "makes its own mud." This is simply not true. Water and dirt does make "mud" - but that is not good drilling mud. There are many different kinds of clay and each kind has different properties. Good drilling mud is made with "bentonite" clay. Bentonite is a very special type of clay that comes from weathered volcanic ash. It is mined and processed from just a few areas; the largest commercial deposits are in Wyoming, USA. Wyoming bentonite is shipped all over the world for use by professional drillers and others.

One of the special properties of bentonite is the way it quickly swells to as much as 10 times its original volume when it is completely mixed with water. When bentonite has completely swelled, it is said to be "fully hydrated." When the water condition is correct (see below) a high-quality bentonite designed for water well drilling will take at least 30 minutes of mixing through the mud pump before it is fully hydrated. If the water is too "hard" or the pH is not in the range of 8.5 to 9.5, then the bentonite will take longer to hydrate, or might not fully hydrate at all.

Even if the local clay seems "almost like bentonite" that local clay will form a wall cake that is many times thicker than the wall cake formed by good bentonite. Thick wall cake is very hard to remove when developing the well and may remain to clog up the aquifer. The wall cake formed by high-quality bentonite is much easier to remove.

The amount of bentonite needed to make a good drilling mud depends on the formation being drilled. As different soil types are encountered, it may be necessary to adjust the viscosity of the mud by adding more bentonite (already hydrated) or more water (conditioned with soda ash). The following table gives the recommended mud viscosity for drilling in different types of soil:

Table 1 Drilling Mud Thickness Guidelines[4]

Material Being Drilled	Sediment Grain Size	Marsh Funnel Viscosity (seconds/quart)
Natural swelling clays*	<0.08mm	32 to 37
Non-swelling clays and fine sand	0.08-0.43mm	40 to 45
Medium sand	0.43-2.0mm	45 to 55
Coarse sand	2.0-4.8mm	55 to 65
Gravel	4.8-19.0mm	65 to 75
Coarse gravel	>19.0mm	75 to 85

*Note: When drilling in clay the cuttings tend to form clumps which may be as difficult to lift as gravel so a thicker mud than is indicated here may be needed.

Most high-quality or "premium" bentonite sold for water well drilling comes in 23 kilogram (50 pound) sacks. The amount of bentonite required to achieve the viscosities listed above ranges from **one-half to a full sack per 378 liters (100 gallons)**. As we will learn in the following lesson, it works best to first mix the bentonite very thick – up to a full sack in a 55-gallon drum of water – and then lower the viscosity to the desired range by adding water after putting the hydrated bentonite into the mud pits.

[4] These viscosity guidelines were developed for drilling with big rigs equipped with powerful mud pumps. The low pressure pumps on most small drill rigs have difficulty pumping mud with high viscosity, so larger gravels can be hard to lift. These mud guidelines are appropriate for the trailer-mounted hydraulic rigs which tend to have more powerful pumps.

There are different grades of bentonite; "Premium" or "High Yield" is best for drilling water wells. The oil drilling industry sometimes uses a grade that is coarser and which does not swell as much as high quality bentonite. The oilfield grade may be half the cost of premium bentonite. But oilfield bentonite may require four sacks to reach the same viscosity as one sack of premium bentonite, so it is not a bargain.

- Have you located a source of bentonite? If so, what is it?

- What might you do if bentonite cannot be found in your area?

Soda Ash

Soda ash is one common name for sodium carbonate. It is a harmless white powder used in the making of glass and in many other industrial applications. Soda ash can often be purchased in the detergent section of stores as washing soda, sal soda, or natron. (Sodium bicarbonate, called baking soda, is not the same thing.)

Soda ash dissolved in water – before adding bentonite - will adjust the pH and the "hardness" of the water to the ideal range for hydrating the bentonite. Mix approximately **60 grams of soda ash per 100 liters of water (or 1/2 pound per 100 gallons)**. If the water is far below or above the desired range of pH or hardness, then twice the amount of soda ash may be used.

When make-up water is added to the mud pits, it should also be treated with soda ash if the water is not already in a pH range of 8.5 to 9.5. Having the mud "go bad" while drilling because the water chemistry has changed can lead to a stuck bit or collapsed borehole.

A simple method for measuring the proper amount of soda ash is given in Appendix 4.

Polymer

Drilling polymer is a special form of starch that gets very thick when mixed with water. It comes as white granules or as a clear liquid. Liquid polymer is easier to mix, but dry polymer is weighs less and so is easier to store and transport. There are different kinds of polymer, and not all types behave the same way. Some common polymers are Poly-Sal, EZ-Mud DP, and Kwik-Vis-D. (An older type of polymer was called "revert" and this term is still used by some drillers to describe a polymer.) It is necessary to read the manufacturers' instructions to be sure you are using the polymer correctly. In general, it takes a very small amount of polymer to make a thick drilling fluid.

When drilling in heavy clay, the clay will clump together to form chunks that can be as hard to remove from the borehole as large gravel. So the drilling mud needs to be thick enough to lift

these cuttings. If not removed, the clumps can form a "boot" or "collar" around the drill pipe, cutting off circulation. Adding polymer to the drilling mud – after the bentonite is fully hydrated – will help prevent these clumps from forming.

Completely hydrate the bentonite first and then add polymer. If polymer is added before the bentonite is fully hydrated, then the polymer will coat the grains of bentonite and prevent them from absorbing any more water. The result is small clumps of dry bentonite that will migrate into the formation. If the drilling mud already includes polymer, and additional bentonite is needed to increase the viscosity or to replace lost drilling fluid, first hydrate the bentonite in a separate mixing drum before adding it to the active drilling fluid.

Different polymers are used at different rates, so check the manufacturer's specifications. The recommended rate for two common dry polymers (Bariod "EZ-Mud DP" or WYO-BEN "Kwik-Vis-D") in a bentonite-based drilling mud ranges from **30 to 90 grams per 100 liters (0.25 to 0.75 pounds per 100 gallons)**. A range is given because the drilling mud may need more or less viscosity for the particular formation. Use the minimum amount of polymer needed to lift cuttings and keep clay from clumping.

A simple method for measuring the proper amount of polymer is given in Appendix 4.

Polymer may be used by itself, instead of an additive to bentonite, when reaming the borehole. The mud pits are pumped out to remove all of the bentonite, fresh water is mixed with polymer using the mud pump, and drilling is resumed. This method removes most of the bentonite wall cake thus making it much easier to develop the well. Because polymer may be more expensive or more difficult to obtain than bentonite, some drillers switch to polymer only when they are reaming the aquifer zone where they plan to place a well screen.

Polymer is easily broken down (made thin like water) by adding common household liquid bleach (3%-5% sodium hypochlorite). This is the same bleach used to disinfect the well after installing a hand pump. It takes about 4 liters (1 gallon) of bleach to break down 400 liters (100 gallons) of polymer, when the drilling mud is only polymer and water. Only the fluid in the borehole needs to be treated. A 30-meter (100') borehole 200 mm (8") in diameter has a volume of around 900 liters (240 gal.). So, when drilling with polymer alone, it would take 9 liters (2.4 gal.) of bleach to treat the polymer when the well is being developed. If polymer is used only to enhance a bentonite drilling mud, then much less bleach is needed to break down the polymer.

If the polymer is not broken down with bleach, then it can promote bacteria growth. For this reason, whenever polymer is used, it is important to add bleach to the well as it is being developed.

Other Additives

Other drilling mud products are available for a wide variety of applications and circumstances. These are beyond the scope of this introductory manual. More information can be obtained from these major distributors of well drilling products:

WYO-BEN, Inc. www.wyoben.com

Bariod Industrial Drilling Products www.baroididp.com



5. How Much? - 5 minutes

A manufacturers' application rate for a drilling mud component in pounds per 100 gallons can be difficult to relate to the volumes that are being used on a well drilling site. So a simple measurement method and a set of tables are presented in Appendix 4 to make it easier to determine how much water, bentonite, soda ash, or polymer to add.

The following summarizes the materials needed to make drilling mud for a 20 cm (8") diameter borehole 60 meters (200') deep. Initially, only the mud pit needs to be filled but as drilling progresses, much more drilling mud will be required to fill the borehole and to replace what is lost through seepage into the soil.

	Mud Pit + Loss	+ Borehole	= Total	
Water:	750 L (200 gal.)	1,900 L (500 gal.)	2,650 L (700 gal)	
Soda Ash:	0.5 kg (1 lb.)	1.1 kg (2.5 lb.)	1.6 kg (3.5 lb.)	
Bentonite:	46 kg (100 lb.)	115 kg (250 lb.)	161 kg (350 lb.)	= 7 sacks
Dry Polymer:	0.2 kg (0.5 lb.)	0.6 kg (1.2 lb.)	0.8 kg (1.7 lb.)	

At most drill sites in a rural district, getting enough water is the greatest challenge. It may take several hours for an army of women and children, walking from a river several kilometers away carrying buckets of water on their heads, to fill just one mud pit. So it is essential to plan ahead for how water will be brought to the drill site and stored during drilling.

It is very useful to have extra 55-gallon drums, a small 12-volt water pump, and hoses so that water can be collected from a source a distance away from the drilling site. Carry the drums in the drilling equipment transport truck to a river or pond, hook the pump to the truck battery and pump water to fill the drums. The pump can also be used to transfer water from the drums on the truck to the storage drums at the drilling site.

As noted above, using a portable "bladder tank" is an efficient way to store water on the drilling site. When finished, the tank can be easily drained, rolled up, and loaded on a truck by two men. Bladder tanks come in sizes ranging from 1,000 liters to more than 200,000 liters. A 6,000 liter (1,585 gallon) tank should provide more than enough capacity for a LS200 drilling operation. Gathering water to fill a bladder tank is no less work than when using 55-gallon drums to store water, but the bladder should need to be filled only once at a drill site so drilling would not be interrupted to collect more water.

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Lesson 3.7 Drilling Mud Part 2 – Mixing Mud

Purpose

To learn how to mix and monitor drilling mud

Objectives

By the end of this lesson, participants will have

- Used pH paper to measure acidity/alkalinity
- Adjusted pH using soda ash
- Mixed bentonite drilling mud
- Used a Marsh Funnel to measure mud viscosity

Materials

- pH test strips
- Marsh Funnel and watch with second hand
- Soda ash
- Bentonite
- Polymer
- 55-gallon drum
- Mud pump and hoses
- Water

Preparation

- Study lesson ahead of time.
- Make up 3 or 4 water samples with different pH, ranging from mildly acid to alkaline. One should be between 8.5 and 9.5. Number the samples.

Time

120 minutes

Steps

1. Introduction
2. Measure pH
3. Adjust pH
4. Mix Bentonite
5. Measure Viscosity
6. A Case Study

This lesson is best taught while the practice drill site is being set up, but it can also be taught as a demonstration apart from the drill site. Normally, only one or two people mix mud while the rest of the crew digs pits and sets up the rig. But everyone should learn how to properly mix mud, so be sure to leave enough time for the entire crew to participate in this lesson.

1. Introduction - 5 minutes

In the previous lesson we discussed how water, soda ash, bentonite and polymer make a "properly engineered drilling fluid." In this lesson we will practice making good drilling mud. We will also test its viscosity to make sure it is suited for the formation we are drilling.

2. Measure pH - 15 minutes

	pH Scale	Examples
Strong Acid	0	Battery acid strong Hyrofluoric acid
	1	Hydrochloric acid
	2	Gastric acid, vinegar lemon juice
	3	Soda, orange juice
	4	Tomato juice Acid rain
	5	Soft drinking water Black coffee
	6	Urine, saliva
Neutral	7	"Pure" water
	8	Sea water
	9	Baking soda
	10	Milk of Magnesia
	11	Ammonia solution
	12	Soapy water
	13	Bleach, oven cleaner
Strong Alkaline	14	Liquid drain cleaner

Figure 45 pH Scale

The term "pH" refers to how acidic or alkaline a liquid is. A pH of 7.0 is neutral, a pH lower than 7.0 is in the acidic range, and a pH higher than 7.0 is in the alkaline range. As described in the previous lesson, the pH of the water used to make drilling mud has a significant effect on whether bentonite can be fully hydrated. The pH of the water, before adding bentonite, should be in the range of **8.5 to 9.5**; this is slightly alkaline.

There are several ways to measure pH but the easiest is to use a pH test strip. This is a paper strip that contains a chemical that changes to different colors depending on the pH. To use it, just dip the strip in the water, wait a few seconds for the color to develop, and then compare the color of the strip with a color chart supplied by the manufacturer.



Figure 46 pH Strips

Different brands of pH test strip have slightly different color development times so read the manufacturer's instructions.

Working with your team, practice measuring the pH of the different samples supplied by the instructor.

- Which sample was most acidic? _____
- Which one was most alkaline? _____
- Which sample would work best for mixing bentonite? _____
- If the pH of your water is not in the right range, what can you do?

_____

3. Adjust pH - 15 minutes

Adding soda ash to water that is either too acidic or too alkaline will bring it into the pH range needed for bentonite to hydrate properly. Soda ash will also condition the water if has too many minerals ("hard" water).

There are just 4 easy steps:

1. Determine how much water needs to be treated.
2. Using the tables in Appendix 4, measure the amount of soda ash needed.
3. Dissolve the soda ash in the water.
4. Re-test to make sure the pH is between 8.5 and 9.5 before adding bentonite.

- Working with your team, use the values in Appendix 4 to determine how much soda ash will be needed to condition the following volumes of water:

  One 55-gallon drum: _____"scoops" of soda ash

  Two mud pits of one cubic meter each:_____"scoops" of soda ash

4. Mix bentonite - 45 minutes

Now that we've tested and conditioned our water, we're ready to mix bentonite. Some drillers mix it directly in the mud pits, but there are two problems with this:

- The "mud mixer" attachment that comes with the LS200 can't completely mix the bentonite in a single pass. As a result, clumps of bentonite tend to settle to the bottom of the pit. The suction hose will not pick up all of these clumps, leaving a significant amount of bentonite that is not fully hydrated at the bottom of the pit.
- Most soil is either porous or cracked, so – until the mud gets thick - water will soak into the ground and be lost through the sides and bottom of the pits.

For these reasons, Lifewater recommends first mixing the mud in a large trash can (114 liter or 30 gallon capacity) or in a 55-gallon (208 liter) drum or barrel. Very slowly add a half sack of bentonite to the water and circulate it with the mud pump. This results in very thorough mixing with no lumps.

When mixed in a vessel this size, use a full sack of bentonite to get a very thick mud. This mud will then be diluted when it is added to the mud pits.

It takes at least **30 minutes** of circulation through the mud pump to mix and fully hydrate a premium grade of bentonite. A lower grade of bentonite may take longer.

The suction strainer will clog up with clumps of bentonite so it must frequently be cleaned off by hand.

This drilling crew is mixing mud in a large trash can. The mud pump from the drill rig circulates the mud, getting the bentonite fully hydrated.



Figure 47 Mixing Mud

5. Measure Viscosity - 20 minutes

As explained in the previous lesson, it is necessary to match the viscosity (thickness) of the drilling mud to the formation being drilled. When drilling through silt or fine sand, the mud need not be as thick as when drilling through gravel.

If the drilling mud is not thick enough, it will not lift cuttings out of the hole. But if the mud is too thick, then the cuttings can't drop out in the settling pit and they will be re-circulated down the borehole.

A **Marsh Funnel** is used to measure mud viscosity. The two parts are a funnel with a screen and a quart measuring cup. [Marsh Funnels can usually be purchased from the local distributor of drilling supplies.]

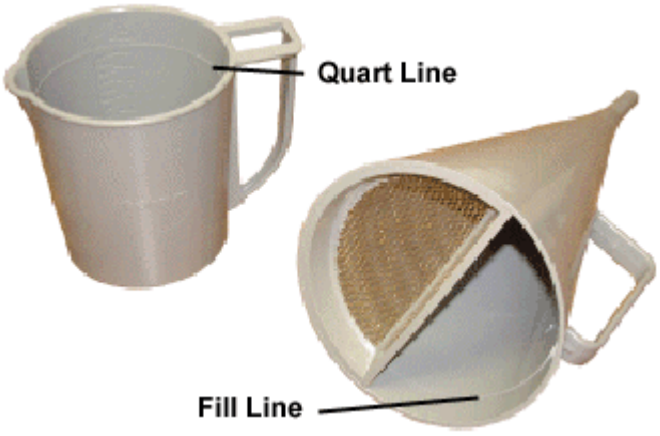


Figure 48 Marsh Funnel and Cup

To measure mud viscosity:

1. Hold the Marsh Funnel in an upright position with your finger over the outlet.
2. Using the quart cup, pour drilling fluid through the screen in the top of the funnel until it reaches the fill line marked on the inside of the funnel. It will take more than one quart.
3. Pour out any drilling mud remaining in the quart cup.
4. Holding the funnel over the quart cup, remove your finger from the funnel outlet and measure the number of seconds that it takes to fill the quart cup up to the mark. (The funnel holds more than a quart, so it will not be empty after a quart flows through.)



Figure 49 Measuring Viscosity

The resulting seconds per quart (shortened to "seconds") represents the viscosity of the drilling mud. Water has a Marsh Funnel viscosity of 26 seconds, thin drilling mud is around 35 seconds and very thick mud has a Marsh Funnel viscosity greater than 70 seconds.

The outlet of the Marsh Funnel has a set (calibrated) diameter so if it becomes clogged or damaged in any way, the funnel will not give accurate results.

Therefore, it is important to wash the funnel and the cup in clear water after taking a measurement. Keep the funnel and cup in a protected place and never use them for any purpose other than measuring mud viscosity.

6. A Case Study - 20 minutes

Read this case study and discuss the questions on the following page.

Case Study

A beginning drilling crew visited many hardware and plumbing stores trying to purchase bentonite. They finally found a shop owner who, when asked if he carried bentonite replied, "I don't any more - but there might still be a sack somewhere." After the crew made a long search in a dark warehouse, a bag that "might be bentonite" was located. It was much coarser than high-quality bentonite, but it was all that could be found.

The crew dug good mud pits and, since the soil was sandy, lined them with a heavy plastic tarp to prevent water loss. Using the mud mixer on the bypass hose, they mixed their bentonite in the suction pit.

The formation that was being drilled was fine sand. The sediment above the water table was very porous, so the drilling mud kept soaking into the sand. The crew added more water and bentonite to the pits, but they could not get the mud thick enough to stop the loss.

Because of the problems with the drilling mud, the borehole could not be advanced very far below the water table. A casing was set and a hand pump installed, but the well did not produce much water.

When the crew cleaned out the mud pits, they discovered why they could not get the mud thick enough. Much of the bentonite was in clumps at the bottom of the pit! It was also suspected that the pH of the water was not suitable, but they did not have a way to test it or adjust it. So even if they had been using good-quality bentonite (which was doubtful) their poor method of mixing it kept it from being fully hydrated before they started drilling.

The worst part of this story is that small clumps of un-hydrated bentonite migrated into the aquifer because a good wall cake was not being formed. Those clumps eventually hydrated beyond where they could be removed by well development, thus reducing the flow of water into the well.

- What reasons can you think of for why the bentonite did not hydrate properly?

- What things could this crew have done differently?

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Lesson 3.8 Drilling Mud Part 3 – Using Mud

Purpose

To learn how to use drilling mud

Objectives

By the end of this lesson, participants will have

- Prepared mud pits ready to start drilling
- Observed mud behavior while drilling
- Practiced corrective actions for common drilling mud problems

Materials

- Same as previous mud mixing lesson
- Shovels
- 20-liter (5-allon) buckets
- Drill rig ready to operate

Preparation

- Study lesson ahead of time.
- Set up drill rig

Time

60 minutes

Steps

1. Fill the Mud Pits
2. Monitor Drilling Mud

This lesson should be taught while the drill rig is operating. Observing the mud behavior is essential. A classroom review and discussion of the principles is helpful to reinforce what was experienced on the rig.

1. Fill the Mud Pits - 15 minutes

Once it is fully hydrated, a portion of the very thick mud that has been mixed in a 55-gallon drum (or large trash can) may be used to coat the sides and bottom of the mud pits if the soil is very porous (See lesson 3.7). This can be done as the mud pits are being filled with water. Start with the suction pit, and when it is full and the thick mud has mixed with the water, begin filling the settling pit.

When the pits are nearly full, measure the viscosity of the drilling mud and add additional hydrated bentonite to reach the viscosity needed for the soil that is being drilled (see the table in the previous lesson). It will usually be necessary to mix several 55-gallon drums (or large trash cans) with thick bentonite before the pits are full and the drilling mud is ready to use.

Once drilling begins, keep a 55-gallon drum (or large trash can) full of very thick hydrated bentonite so it is ready to add to the drilling fluid whenever needed.

ALWAYS add newly-hydrated bentonite to the bucket around the suction hose. This ensures that it will be thoroughly mixed with the existing drilling mud.

NEVER add clear water to the suction bucket, since this will quickly lower the viscosity of the drilling mud in the borehole and cause cuttings to drop out around the drill bit. To gradually thin the drilling mud, add water to the front of the settling pit so the water has time to mix with the existing drilling mud.

2. Monitor Drilling Mud - 45 minutes

As the drill bit advances through different formations (types of soil) it may be necessary to change the viscosity of the drilling fluid. **Watch** these four things:

1. Get the cuttings out

Watch when the quill is disconnected to add another section of drill pipe. If drilling mud flows out of the top of the drill pipe, then the drilling mud is too thin.

- In this photo drilling mud is flowing out of the drill pipe. Why do you think this is happening?



Figure 50 Drill Pipe "Geyser"

When the drilling mud in the borehole is full of cuttings, it is heavier (more dense) than the drilling mud inside the drill pipe. Therefore, the mud outside the pipe pushes up on the mud inside the pipe, causing it to flow out.

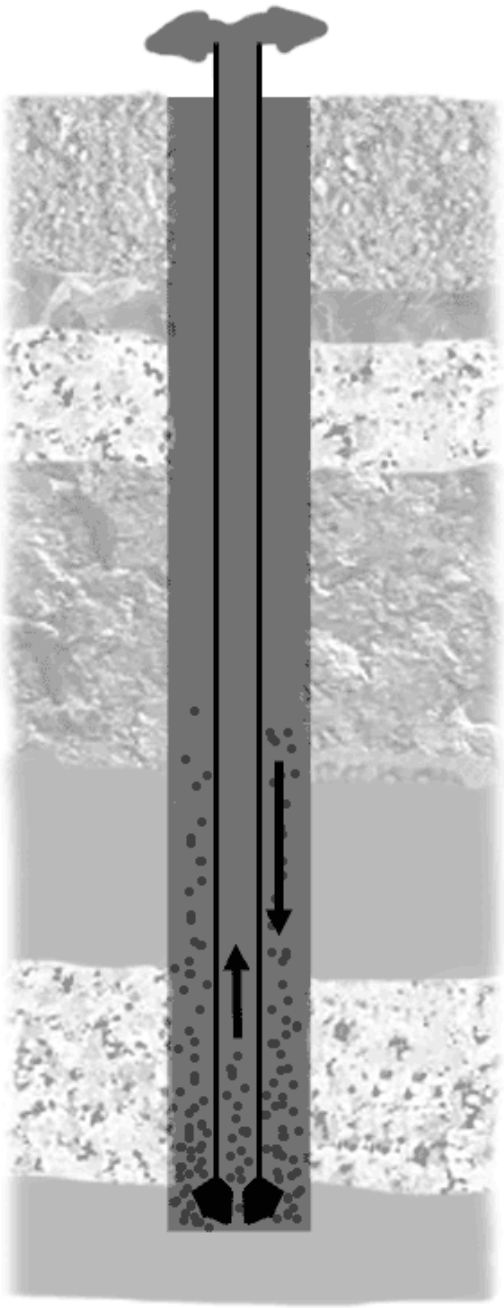


Figure 51 Falling Cuttings

<u>This is a dangerous situation!</u>

When you see mud flowing out of the drill pipe, two things are happening:

- Cuttings are settling around the drill bit, which could cause it to get stuck and be unable to rotate.
- Cuttings are flowing up into the drill pipe where they could plug the drill bit and prevent circulation.

<u>Take immediate action:</u>

- Reconnect the quill and lift the bit off of the bottom of the borehole.
- Resume rotation of the bit.
- Resume circulation until all cuttings have been flushed out.

Two things contribute to this problem; the drilling mud is too thin to lift the cuttings and the drilling mud is not circulated long enough to bring the cuttings to the surface.

To clear out the borehole, pour a bucket full of thick hydrated bentonite directly into the bucket around the suction hose. This is called a “sweep” or a “slug.” The slug of extra-heavy mud will push out cuttings that are remaining in the borehole. It should not be necessary to do this at every drill pipe change.

2. Maintain circulation

If the drilling mud is not circulating at the full capacity of the mud pump, then cuttings will not be effectively removed from the borehole.

The most common cause of reduced circulation is the strainer on the suction hose getting clogged with bits of grass or roots. It takes constant effort to keep the suction strainer clear. You can't lift the strainer out of the water because that will stop flow completely. So this job has to be done kneeling down on the edge of the suction pit. At first, the suction may feel like it will hurt your hand, but it won't.

Another reason for circulation to stop is when the mud pump runs out of fuel. It is a serious problem if this happens during drilling because it could cause the bit to immediately get stuck. While a new section of drill pipe is being added, check the fuel level in the mud pump. If it needs more fuel, turn off the mud pump and fill the tank. **NEVER** add fuel to an engine that is running as it could cause a fire or explosion.

3. Maintain the fluid level

As the borehole gets deeper, it requires more drilling mud to fill it, so additional water and hydrated bentonite periodically needs to be added to the suction pit. A 30-meter (100') borehole that is 200 mm (8") in diameter holds 900 liters (240 gallons).

When drilling in porous material such as sand or gravel, the drilling fluid may soak into the formation in significant amounts. This should not happen if a good wall cake has formed, but sometimes a very porous formation will take up a lot of drilling mud before a wall cake can form. Fluid loss can be so rapid that the suction pit is drained and there is no return flow to bring up cuttings. If this happens, the drill bit must be raised immediately. See the lesson on "Problem Solving" for ways to deal with this situation.

It is helpful to push a small stick into the wall of the suction pit to mark the top of the drilling fluid when drilling begins. This way, it is more obvious when the fluid level begins to drop.

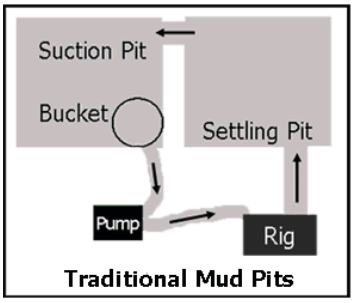
4. Are the cuttings settling?

Remember, drilling mud needs to be thick enough to lift cuttings out of the borehole, but not so thick that they can't settle out in the mud pit. If the mud pit is too small, then coarse sand will pass through to the mud pump. This sand damages the pump, the hoses, and the fittings. It

can also clog the drill bit. As discussed in Lesson 3.3 (Drill Site Set-up) the design of the mud pit is very important.

In a "traditional" mud pit, where the settling pit is about a meter square and nearly a meter deep (Figure 52 inset), the mud flows quickly through by the shortest route. There is almost no flow in the corners of the settling pit so this part of the pit is wasted. As noted in Lesson 3.6 (The Role of Mud) the deeper the pit the longer it takes for cuttings to drop out. Therefore, a shallower, narrower, and longer pit will allow more time for cuttings to settle

With the "curved channel" design of mud pit shown in Figure 52, heavier cuttings will drop out quickly in the first several meters between the drill rig and the curve. Because the channel is shallow (about 13 cm or 5" deep), it is very easy to shovel out the settled cuttings. This is best done while there is no flow during a drill pipe change. Smaller cuttings should drop out before they reach the suction pit. The channel dimensions can be adjusted as needed, but the total channel length should not be less than around 6 meters (20') and the width should be at least 38 cm (15"). These dimensions will give a total volume of 650 liters (170 gal). With any mud pit design, some percentage of fine sand will remain suspended due to the viscosity of the mud.





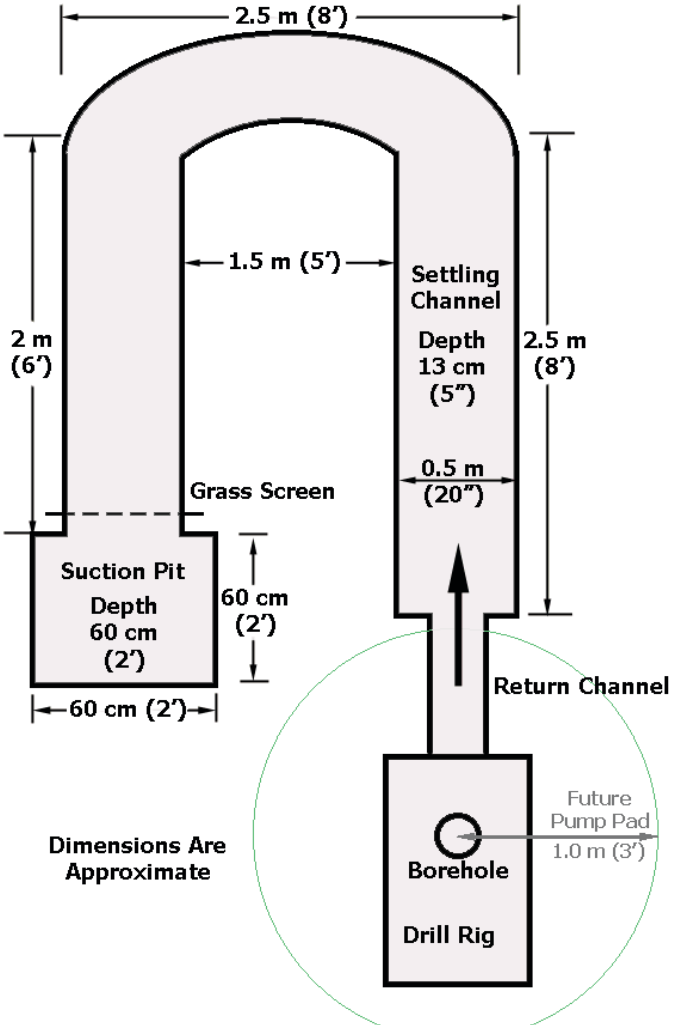


Figure 52 Channel Mud Pit Design

Besides the Marsh Funnel, there are two other tools for measuring drilling mud; the mud balance and the sand content kit. These tools are not included in Lifewater's initial drilling training, but can be part of advanced training, particularly where deep boreholes are being drilled in difficult formations.



Figure 53 Mud Balance

The **mud balance** looks like a standard balance beam scale, but it is specifically designed for weighing a fixed volume of drilling mud. Compare the weight of a sample of mud as it comes out of the borehole with a sample collected at the end of the suction pit. The suction pit sample should be lighter than the sample from the borehole, showing that cuttings are settling out of the drilling mud.

The **sand content kit** consists of a fine mesh screen and a graduated cylinder. A measured volume of drilling fluid is washed through the screen and collected in the cylinder. Markings on the cylinder show the percentage of sand in the sample. Comparing the sand content of the drilling mud between the beginning and end of the mud pits shows how much sand is being settled out.



Figure 54 Sand Content Kit

Lesson 3.9 Borehole Logging

Purpose

To practice identifying different sediments.

Objectives

By the end of this lesson, participants will have

- Handled different sediment types and observed their characteristics.
- Practiced preparing a boring log.

Materials

- Several liters each of clay, silt, fine sand, coarse sand, and gravel
- Several dozen gallon sized plastic zip-lock bags
- Labels and permanent marking pens
- About 2-3 liters of hydrated bentonite
- Copies of a boring log form

Preparation

- Study lesson ahead of time
- Make several sets of labeled samples in gallon plastic bags. With and without drilling mud mixed in

Time

75 minutes

Steps

1. Recognize Different Sediments.
2. Log a Borehole.
3. Prepare a Graphic Log.

1. Recognize Different Sediments - 25 minutes

Examine the labeled dry sediments that the instructor has laid out. Pick each one up, rub it between your fingers, and closely examine the individual grain sizes. Take time to get to know each one well.

➢ Describe the differences in feel between clay and silt.

_____

➢ Describe the differences in feel between silt and sand.

_____

Now carefully examine the same labeled sediments that have been mixed with drilling mud.

- In what ways has the drilling mud changed the feel of the different sediments?

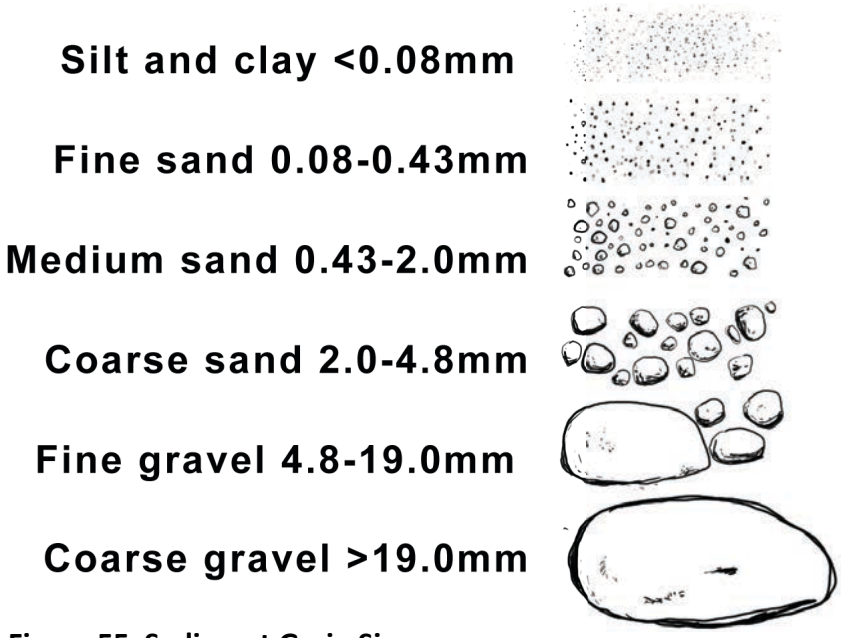


Figure 55 Sediment Grain Sizes

2. Log a borehole - 30 minutes

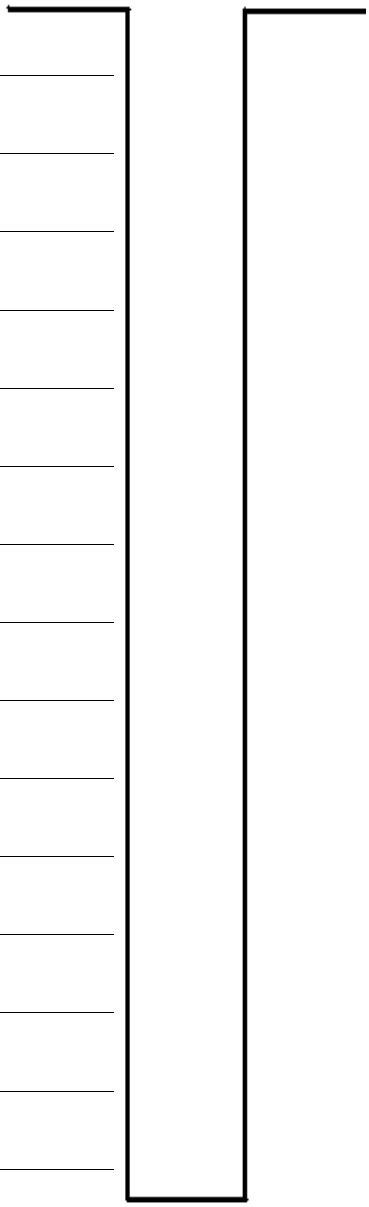
The LS200 uses drill pipe that is 5 feet (1.5 meters) long. It is necessary to take a cuttings sample at the end of each drill pipe section. In countries that use the English system of measurement, the samples will be recorded in 5-foot increments: 5', 10', 15', and so on. In countries using metric measurements the samples will be recorded in 1.5-meter increments: 1.5m, 3.0m, 4.5m, and so on. Samples are also collected whenever there is a change in the drilling conditions. The actual depth at which the change occurred is noted by the driller and when those cuttings reach the surface, they are labeled with that depth.

Now examine the new set of sediment samples, mixed with drilling mud, arranged in a different order, and labeled only with numbers. The numbers represent the depth in meters at which the sample was collected.

Pay close attention to each sample in this exercise because some sediment types may be mixed together. When that occurs naturally, as it often does, the sediment is named using the two

most abundant types. For example, “sandy silt” is mostly silt but with some sand in it. “Coarse gravelly sand” is coarse sand that has gravel mixed in with it.

- Using the spaces below, or a separate sheet of paper, write down the sediment type for each sample in the class exercise: (This is called a “boring log” or record.) Many geologists like to put the dominant component as the first word of the description and written in capital letters. After that other components and color are listed. So a description might look like this: SILT, fine sand, dark brown.



1.5 meters (5’): _____

3.0 meters (10’): _____

4.5 meters (15’): _____

6.0 meters (20’): _____

7.5 meters (25’): _____

9.0 meters (30’): _____

10.5 meters (35’): _____

12.0 meters (40’): _____

13.5 meters (45’): _____

15.0 meters (50’): _____

16.5 meters (55’): _____

18.0 meters (60’): _____

19.5 meters (65’): _____

21.0 meters (70’): _____

22.5 meters (75’): _____

3. Prepare a Graphic Log - 20 minutes

On the drawing provided next to your descriptions, shade in the borehole so that there is a graphic representation of the different layers of sediment. This is a "graphic log" drawn from a boring log. Use a different pattern to represent clay, silt, sand, and gravel.

Your final graphic log should look something like the drawing to the right, except that the sequences of sediment will match what you wrote down from the class exercise.

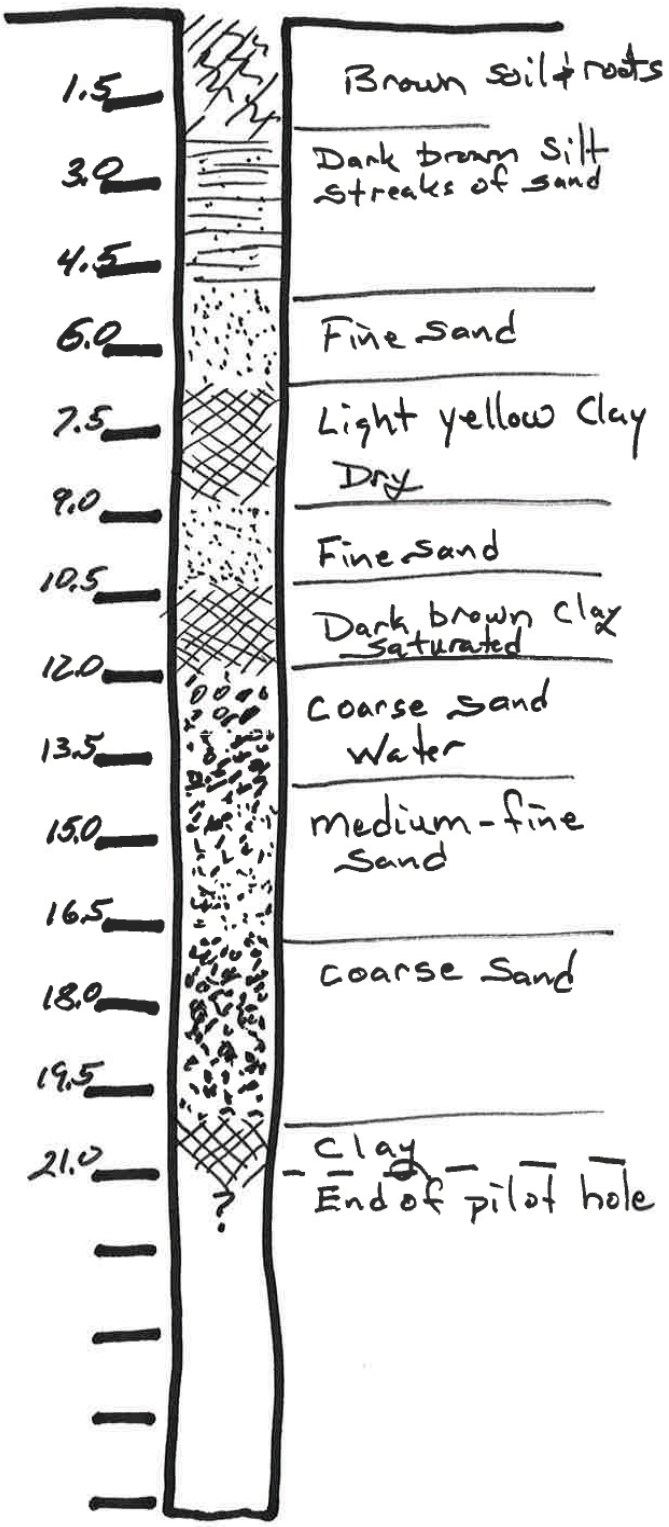


Figure 56 Graphic Log

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Lesson 3.10 Problem Solving

Purpose

To learn how to identify and correct common drilling problems

Objectives

By the end of this lesson, participants will have

- Identified things that can – and will – go wrong during drilling
- Shared their experiences in solving drilling problems

Materials

- Poster of "Casing Off" Contamination

Preparation

- Study lesson ahead of time

Time

75 minutes

Steps

1. Introduction
2. Problems You Will Encounter

1. Introduction - 15 minutes

It is often said, "If something can go wrong, it will." Well drillers know from experience the truth of this saying. Problems come up frequently. Sometimes bad things just happen, but many problems can be avoided. In either case, the problem needs to be solved. That is why it is also said, "Well drilling is a problem-solving exercise."

When a problem comes up, it is important to quickly figure out what is happening and take immediate steps to keep it from getting worse. Trying to decide who is to blame does not solve the problem!

Case Study

A drill crew was making good progress reaming out their borehole. The equipment and the drilling mud were working well. All of a sudden, as the drill bit was approaching the bottom of the pilot hole, the mud pump stopped.

The driller started yelling at the mud engineer, criticizing him for not paying attention to the fuel level. The mud engineer did not appreciate being yelled at, so he let the driller know how he felt. Everyone was getting tired and irritable, so a big argument opened up.

Eventually, the mud engineer got the pump working again. But when the driller started working the drill pipe up and down the borehole to ream it out, he discovered that he could not pull the bit up. It was stuck on the bottom of the hole!

- What happened here? _____

_____

- Why did the drill bit get stuck? _____

_____

- How could this problem have been avoided? _____

_____

2. Problems You Will Encounter - 60 minutes

The following are things that commonly go wrong on a drill site. It is wise to study this section to be prepared with the proper response when one of these problems occurs.

Stuck Bit

Frequent reference has been made to raising the drill bit when circulation is lost or for some other reason cuttings are not being brought to the surface. The reason for this action is that a bit that is stuck while resting on the bottom of the hole is very difficult to get free. There are three conditions that can be called a "stuck bit:" (1) the bit can't be rotated (2) the bit can't be raised or lowered, and (3) the drilling mud will not flow out of the bit due to a clogged outlet. If all three conditions occur at the same time, then it may not be possible to recover the entire string of drill pipe.

If some mud still flows through the bit then rotate, or raise and or lower the bit – whichever direction it can be moved – in short "jerking" motions until it begins to break free. With the LS100/200 be careful not to put too much force on the clutch or it will burn out. Do not pull up so hard that the mast begins to bend. Also, do not attempt to rotate the bit to the left (anti-clockwise) or the drill pipe will unscrew. If these measures do not loosen the bit, then move the drill rig, erect a tripod over the hole, and use a block and tackle to pull the drill pipe out. A jack and chains can also be used to lift the drill pipe. Be aware that attempting to pull out the drill pipe is likely to break it.

Swelling Clays

Some forms of clay will swell and expand significantly when they get wet, or when pressure is released from them in a borehole. The case study in lesson 3.7 "Drilling Mud Part 2: Mixing Mud" describes what happens when a layer of swelling clay is encountered; it closes off the borehole. The only solution is to repeatedly ream out that section of the borehole until the clay has expanded to its full extent and the hole remains open.

Clay Clumps

Clay cuttings may stick together when they get wet, forming clumps that can be as hard to remove as large gravel. If available, add polymer to the drilling mud to coat the clay and prevent it from sticking. Otherwise, try thickening the drilling mud or adding a second mud pump. A second problem with sticky clay is the formation of a "boot" or "collar" around the drill pipe. This will reduce the return flow of drilling mud and cause the bit to get stuck. Using polymer to prevent a boot from forming is the best solution. If one does form, then the drill pipe and bit must be pulled out of the borehole and the boot removed.

Boulders

The LS100 and LS200 can not drill through hard rock. When the drill rig is bouncing around and no progress is being made, it is time to pull out and move the rig. The first and second times this happens, just move a meter away so the same mud pits can be used. If the bit stops at the same depth on the third try, then it may be a layer of rock and not an isolated boulder that is in the way. At this point, consider trying another location in the same area.

Gravel

If a zone of large gravel is encountered, the LS100/200 mud pump might not be able to generate enough upward velocity to lift the individual pieces, no matter how thick the drilling mud is. ("Large" would be more than 4 cm or 1.5" in diameter.) If a second mud pump is available, then they can be hooked up in series to generate more pressure. Connect the output of one pump to the input of the second pump. The mud pumps should have similar capacities. If this is not possible, then consider completing the well at the depth achieved, since gravel is often a good aquifer.

"Flowing Sand"

This condition is also called a "collapsing formation." It is usually encountered when drilling in loose sand, and is worse when drilling below the water table. This occurs because the groundwater or drilling fluid lubricates the sand grains but there is not enough hydrostatic pressure (see lesson 3.6) to hold back the sand so it flows into the borehole. The drill bit may be advancing, and cuttings may be coming up, but when circulation is stopped to add a drill pipe, the borehole fills with sand. If there is a firm layer above the sand, the borehole will just get wider and wider. In this case the drill crew might not even be aware that they are making a big cavern rather than a nice straight borehole. So it is important for the Driller to pay attention to the volume of cuttings coming out of the borehole compared to the depth he is making.

A collapsing formation is a very difficult problem to correct, so it is important prevent it from starting.

- Maintain a properly weighted drill mud. If the mud is too thin, it can't seal off the borehole with a good wall cake and it can't exert enough pressure against the wall.
- The fluid level in the borehole must be kept high. It takes at least 3 meters (10") of drilling mud above the water table to generate enough hydrostatic pressure to hold up the borehole wall. (If the water table is less than 3m below ground, you must rely on the mud weight.) If the borehole is left open overnight (always remove the drill pipe), then the water level must be periodically checked and if the level drops add more water or drilling mud.
- When removing drill pipe, or adding well casing, take care not to drag against the borehole wall.

Lost Circulation

"Losing circulation" means that no, or very little, drilling fluid is returning up the borehole. It is a serious problem because it means that no cuttings are being removed. Lost circulation can have a number of causes; a clogged suction strainer and a clay boot have already been discussed. The cause that is most difficult to correct is drilling into a very porous formation or, if drilling in rock, encountering a large crack or fissure. In any case, the driller's first reaction must be to lift the drill bit off of the bottom of the borehole and continue rotation. If cuttings settle out while the problem is being solved, then the drill bit could get stuck at the bottom.

If lost circulation is due to fluid loss within the borehole, then the first question to answer is whether this zone might be a productive aquifer. If the formation is porous enough to absorb drilling fluid it may also be able to produce water. Check the other clues for reaching the aquifer: fresh water mixing with the drilling mid, mud temperature change, and coarse material (sand or gravel) in the cuttings.

If the borehole must be advanced deeper, a common way to seal off a porous zone is to add "Lost Circulation Material" (LCM) to the borehole at that zone. This material can be anything

that is capable of plugging up the leak. Shredded corn husks, shredded newspaper, rice hulls, sawdust, and similar items have been employed as the need arises. The LCM should be pumped directly into the borehole to fill it, then let sit without circulating the mud, for up to one hour. Watch the fluid level in the borehole; if it ceases to drop, then the porous zone has been sealed. [Obviously, if the porous zone is an aquifer and the borehole is being deepened only to expose more of it, you do not want to seal it off with LCM.]

If adding LCM does not stop fluid loss, and the porous zone is not an aquifer, then it may be necessary to "case-off" that part of the borehole. This is accomplished by reaming the borehole past the porous zone and installing a large-diameter casing open at the bottom. This casing should be large enough to accommodate the next-smaller reaming bit. A 200 mm (8") diameter casing may be needed. Using the mud pump and drill pipe, pump wet cement (with no sand or gravel) into the large casing so that it fills the bottom several meters of the casing. Then fill the casing with drilling mud, seal off the top of the casing with the well flushing tool, and pump in more mud under pressure. This will push the wet cement out of the bottom of the casing and up the annular space between the casing and borehole wall. Pump in just enough water so that about 30 cm (about one foot) of cement remains in the bottom of the casing. Let the cement set up overnight. The next day, drill through the cement plug at the bottom of the casing and continue advancing the borehole.

Contaminated Zone

In some locations, such as an urban slum, it may be necessary to drill through a layer of severely contaminated soil before reaching an aquifer with safe water. Or there might be an upper aquifer that has poor water quality and it is necessary to drill past it to a better aquifer. In these cases, the annular space between the casing and the borehole will serve as a path for the contamination to get in to the good aquifer.

To prevent contamination of the lower aquifer, any upper contaminated zones must be "cased-off" as described in the previous section on lost circulation. In this situation, keep drilling until a clean layer with low permeability (such as clay) is encountered. Then ream the borehole enough to fit a 200 mm (8") diameter casing. Pump in wet cement, followed by drilling mud under pressure, until there is a small plug remaining at the bottom of the casing. Let the cement plug set up overnight, then drill through it to finish the borehole in an aquifer with good water quality. The casing and the cement plug will prevent the contamination in the upper zone from reaching the lower part of the well. The stages of casing-off a contaminated zone are illustrated in Figure 57.

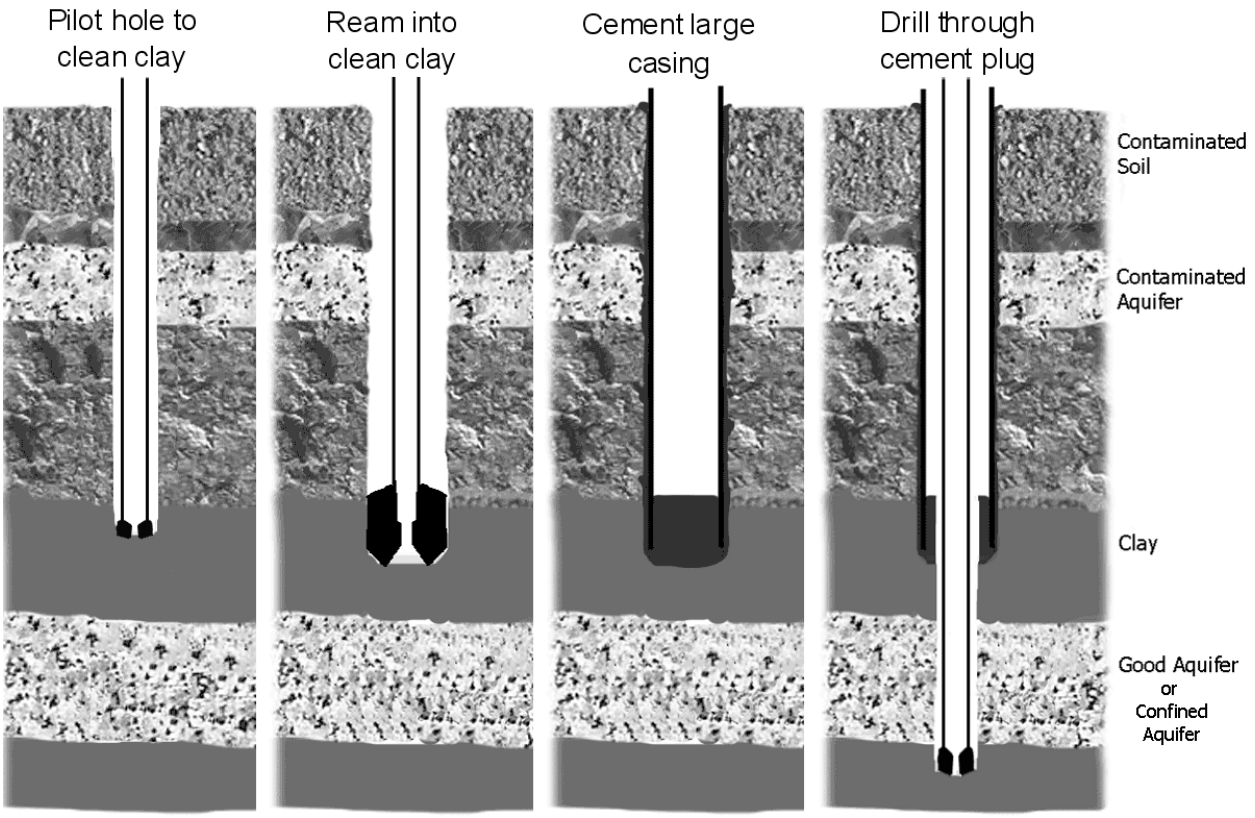


Figure 57 Stages of "Casing-Off Contamination or a Confined Aquifer

Flowing Well

When a confining layer above an aquifer is penetrated by the drill, the water level in the borehole may rise to a level higher than the depth at which groundwater was first encountered. In this case the well is said to be "artesian." There are two types of artesian wells; one where the static water level is below the ground surface and one where the static water level is above the ground surface. The latter is called a "flowing well" because water flows out of the well on its own. (This is illustrated on Figure 7.)

A flowing well is a blessing because a pump may not be needed, but it can also become a serious problem if the water flow is not controlled. Just as fire is useful but must be controlled, a flowing well can be helpful or harmful according to how it is controlled. Depending on the rate of flow and its pressure, a flowing well can erode the borehole outside of the well casing turning the well into a pit and creating a pond or a swamp. When this happens, what was safe groundwater can quickly become contaminated by animals and surface runoff.

A flowing well might not be obvious at first. It may not be discovered until the morning after the aquifer has been penetrated with a pilot bit, when a pool of water is found around the drill site. There are many different conditions that may be encountered, so there is no single solution to getting control of the water flow. To stop the flow of water, it is necessary to

increase the hydrostatic head in the well. Sometimes this can be accomplished simply by raising the level of the mud pits. To continue drilling it is then necessary to raise the height of the drill rig. It may also be necessary to use a very heavy drilling mud. Hopefully, the borehole can then be reamed out and a 100 mm (4") casing installed. If the water level in the well can be lowered by pumping and then held at a low level (by pumping at the same rate as the well is flowing) then the annular space can be filled with cement grout. This should seal the annular space so that the well can only flow through the casing, not around it, thus the flow can be controlled with a valve. The procedure is similar to that shown on Figure 57. If it is known that flowing wells are common in the area, then the borehole should always be cased-off.

No Aquifer Found

Every well driller occasionally encounters a "dry hole", even when a skilled geologist is directing where to drill. The goal of drilling is to find a thick layer of sand or gravel that produces good water. But sometimes the depth limit of the rig is reached without finding an obvious aquifer.

Even if an obvious aquifer is not found, there may actually be several very thin layers of sand or gravel that can produce enough water to support a hand pump. All that is needed is a flow of about 20 liters/minute (5 gpm). So it is very important to pay close attention to the cuttings coming out of the borehole or else these layers might be overlooked. It may be possible to place short well screens at multiple thin aquifers even if they are widely separated. In a situation like this it is especially important to thoroughly develop the well so as to get the most flow possible.

In some areas, the only aquifer that can be found is a thin layer of partially-decomposed bedrock just above the point at which the drill can go no farther. These layers can often supply enough water to support a hand pump.

No matter how hard a drill crew tries, there will always be boreholes from which no water can be pumped. This possibility must be discussed with the village or property owner before drilling begins. Never promise to find water! Promise to do your best and trust God for the results. It costs money to drill a borehole, whether it produces water or not. So before drilling, work out an agreement with the village or owner regarding who will pay the cost of drilling a dry hole and how many attempts will be made to find water.

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Lesson 4.1 Designing the Well

Purpose

To learn how to set well screen at the correct depth to get maximum water flow.

Objectives

By the end of this lesson, participants will have

- Reviewed the components of a well
- Examined sample borehole logs and decided on screen placement
- Practiced making the measurements for installing a well screen
- Cut slots in a section of well screen

Materials

- Posters of Well Components and Well Design Exercise
- PVC casing
- Tools: measuring tape, marking pen, hack saw

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. Proper Well Construction
2. Good Well Design
3. Laying Out the Well Screen and Casing
4. Cutting Well Screen

1. Proper Well Construction - 15 minutes

It takes more than a hole in the ground to make a good well. The manner in which a well is constructed will not only influence the volume of water that it can produce but it can affect the performance of a hand pump. A properly located and constructed well can provide safe water for many decades. But a poorly constructed well can cause the down-hole components of a hand pump to fail prematurely.

As we go over each component of a properly constructed well, write in their names on the diagram below. Try to picture how the parts function together to make the system work as a whole. Keep in mind that different countries use different terms.

Label these parts: handle, head, spout and tank, base (or pedestal), pad, borehole, sanitary seal, casing, gravel pack, well screen, riser main, pump rod, pump cylinder, tail pipe, aquifer, water level.

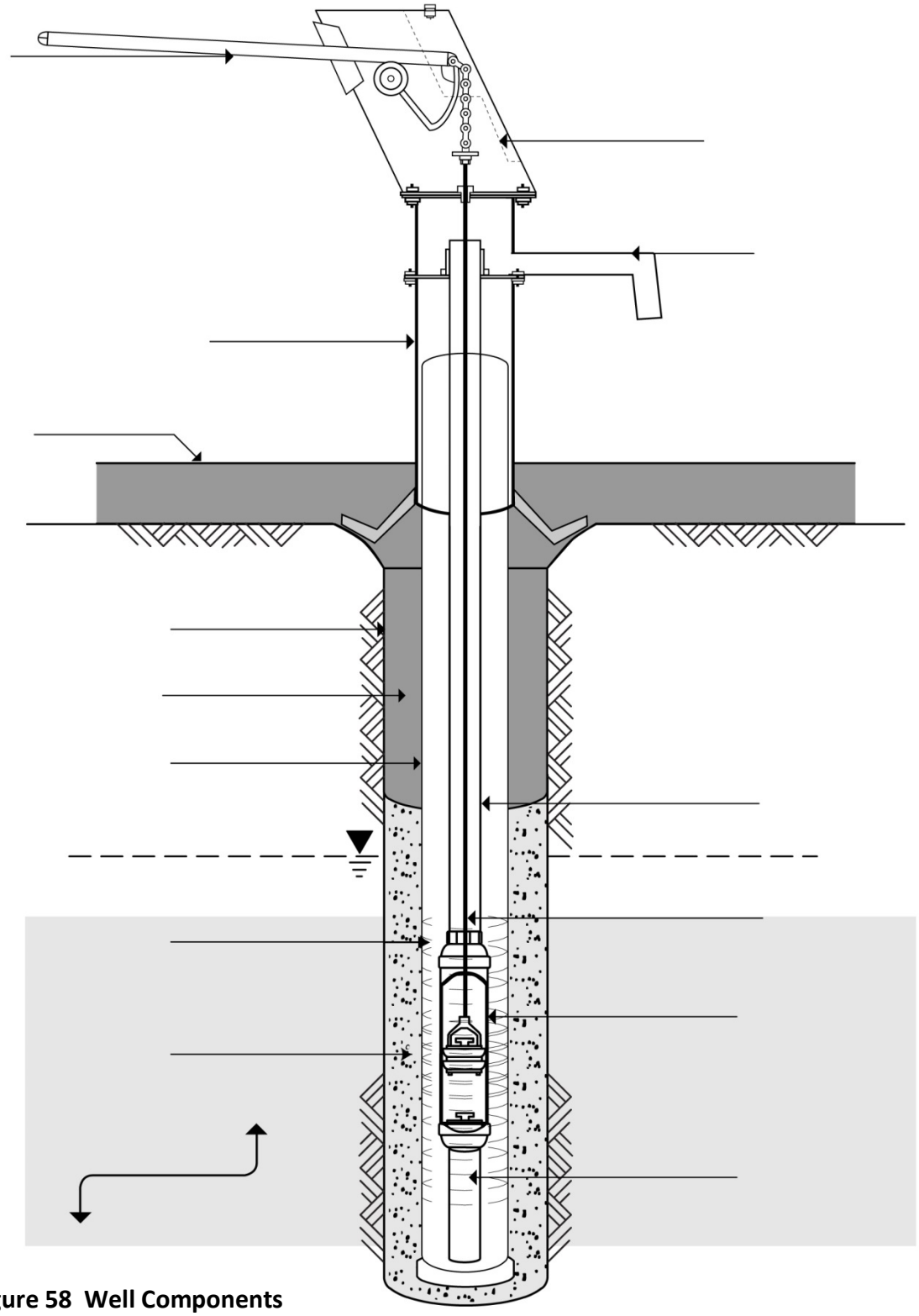


Figure 58 Well Components

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Key Elements of Well Construction

Borehole – The borehole needs to be about 50 mm (2 inches) wider all around than the diameter of the well casing. If you are using a 100 mm (4 inch) casing, to have 50 mm of space on all sides, the borehole would need to be 200 mm (8 inches) in diameter. If your casing is 75 mm (3 inches) in diameter then the borehole should be at least 180 mm (7 inches) in diameter. There can be no obstructions anywhere in the borehole. The borehole must be deep enough so that it extends below the lowest expected water level.

Casing – The wells we work with typically use PVC plastic pipe to line the borehole. The bottom is capped and the lower section is slotted to permit water to pass inside the casing. This slotted section of casing is called the **well screen**. (See lesson 4.2.)

Gravel Pack – A layer of coarse sand or gravel surrounding the well screen allows the well development process (lesson 4.6) to open up flow paths through the aquifer into the well.

Pump Pad and Sanitary Seal – These are the parts of a pump installation that prevent surface water from contaminating the well. The sanitary seal is made of concrete that completely fills the space between the borehole and the casing. It should be at least 5 meters (15') deep or to the water table if it is closer. The pump pad needs to be thick enough and reinforced to keep it from cracking and allowing surface water to seep into the well. (See lessons 4.5 and 4.7.)



2. Good Well Design - 30 minutes

To "design" a well is to determine the depths at which to place the well screen, the top of the gravel pack, and the sanitary seal. Everything is measured down from the ground surface. Good well design requires a good boring log (lesson 3.9) and knowledge of where the water table is. With good design a well should produce as much water as the aquifer is capable of yielding and the pump is capable of lifting.

The well screen should be placed within the best aquifer encountered in the borehole (lesson 4.2). It is also desirable to have the well screen as far as possible below the water table. If there is a large range in water table depth during the dry and wet seasons this prevents the well from going dry. But the deeper the borehole is below the water table the more unstable the borehole walls may become so there is often a trade-off between what is desirable and what is possible for the drill rig to accomplish.

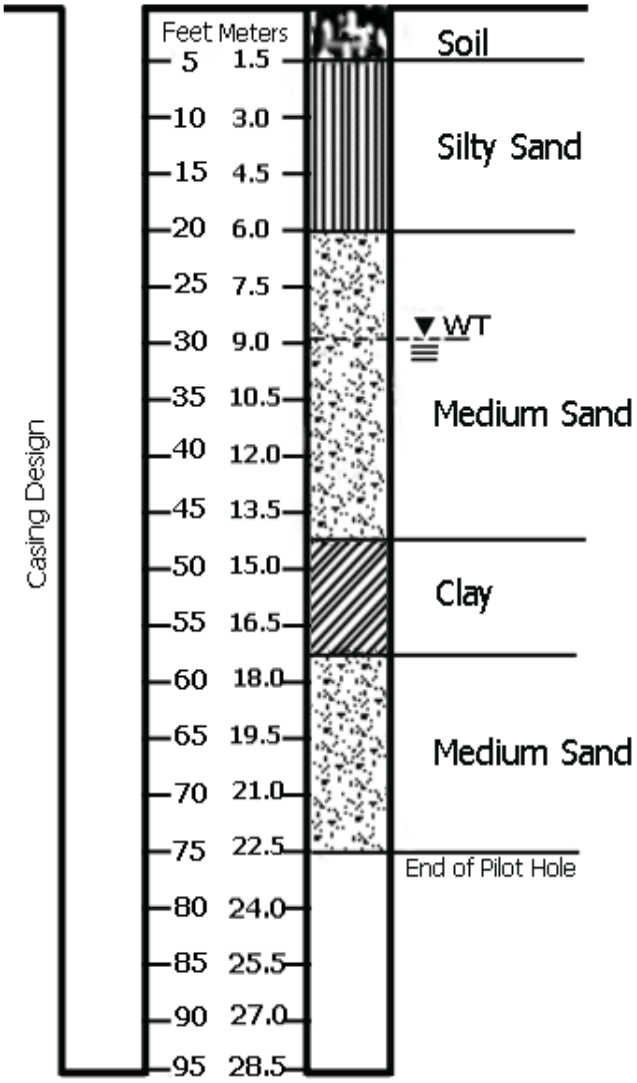
If the aquifer is thick enough, use at least 3 meters of well screen. Where there are several thin aquifers, place a well screen in each one.

The gravel pack should extend one meter above the top of the well screen. The volume of coarse sand or gravel to be used is calculated from the diameter of the borehole minus the diameter of the casing and the length of well screen (lesson 4.3).

The sanitary seal should extend at least 5 meters (15') down from the ground surface (lesson 4.5). The space between the top of the gravel pack and the bottom of the sanitary seal can be filled with cuttings from the borehole.

Study each of the following boring logs to determine the best depth for the well screen. Draw where you would place the casing and well screen. In the spaces provided below each boring log, write the distance from ground surface to the top and bottom of the well screen and to the top of the gravel pack. (In these boring logs, "WT" refers to the depth at which the driller first noticed groundwater; it might not be the actual water table.)

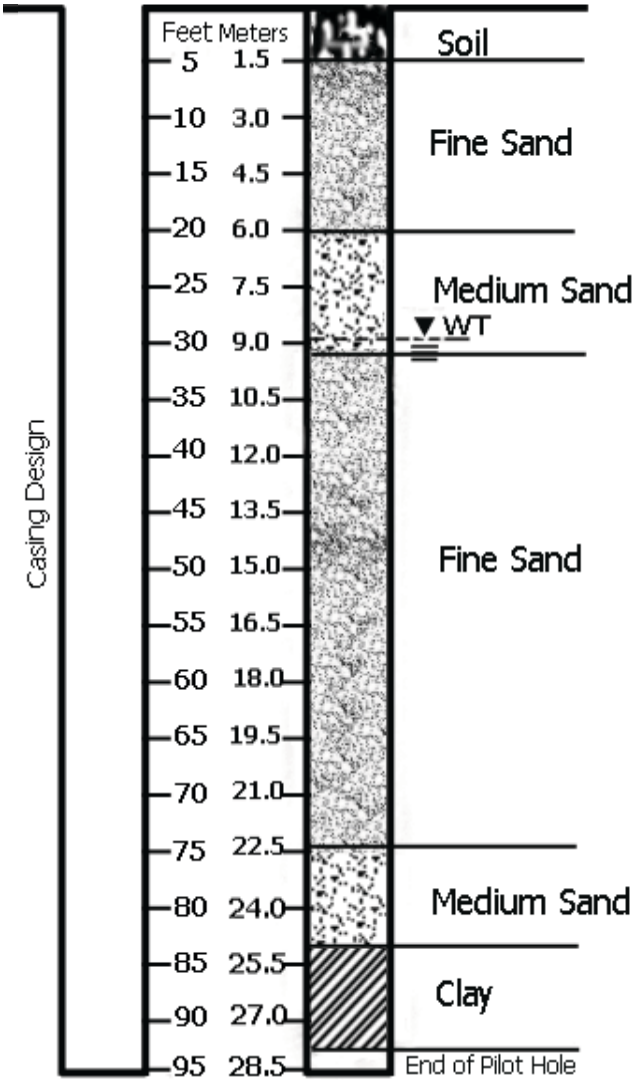
Boring Log #1



Screen top:_____ bottom:_____

Gravel pack top:_____

Boring Log #2

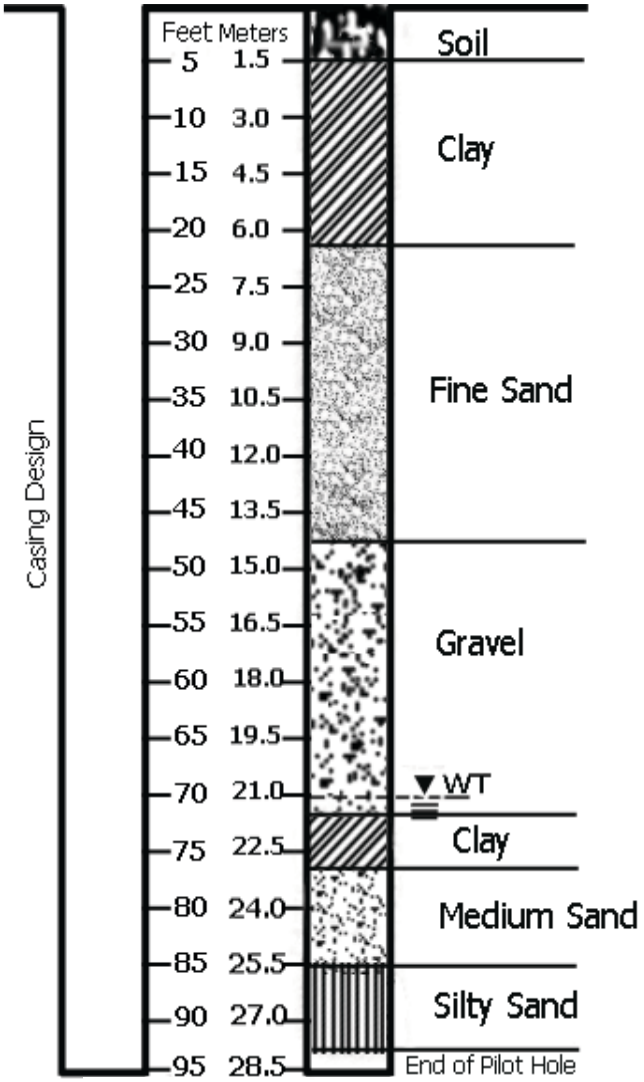


Screen top:_____ bottom:_____

Gravel pack top:_____

Figure 59a Well Design Exercises

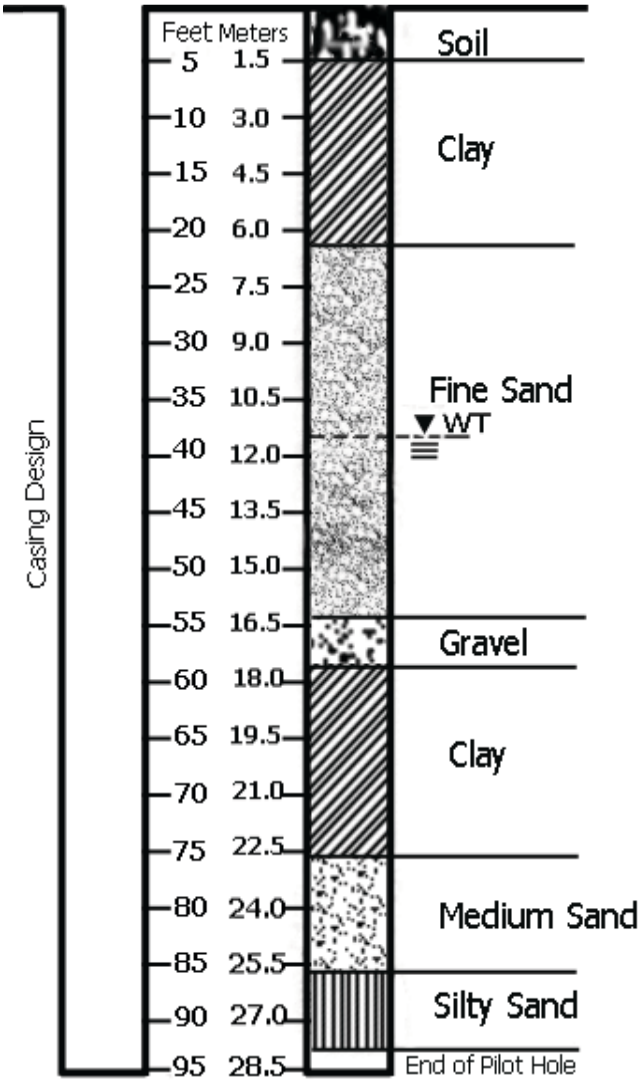
Boring Log #3



Screen top:_____ bottom:_____

Gravel pack top:_____

Boring Log #4



Screen top:_____ bottom:_____

Gravel pack top:_____

Figure 59b Well Design Exercises (continued)

Note: It is poor practice to allow a connection between two separate aquifers unless it is known that they have similar water quality.

3. Laying Out the Well Screen and Casing - 20 minutes

After you have decided on the depth for the well screen the next step is to transfer that information to the well screen and casing. This work will normally be done while the borehole is being reamed. It is very important that the casing be ready to install when reaming is finished!

This step requires a little math, but it is easy once you have practiced it a few times. Take the distance from the ground surface to the bottom of the well screen. For example let's say that distance is 27 meters. So in this example our total length of casing and screen is 27 meters.

Well screen and blank casing normally comes in 6-meter (20-foot) lengths. In this case we are using a 6-meter well screen.[5] So with this example we would divide 27 meters by 6 meters which is 4.5. Rounding up shows that we will need 5 sections of casing and screen.

Section one (first in the hole) will be the well screen. Then we will add 4 more blank sections above it. On section 5 (the last section) we need to mark where the ground surface will be on the casing. When this mark lines up with the ground surface we will know that the bottom of the well screen is at the design depth.

To determine where to put this mark, determine the number of full sections below ground. In this example, where the bottom of the screen is at 27 meters, that is 4 sections or 24 meters (4 x 6m). Subtracting 24 meters from 27 meters gives 3 meters. So section number 5 will be 3 meters below ground and the rest of that section will be above ground. So the "ground line" where we place our mark is 3 meters from the lower end of section 5.

The casing will get muddy as it is installed, so wrap electrical tape or masking tape around the casing to make the ground line mark. Do not cut the top casing section at the ground line mark. There needs to be 1 meter of casing sticking up above the ground surface.

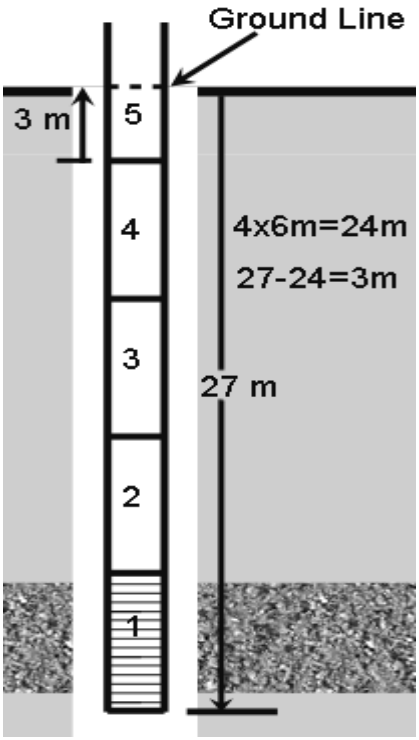


Figure 60 Well Design Example

To avoid making mistakes, always draw a sketch like Figure 60 that shows the ground surface and each screen and casing section. Write the distances on the drawing. It also helps to number the casing sections. This drawing can be made on the boring log or on a separate piece of paper.

The well design information will be transferred to the final boring log in the well completion report (lesson 7.3). Whoever makes the well design sketch should have another crew member check the math. Once you start adding casing to the borehole, it is very hard to pull it back out to correct an error!

[5] Some drillers like to add a 1 meter blank section of casing below the well screen as a sediment trap. This is not necessary when a hand pump is used and can create a low-oxygen zone in the well. If a sediment trap is added, the measurements for designing the well would still be based on the bottom of the well screen. Just make sure the borehole is deep enough to leave room for the trap.

- Calculate the following design information for each of the four sample boring logs in the previous section:

Boring Log #1 Length of screen:_____ Total 6 m blank sections:_____

Ground line mark on top section: _____ from bottom of top section.

Boring Log #2 Length of screen:_____ Total 6 m blank sections:_____

Ground line mark on top section: _____ from bottom of top section.

Boring Log #3 Length of screen:_____ Total 6 m blank sections:_____

Ground line mark on top section: _____ from bottom of top section.

Boring Log #4 Length of screen:_____ Total 6 m blank sections:_____

Ground line mark on top section: _____ from bottom of top section.

4. Cutting Well Screen - 45 minutes

If you are not using commercially-slotted well screen then it is necessary to cut slots by hand in a blank section of PVC casing. It will normally take two men at least an hour to cut six meters of screen by hand and this task must be completed before reaming has been finished.

The slots in the well screen need to be wide enough so that silt particles will not clog them, but small enough so that the gravel pack can't pass through. For commercial well screen the most common widths used in water well construction are 0.02 inches (0.5 mm) and 0.03 inches (0.76 mm). When using a new hacksaw blade to cut slots by hand, the width is around 0.037 inches (0.94 mm). Therefore, grains of coarse sand or gravel used in a gravel pack must always be greater than 1 mm in diameter (lesson .4.3)

When using 100 mm (4") casing, the slots should be cut in three straight rows, leaving an uncut space between each row of slots. The uncut sections should be at least 5 cm wide or the well screen will be too weak to handle.

Here is a simple method for marking guide lines on the casing:

1. Using a pencil, draw a straight line down the length of the casing. This will be the base line.
2. Wrap a string around the casing and mark the string or tie a knot in it where it comes together. This length of string represents the circumference of the casing.
3. Fold the string so that it is in three equal lengths. Mark the folds with a permanent marker, or tie knots at those points (this requires adjusting the end knot). Now the string has three marked sections equal in length.
4. Make a mark on the string 5 cm (2") from the end. Make another mark 5 cm (2") from the first 1/3 mark, and again for the next 1/3 mark (the drawing shows what this will look like.)
5. Starting from the base line, wrap the string around the casing again. Mark the casing at each of the marks on the string. Repeat this at intervals of about 1 meter (3') along the length of the casing that is to become well screen.
6. Draw straight guide lines between the marks on the casing.

Cut the slots between the widely-spaced guide lines and leave the narrow 5 cm (2") sections solid. The cuts should line up with each other and be spaced about 1 to 1.5 cm (¼"-½") apart. Do not cut through any lines! Doing so will weaken the narrow support sections and could cause the well screen to break when it is lifted. It is helpful to mark "Xs" in the narrow support sections as a reminder not to cut into them.

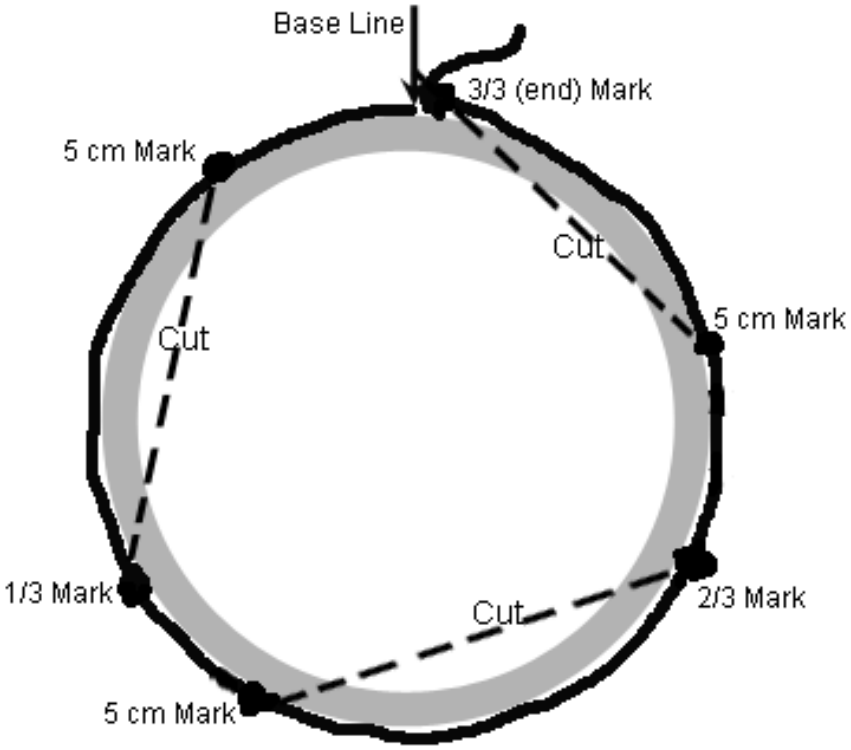


Figure 61 Marking Well Screen

Leave at least 20 cm of uncut casing at each end of the well screen for attaching a cap and the next section of casing. When all of the slots have been cut, use a clean cloth tied to a rope to knock loose the small PVC pieces and wipe out the inside of the screen.

Lesson 4.2 Installing Casing and Screen

Purpose

To introduce principles and practices for proper casing installation.

Objectives

By the end of this lesson, participants will have

- Studied how the well screen and gravel pack function to provide clear water
- Examined different grades of PVC casing
- Practiced installing casing in a borehole
- Identified hand pump malfunctions resulting from improper well construction

Materials

- Well components posters, labeled & unlabeled
- Borehole, PVC casing, glue, rope

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. What The Well Screen Does.
2. Good Casing and Well Screen
3. Installing Casing
4. When Things Go Wrong
5. Open Hole Completion

1. What the Well Screen Does - 5 minutes

The well screen, combined with a good gravel pack, lets water into the well. The casing, with a proper sanitary seal, allows that water to be lifted to the surface without being contaminated. The following drawing represents a close-up of the well screen, gravel pack, and aquifer.

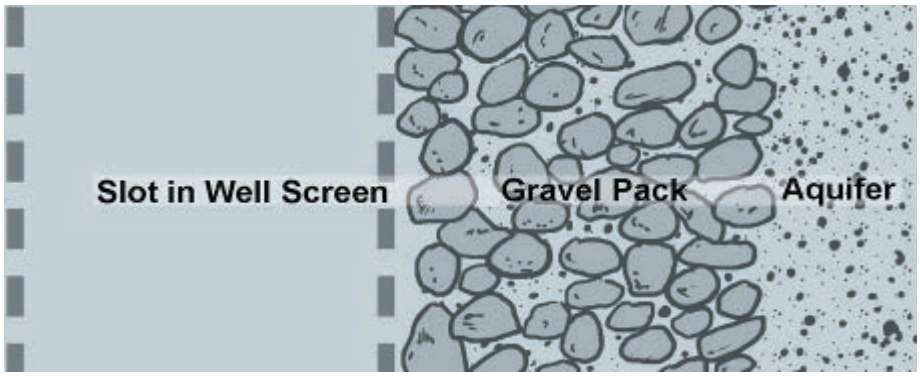


Figure 62 Well Screen and Gravel Pack

As explained in lesson 4.3, the slots in the well screen and the gravel pack must, at first, allow silt and other fine sediments into the well. These sediments may be naturally-occurring in the aquifer as well as left over from drilling. The process of well development (lesson 4.6) removes this fine material from the immediate area of the well and opens up flow paths through the aquifer.

2. Good Casing and Well Screen - 5 minutes

The shallow water wells drilled with the LS200 rig use PVC plastic pipe for well casing and screen. (See lesson 6.1.) PVC that is suitable for use in a well is rated Schedule 40. PVC pipe that is thinner than this may not be able to hold back the water pressures generated in a well and may collapse. This collapse might not happen immediately, but perhaps months later if the water level drops.

Using 75 mm (3-inch) diameter casing can save money, but Lifewater recommends 100 mm (4-inch) casing since that size allows a submersible pump to be installed in the well at a future date.

Methods for working with PVC pipe are covered in lesson 6.1.

3. Installing Casing - 5 minutes

Casing is installed with the LS200 drill rig still in place over the borehole. Remove the hinge pin on the right side of the shuttle (as viewed from the winch) and swing the motor and transmission out of the way. Replace the 2-inch slip used during drilling with the 4-inch slip designed to hold the bell end of the casing. The bell (or coupling) end up well casing should be up. (Only the riser main of an Afridev pump is installed with the bell end down.)

The borehole should have been reamed about 2 meters deeper than the bottom of the casing. And drilling mud should be circulated until all cuttings have been removed from the borehole. But some cuttings might remain and pulling the drill pipe out of the borehole could knock some sediment from the walls. So it is wise to use a weighted string to make sure the borehole is at the right depth before installing the casing.

It is also useful to make a weighted "dummy"[6] made from 110 mm (4") and 63 mm (2") casing that can be lowered in the borehole to test if there are any sections of swelling clay or protruding rocks that would interfere with placing the casing.

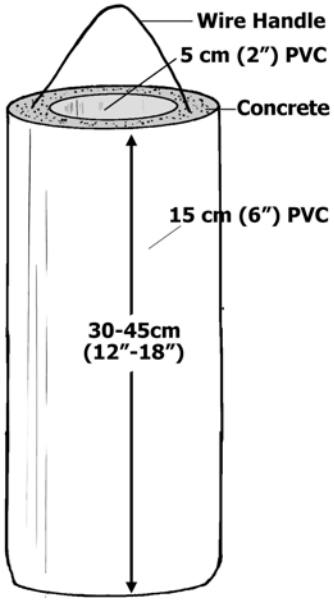


Figure 63 Weighted "Dummy"

Glue a cap and one set of centralizers onto the bottom of the well screen as shown in Figure 64. Centralizers can be made from strips of PVC softened in a fire and bent. They can be attached to the casing with electrical tape. A single set of centralizers at the bottom of the well screen is usually enough to keep the well screen in the center of the borehole. Avoid placing centralizers above the well screen, since they can cause the gravel pack to "bridge."



Figure 64 Casing Centralizer

Carefully lower the first section of casing and well screen into the borehole. Because PVC casing floats, it will take a slight effort to push it down while the casing fills with drilling mud. But if there is any strong resistance, then **do not try to force the casing down**. There could be a layer of swelling clay. Never force the screen past a narrow spot caused by a layer of clay or other obstruction. You will fill up the slots and the obstruction will prevent the gravel pack from reaching the well screen. It will be a muddy well.

With the bell end of the well screen held by the slip on the drill table, glue the next section of casing, holding it in place at least 5 minutes for the PVC glue to dry (lesson 6.2). Different brands of PVC glue have different drying times and are affected by temperature. So don't be impatient; make sure the glue is dry. . Repeat for each section of casing.

Line up the ground line mark on the top (last) section of casing with the ground surface. Cut off the casing about one meter above the ground surface.

Casing installation should be a smooth, continuous operation. This is only possible if every section is ready to be placed before the reaming operation is finished.

[6] Peter Ball, "Drilled Wells" SKAT 2001

4. When Things Go Wrong - 5 minutes

Read this case study and answer the questions:



Figure 65 Forcing Casing

A Lifewater Lead Trainer had just arrived at a drill site to give a partner crew advanced training. After brief introductions, the crew went back to work on the borehole they had started earlier in the day. The trainer watched the crew work for several hours and was impressed with their drilling skills.

When the crew started installing the casing, a problem arose. They had been drilling through several different layers of clay.

The problem they were having was getting the casing into the borehole. They had just finished reaming it to 200 mm (8") and were installing 100 mm PVC casing. It was a 20-meter deep borehole, but they could not get the casing past about 6 meters.

So they all grabbed onto the casing and started pulling it down as hard as they could. After one crew member climbed the drill mast to fill the casing with water to make it heavier the trainer yelled, **"Stop!"**

- Why do you think the trainer yelled "Stop!"?

The trainer explained that if the casing didn't go easily into the borehole, then they would never be able to get a gravel pack around the well screen. The crew chief said, "This is how we always put in casing." So the trainer asked, "Tell me about the last well you installed this way; does it produce clear water?" "No," answered the crew chief, "it is always muddy." So the trainer took that opportunity to remind the crew what the gravel pack does and how critical it is for the proper functioning of a well. After reaming the troublesome section several more times, the layer of swelling clay was conquered and the casing was installed with enough clearance to put in a good gravel pack.

- What are some lessons that can be learned from this incident?

_____

_____

_____

If a well is not constructed properly, it can affect the long-term performance of any pump that is installed in the well. Each team will be assigned one or more of the following problems related to well construction. For each problem, describe how it might affect the long-term performance of a hand pump. Discuss this for 10 minutes and then present your findings to the class.

Problem 1: Crooked borehole

Problem 2: No sanitary seal

Problem 3: Gaps in the gravel pack

Problem 4: Well not deep enough

Problem 5: Casing forced past a clay layer

Problem 6: Cracked pump pad

5. Open Hole Completion - 5 minutes

The preceding discussions assume that the well is being completed in sediments (sand and gravel) since those are the soil types most frequently drilled with small rigs. However, as noted in Lesson 3.2 Small Mud Rotary Drill Rigs, the trailer-mounted hydraulic powered rigs are capable of drilling through rock and are therefore able to tap into groundwater found in fractured bedrock. Typically, there will be a layer of sediment over the bedrock. So the normal practice is to drill to the top of the bedrock, ream the borehole to at least 20 cm (8”) and install 15 cm (6”) casing. The bottom of the casing is sealed with concrete so that it flows up into the annular space to form a sanitary seal (see Figure 57, Casing-Off). Then, using a smaller diameter bit, the bedrock is penetrated until enough fractures have been encountered to provide a sufficient flow of water. With this approach, an inner casing and well screen may be installed but a gravel pack is not needed since the bedrock should not produce any silt or sand to keep out of the casing.

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Lesson 4.3 Gravel Pack

Purpose

To introduce principles and practices for proper gravel pack installation.

Objectives

By the end of this lesson, participants will have

- Practiced floating-in a gravel pack

Materials.

- Gravel and coarse sand , set of sifting screens, buckets
- Alt: Samples of sifted and washed gravel pack
- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

75 minutes

Steps

1. Sift and Wash Gravel
2. Calculate Gravel Quantity
3. Flush Mud from the Borehole
4. Float in the Gravel Pack
5. Gravel Pack or Filter?

1. Sift and Wash Gravel - 15 minutes

There are two features to look for in selecting good gravel pack. First, the individual sand or gravel grains must be rounded, not angular. Rounded grains come from streams, rivers, and beach deposits. Angular grains come from crushed rock. Never use crushed rock for the gravel pack. Angular grains will lock together over time and reduce the flow of water into the well.

Second, the rounded grains should be within a narrow size range; there should not be a mixture of small, medium and large grains. A mix of grain sizes will also reduce flow into the well.

Prepare the gravel pack by sifting it with a series of screens. First use a screen with approximately 6 mm (1/4-inch) openings to remove the larger material. (Keep this for making concrete.) Then sift what passes the 6 mm screen using a screen with approximately 3 mm (1/8-inch) openings. The coarse sand that is retained on the 3 mm screen is good to use for a gravel pack. Gravel pack prepared this way will have a grain diameter between 3mm and 6mm.

After sifting, thoroughly wash the gravel pack to remove silt and clay that may be sticking to the grains. Spread it out in the sun to dry and then store it in sacks. Instructions for making sifting screens are provided in Appendix 5 Making Gravel Pack Screens.

Preparing gravel pack takes a lot of work, so it is best to do it on days when there is no drilling. In some countries, commercially sifted and washed gravel pack can be purchased. Considering the amount of work required to prepare gravel pack, the greater cost of commercial material may be offset by the savings in labor.

2. Calculate Gravel Quantity – 30 minutes

Use Table 2 to determine how many liters of gravel will be required to bring the gravel pack up to a point that is 1 meter above the top of the well screen. Two calculations are required: the volume in the open borehole below the casing and the volume in the space between the casing and the borehole (this space is called the "annulus"). It is hard to know the actual borehole diameter in the aquifer, so these calculations are only an estimate.

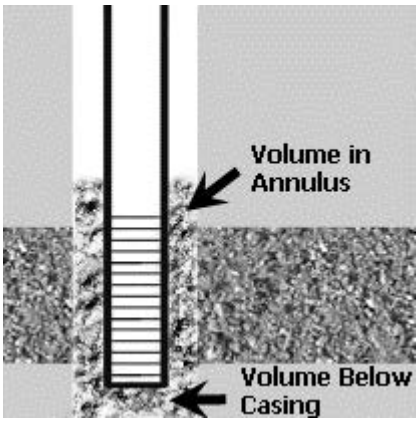


Figure 66 Gravel Pack Volume

Table 2 gives volume of gravel pack in liters per meter of well screen and borehole bottom for two casing diameters and 4 borehole diameters. (Volume = 3.14 X Radius^2 X Height)

Table 2 Calculating Gravel Pack in Liters per Meter (Gallons per Foot)

	3" Casing (90mm OD)		4" Casing (110mm OD)	
Borehole diameter	**Annulus**	**Bottom**	**Annulus**	**Bottom**
127mm (5")	6 (0.4)	13 (0.9)	3 (0.2)	13 (0.9)
152mm (6")	12 (0.8)	18 (1.2)	9 (0.6)	18 (1.2)
178mm (7")	19 (1.3)	25 (1.7)	15 (1.0)	25 (1.7)
203mm (8")	26 (1.7)	32 (2.1)	23 (1.5)	32 (2.1)

Example: A well uses 2 meters of 4" diameter well screen in a 7" diameter borehole and there is 0.5 meter of open borehole below the end of the screen. For the annulus volume, multiply 3 meters (well screen plus 1 meter above screen) by 15 liters per meter to get 45 liters. For the bottom, multiply 0.5 meter times 25 liters per meter to get 12.5 liters. The volume of gravel pack needed is the sum of these; 45+12.5 = 57.5 liters. A 5-gallon bucket holds 20 liters, so this well needs a little less than 3 buckets of gravel for a good gravel pack.

3. Flush Mud from the Borehole - 10 minutes

The LS200 drill rig is provided with a casing flushing tool that is used to clean out the drilling mud. One end fits over a 10 cm (4-inch) casing and the other end connects to the quill on the drill rig. Use this tool to slowly pump clear water out of a 55-gallon drum down the well casing. This will force the drilling mud out of the borehole. It will usually require two drums of water, more for a deep borehole, to flush out the drilling mud and add the gravel pack.

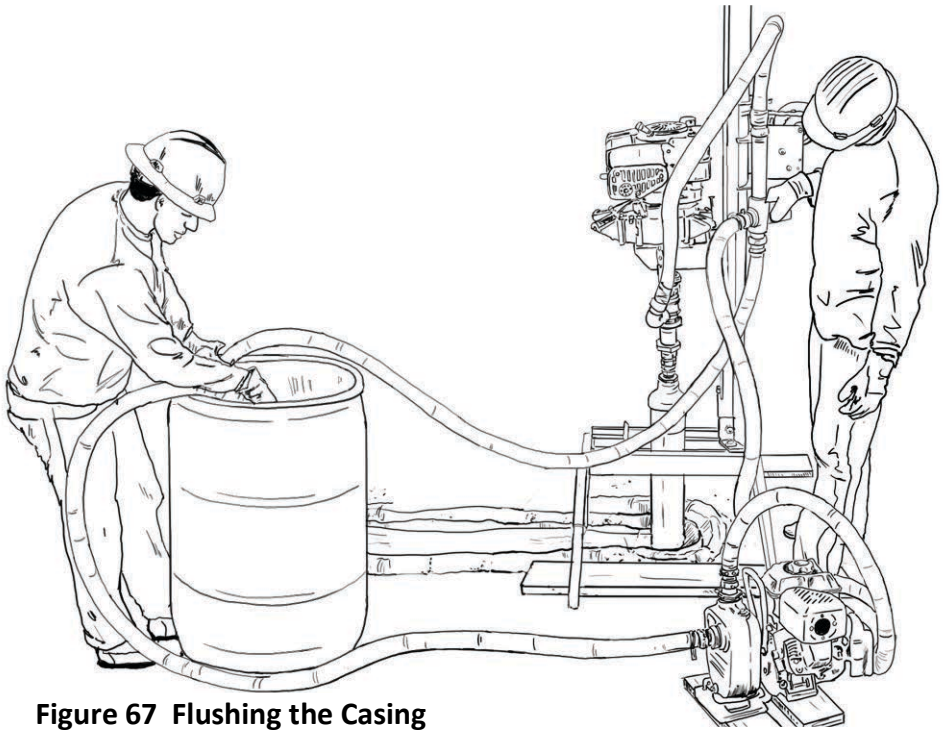


Figure 67 Flushing the Casing

Because the mud pump can't be run slowly enough, adjust the three-way valve so only a portion of the water flows down the casing. Put the bypass hose as well as the suction hose into the drum to re-circulate the remainder of the flow. Dig a trench from the mud pits away from the drill site so the overflow has a place to go. When the return from the borehole starts to look clear, it is time to begin adding the gravel pack.

4. Float in the Gravel Pack - 10 minutes

With the clear flushing water still flowing very slowly, gradually add the gravel pack to the borehole by hand. Apply it evenly around all sides of the casing. Do not pour the gravel from a sack or a bucket, as that will be too fast! Gently shake the casing to break up any "bridge" of gravel that might form. Keep careful account of the amount of gravel that has been added.

When half of the calculated amount of gravel has been added to the borehole, stop pumping water into the casing. Use a weighted string to measure the depth to the top of the gravel pack. It should be at the half-way point on the well screen (assuming there is not much open hole below the casing). If it is much lower, then either the depth or the diameter of the borehole is greater than thought. This is not a serious problem, as long as there is enough washed gravel on hand at the drill site. If the gravel level is already above the top of the well

screen, then this is a problem because it indicates that a “bridge” has formed and the gravel pack is not fully covering the well screen. Increase the flow of clear water and shake the casing to break the bridge. Re-measure the depth to the gravel. If the bridge has not been removed, repeat flushing and shaking once more. If the bridge has still not been removed, then slowly add the remaining gravel. There is nothing more that can be done with the LS200 equipment to remove a bridged gravel pack.

When the calculated amount of gravel has been added, measure the top of the gravel pack. It should be approximately one meter above the top of the well screen. If it is lower, add more gravel to reach the proper depth.

When the gravel pack is in place, the danger of borehole collapse has passed. If it is late, as it often will be at this point, cover the borehole so nothing can fall in and put away all tools before leaving the site.

5. Gravel Pack or Filter? - 10 minutes

Sometimes the gravel pack is called a filter pack because it acts somewhat like a “filter” that keeps fine sediments out of the well. However, a filter holds back and collects things that are too small to pass through it. During well development, the gravel pack around a well screen allows some fine sediment to pass through into the well where it can be removed. This opens up pathways through the aquifer so that groundwater can more easily flow into the well.

If the gravel pack is too thin, has gaps, or is not evenly distributed around the well screen, then fine particles will continue to get into the casing after the pump has been installed. When this happens, the well is said to be “pumping sand.” The sand and silt gets into the pump to cause premature wear. Sand can eventually fill up the casing almost to the water level. After placing the gravel pack, the well must be “developed” (lesson 4.6) to open up flow paths from the aquifer into the well screen. Drilling may cause clay to be smeared on the borehole walls and the bentonite clay and other materials used to thicken the drilling fluid can migrate a short way into the aquifer. “Developing” a well (lesson 4.6) consists of vigorously pumping or bailing until a good flow of clear water is obtained. Without this step, which can take a day or longer, a well that could produce a good flow of water may only produce a trickle or none.

Lesson 4.4 Initial Well Yield Test

Purpose

To determine if a newly-installed well can produce enough water

Objectives

By the end of this lesson, participants will have

- Used a bailer to measure well yield
- Option: Constructed a bailer

Materials

- Borehole with casing and gravel pack installed
- Option: Bailer construction supplies and tools (see Appendix 8)

Preparation

- Study lesson ahead of time
- Option: Assemble bailer materials

Time

60 – 120 minutes

Steps

1. Decision point
2. Well yield test procedure

1. Decision Point - 5 minutes

An important decision must be made at this point. With the casing and gravel pack in place, the risk of the borehole collapsing is past. This is the time to determine if the well can produce enough water to supply a hand pump. If it can, then proceed with placing the sanitary seal, developing the well, building the pump pad, and installing a hand pump (lessons 4.5, 4.6, 4.7, and section 5). If the well can't produce enough water, even after preliminary development, then recover as much casing as possible and close the borehole (lesson 4.8).

2. Well Yield Test Procedure - 60 minutes

First, measure the water level in the well. Write that depth and time in a notebook.

Next, using a bailer remove as much water as possible from the well in 10 minutes. Pour each bailer load into a bucket so the volume of water removed can be measured. Write the volume of water removed and the time spent bailing. The bailing rate should be around 10 liters per minute ((2.6 gallons per minute). If this rate can't be met due to the depth of the well (takes too long to lower and lift the bailer), then increase the bailing time to 20 minutes.

Measure the water level as soon as bailing has stopped. There are three possible results: (a) the water level did not drop a measurable amount during bailing, (b) the water level dropped some, or (c) the well went dry in less than 10 minutes of bailing. Depending on the result, do the following:

(a) No measurable drop in water level. Bail again for another 10 or 20 minutes, recording the time and the volume removed. Measure the water level immediately after bailing. If a bailing rate of around 10 liters per minute (2.6 gallons/minute) can be maintained before the well has been developed (lesson 4.6) then it should be a good well.

(**b) Some drop in water level.** Wait 10 minutes then measure the water level again. Has it recovered to its original level? If not, wait another 10 minutes and measure again recording the depth and the time for each measurement. Record how long it takes for the water level to recover. Once the water level has reached its original level, repeat the bailing and measuring procedure. If the time that it takes for the water level to recover is decreasing, then with further development (lesson 4.6) the well is likely to be good.

(c) The well can be bailed dry. Keep measuring the well to see how long it takes for the water level to recover. If the aquifer is plugged with drilling mud then it may take a lot of development (lesson 4.6) to get a flow of water into the well. It is not unusual for a new well to take 12 hours or more for the water level to recover. Be patient; do not be too quick to declare it a "dry hole." If, after several days of development, the well can still be bailed dry and it takes an hour or more for the water level to recover, then there is probably not enough water flow to support a hand pump. Remove as much casing as possible and close the borehole as described in lesson 4.8.

3. Bailer Construction - 60 minutes

A bailer is a length of PVC pipe, usually about a meter long, with a diameter that easily fits into the well casing. It is used to develop the well by removing drilling mud, silt and sand that remains after the well is drilled.

At the bottom of the bailer is a one-way valve and at the top is an attachment point for a rope. As the bailer is lowered into the well, the one-way valve allows it to fill with water. When the bailer is raised, the valve holds the water. The bailer is brought to the surface and tipped upside down to empty it.

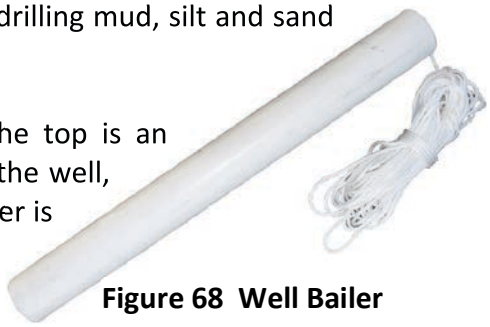


Figure 68 Well Bailer

The bailer may be raised and lowered using a tripod and pulley. As it moves up and down under water it creates a "surge" through the well screen that helps to improve well yield. Bailers are relatively easy to make. There are different ways to make the one-way valve. One example is described in Appendix 6.

Lesson 4.5 Sanitary Seal

Purpose

To understand the importance of a properly installed well seal.

Objectives

By the end of this lesson, participants will have

- Reviewed pathways of well contamination
- Practiced installing a sanitary seal

Materials

- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. Introduction
2. Installing a Sanitary Seal

1. Introduction - 10 minutes

The purpose of a sanitary seal is to prevent contaminated surface water from entering the borehole and contaminating the well water. Shallow groundwater might also be contaminated so sealing the upper section of the borehole will protect the well from this source. Without this seal, water can easily flow through the disturbed soil between the borehole wall and the well casing.

Ideally, the sanitary seal should extend down to the first impermeable sediment layer. If there is no such layer above the aquifer, then the sanitary seal should extend to the top of the gravel pack. This is the well construction standard adopted by most government agencies responsible for protecting the quality of drinking water.

In practical application, the sanitary seal should be placed as deep as possible; preferably at least 6 meters (20') deep. Where the water table is closer than that to the surface, the sanitary seal should extend to the water table.

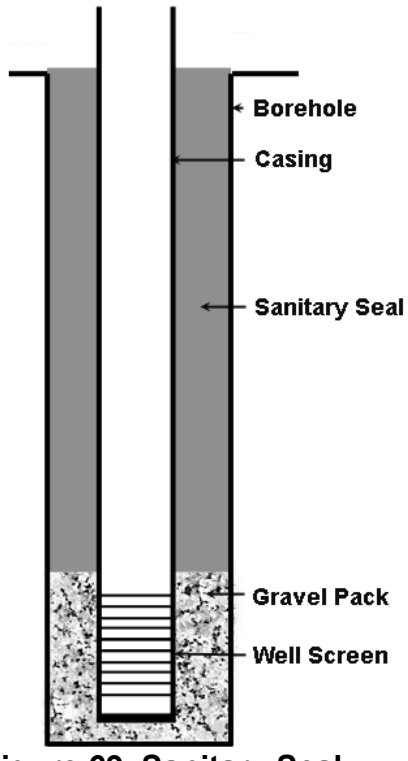


Figure 69 Sanitary Seal

2. Installing a Sanitary Seal - 50 minutes

To install an effective sanitary seal, the borehole diameter should be at least 5 cm (2") greater than the casing diameter. So if a 10 cm (4") casing is being installed, the borehole should be at least 15 cm (6") in diameter. With less space than that, it will be nearly impossible to get a solid seal deep enough to prevent surface water from contaminating the well.

It will be necessary to first determine the volume of the sanitary seal. Use the same calculation method described in lesson 4.3, Gravel Pack. Use the mud mixing setup to get the components properly mixed. The most effective sealing materials are either "neat cement" (cement without sand) or bentonite.[7] Mix with water at a ratio of 4 parts water to one part solids to form a thin grout or slurry that can be poured or pumped down the annular space between the casing and the borehole wall.

To place a sanitary seal to a depth greater than 6 meters, as may be required to meet government standards, the "tremie method" is used. This involves pumping the slurry down a small diameter pipe in the annular space. Extend the pipe to the top of the gravel pack and slowly raise it as the slurry is pumped in. This will prevent the formation of bridges or water pockets. An alternative is to place a large funnel on the upper end of the tremie pipe and slowly pour in the slurry. It is usually necessary to do this standing on a ladder to generate enough pressure to get the slurry to flow through the pipe.

Make a small berm around the top of the borehole and fill it with the cement-bentonite slurry. This will prevent surface water from collecting around the top of the well.

If they are available, bentonite chips or plugs make a very effective sanitary seal. They are much easier to work with than cement or bentonite slurry since the chips will fall through any water in the borehole and swell up later. Add them very slowly, like placing the gravel pack, to prevent the formation of a bridge.

Wait at least 24 hours for the sanitary seal to set up before installing a pump or doing any other work on the well that would move the casing.

[7] Some drillers use a mixture of equal parts cement and bentonite, some use 5% bentonite added to the cement, while others question the value of using a mixture. Where applicable, follow the guidelines of the local regulatory agency.

Lesson 4.6 Developing the Well

Purpose

To learn how to get the maximum flow of water from a well

Objectives

By the end of this lesson, participants will have

- Studied how the well screen, gravel pack, and aquifer should work together
- Practiced developing a well with a bailer

Materials

- Poster of stages of well development
- Bailer
- Surge block (optional)
- Markers and Flip chart

Preparation

- Study lesson ahead of time.

Time

60 minutes

Steps

1. What Developing a Well Does
2. Deelopment Methods

1. What Developing a Well Does - 20 minutes

To "develop" a well means to remove drilling mud and to open up pathways for groundwater to easily flow into the well. Developing does three things:

1. Remove drilling mud.
2. Break down wall cake.
3. Remove fine sediments from the aquifer.

A common mistake made by beginning well drillers is to think that they have adequately developed a well when the water coming out is no longer muddy. But it is necessary to keep developing the well to break down the wall cake that builds up during drilling (lesson 3.6) and remove the fine sediments within the gravel pack and in the first few centimeters of the aquifer.

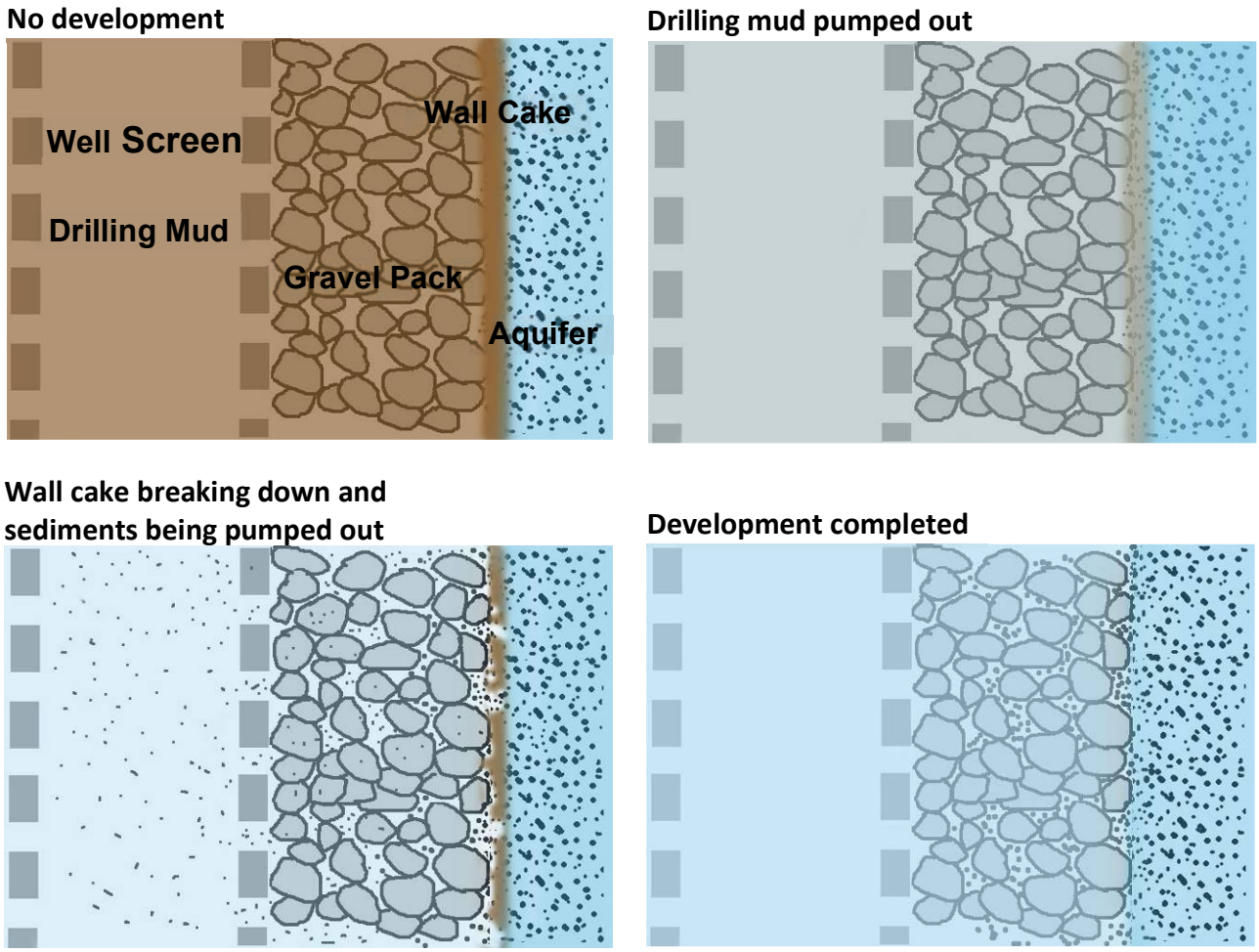


Figure 70 Stages of Well Development

1. Development Methods - 20 minutes

To properly develop a well you must:

- Move water back and forth through the gravel pack; and
- Remove a large volume of water from the well.

There are several methods for accomplishing these two things. Many drillers use a surge block, which is a plunger that is raised and lowered in the well screen. This moves water in and out of the gravel pack. Start at the top of the well screen and slowly work down to the bottom. When using a surge block, it is necessary to frequently pump sand out of the casing. Some drillers keep an old pump (electric submersible or hand pump) which they use to remove sand from the well. Because sand quickly wears a pump out, the development pump is never used for the final pump installation.

For the small diameter, relatively shallow wells drilled by the LS100 and LS200 rigs, using a bailer provides very good surging action and also removes sand. No other development tool is needed. The main disadvantage of developing with a bailer is that it is hard work. It can take several days of bailing to fully develop a well. Using a tripod to raise and lower the bailer makes it a little easier. Bailing their well is a good way for the community to participate in the well construction process and it frees the drilling crew from a time-consuming and tedious activity. It is easy to make a bailer (Appendix 6) so one can be given to the community.

Some drillers use compressed air to surge-develop a well. If done properly, this can be an effective method. However, it is difficult to do it properly. Only a very short burst of air should be applied, which will force water out of the casing. If too much water is forced out too quickly, then the well casing may collapse as a result of the difference in pressure between the formation and casing. If this happens, then the well has likely been destroyed and would need to be re-drilled at another spot. Air surging can also cause air to become trapped in the gravel pack which will reduce well yield. For these reasons this method is not recommended for inexperienced well drillers.

A safer way to use compressed air to develop a well is with an air-lift pump. This consists of an air line, small-diameter PVC pipe, appropriate fittings, and a compressor. Air is introduced into the PVC pipe about 30 cm (12”) above the bottom of the pipe. The rising air bubbles generate suction so that the water outside of the pipe flows in and rises up to the surface carrying sand with it.

For an air-lift pump to function properly, the bottom of the small-diameter PVC pipe should be submerged at least as far below the water table as the water has to be lifted above the water table. For example, if the water table is 20 meters below ground, then the bottom of the air-lift pump would need to extend to a minimum of 20 meters below the water table, requiring a 40-meter deep well. With a small drilling rig like the LS100 or LS200 it can be difficult to drill more than 10 meters below the water table if the aquifer is composed of loose sand or gravel. This will limit the situations in which using an airlift pump is practical.

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Lesson 4.7 Building a Pump Pad – Part 1

Purpose

To examine standards and practices for pump pad construction.

Objectives

By the end of this lesson, participants will have

- Considered the functions of the well pad
- Listed the effects of a poorly constructed pump pad
- Studied the sequence of pad construction

Materials

- Posters of damaged and repaired pump pads
- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

65 minutes

Steps

1. Functions of a Pump Pad
2. Features of a Good Pump Pad
3. Pad Construction Steps

1. Functions of a Pump Pad - 20 minutes

A properly designed and constructed pump pad has at least three very important functions:

- Provides a strong base for the hand pump.
- Prevents surface water from seeping into the borehole.
- Provides a clean and dry place to stand while pumping water.

➢ Can you think of any other benefits of a good pump pad?

_____

_____

A poorly designed and constructed pump pad can result in a broken pump, contaminated groundwater, and an unhealthy environment.

Figure 71 shows a well-built and maintained pump pad and a pad that was poorly constructed and which has not been maintained.

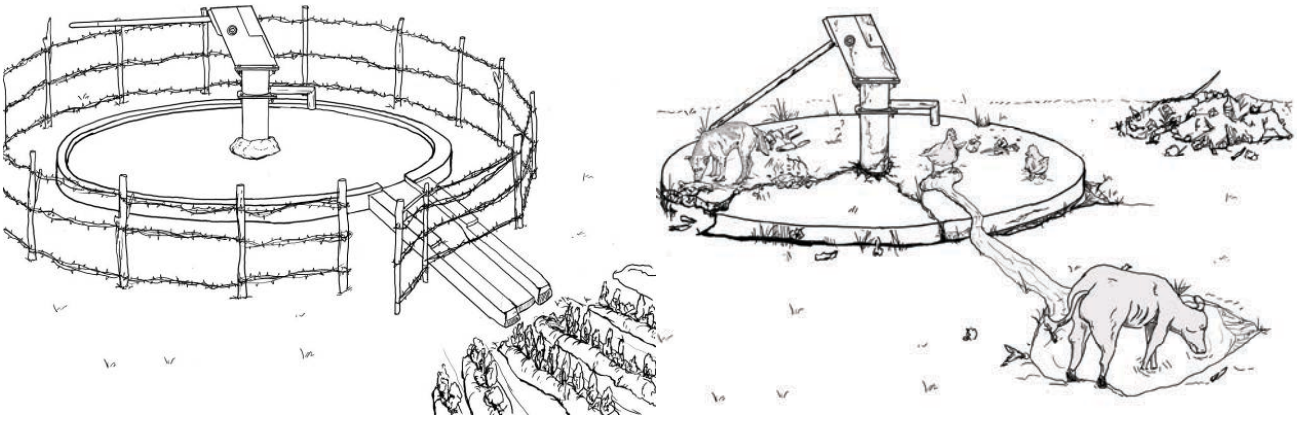


Figure 71 Good and Bad Pump Pads

- List as many problems with the pad on the right as you can find:

_____

_____

_____

_____

2. Features of a Good Pump Pad - 15 minutes

A good pump pad has these features:

- Covers an area at least 1 meter (3 feet) all around the pump base.
- Raised above the ground so that surface water does not flow over it.
- Made with good, strong concrete.
- Reinforced with steel mesh or reinforcing bar (rebar).
- At least 15 cm (6 inches) thick so it will not easily crack.
- Pump is set firmly in concrete so it cannot move.
- Sloped and with a raised curb around the edge that directs spilled water to a drain channel leading to a garden, natural drainage, or soak pit.
- Comfortable place to stand while pumping – especially for children.
- Pump spout is high enough to fit water buckets and jerry cans.
- Placed so that rain runoff does not collect around the pad or undermine it.
- Fenced so that animals cannot gather close to it.

The shape of the pump pad – round, square, or rectangle – is not important as long as the pad has the above features.

3. Pad Construction Steps - 30 minutes

Because it takes time and skill to make a good concrete pad, some well drilling organizations hire an experienced local mason for this step of well construction. This frees the drill crew to proceed to another site. But local masons are not always available, so it is useful for a drill crew to be skilled at pad construction.

A variety of ways have been developed to make a good pump pad, but they all have these steps in common:

1. Cut off the PVC well casing so it will be about 20 cm (8”) above the top of the finished concrete pad.
2. Center the pump base over the well casing and brace it so that the pump stays vertical while the concrete pad is being poured. (Make sure the pump spout will be high enough above the top of the concrete so that a bucket or jerry can will fit under it.)
3. Build a form around the pump that will contain the concrete while it sets.
4. Lay steel reinforcing bar or wire mesh in the form and wire the legs of the pump base to the rebar or wire mesh to keep it stable. Place small rocks under the rebar or wire mesh to raise it about 7 cm (3”) above the soil so the reinforcing will be in the center of the concrete.
5. Mix and pour the concrete, then level it with a board, smooth it with a float, and then finish it with a trowel.
6. Place barriers around the pad and pump so that it cannot be disturbed until the concrete has sufficiently hardened (about a week). Cover the top of the pump base so children can’t drop rocks down it.
7. Install the pump cylinder and riser main and attach the pump head and handle after the concrete has hardened.

Concrete Terminology

In this lesson, many words are used which are unique to concrete work. Different words may be used in the area where you work, but the concepts will be the same. Concrete is a common material throughout the world and it is likely that in this class there are experts at working in concrete. So it is worthwhile to take some time to go over the words used in this lesson and match them to their local meanings.

Form - a frame that holds concrete in the shape that is desired for the finished product.

Screed – a board, normally a little longer than the width of the form, used to level the wet concrete even with the top of the form (also used to mean the process of leveling the concrete).

Float – a small smooth board with a handle that is used to agitate the wet concrete to sink rocks below the surface, eliminate air pockets, bring water up to the surface, and to smooth the concrete (also used to mean the act of "floating the concrete").

Finish – the final stage of adding a surface texture to the concrete. Concrete is most often given a smooth surface using a steel finishing trowel. But it can also be given a rough non-slip surface by brushing it with a broom. Finishing is done in several stages as the concrete begins to set up.

Edge – because the cured concrete will have a sharp edge that can cut bare feet, or crack off, an edging tool is used to make a shallow groove between the concrete and the form. An edging trowel has one edge that curves down to accomplish this.

Stages of concrete curing. Concrete does not "dry"- instead, it gains strength through a chemical reaction called "curing" that starts as soon as water is added. The following stages of curing are useful to understand when working with concrete:

Wet – very soft and easily poured or shaped (less than an hour after adding water).

Set – also called "green" concrete meaning that it is still slightly soft but will hold its shape when the form is removed (several hours old).

Hardened – can be walked on, but has not reached full strength (about a week old).

Cured – the concrete has reached at least 80% of full strength (at least a month old).



Lesson 4.8 Building a Pump Pad – Part 2

Purpose

To examine standards and practices for pump pad construction.

Objectives

By the end of this lesson, participants will have

- Compared alternative pad construction methods
- Reviewed the principles of concrete mixing

Materials

- Wood or brick for demo pad form (optional)

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. Concrete Forms
2. Making Good Concrete

4. Concrete Forms- 40 minutes

The main difference between pad construction methods lies in the materials used to make the concrete form. The form defines the shape and thickness of the pad. Wet concrete is very heavy and will exert strong pressure against the sides of the form, so the form must be sturdy. A poorly-made form will result in a bad pump pad.

The three most common form materials are wood, steel, and brick. The choice of which material to use depends on cost, availability, and local preference. Concrete forms made with wood or steel can be re-used. Brick forms become a permanent part of the pad.

➢ How are pump pads typically constructed in your area?

_____

_____

_____

Wood Form

Making a concrete form out of wood boards is very easy. If the forms are cared for, and cleaned after each use, they can be re-used many times. The face of the boards should be smooth, not rough-cut, so the concrete won't stick to them. They should be at least 4 cm (1.5") thick and not have any splits or knot holes. The boards should be 15 cm (6") wide in order to get a slab of the desired thickness. To make a 2 m square pad, two of the boards should be 2 m (6') long and two should be slightly longer, as shown in Figure 72.

When constructing a pump pad with a wood form, it is easier to first pour the pad around the pump, remove the form after the concrete has set, and then use the same boards to form a drain channel. If a curb is to be added, a second set of boards is used to form the curb after the pad concrete has set. Alternately, a curb can be made by laying bricks around the edge of the pad and then covering them with concrete.

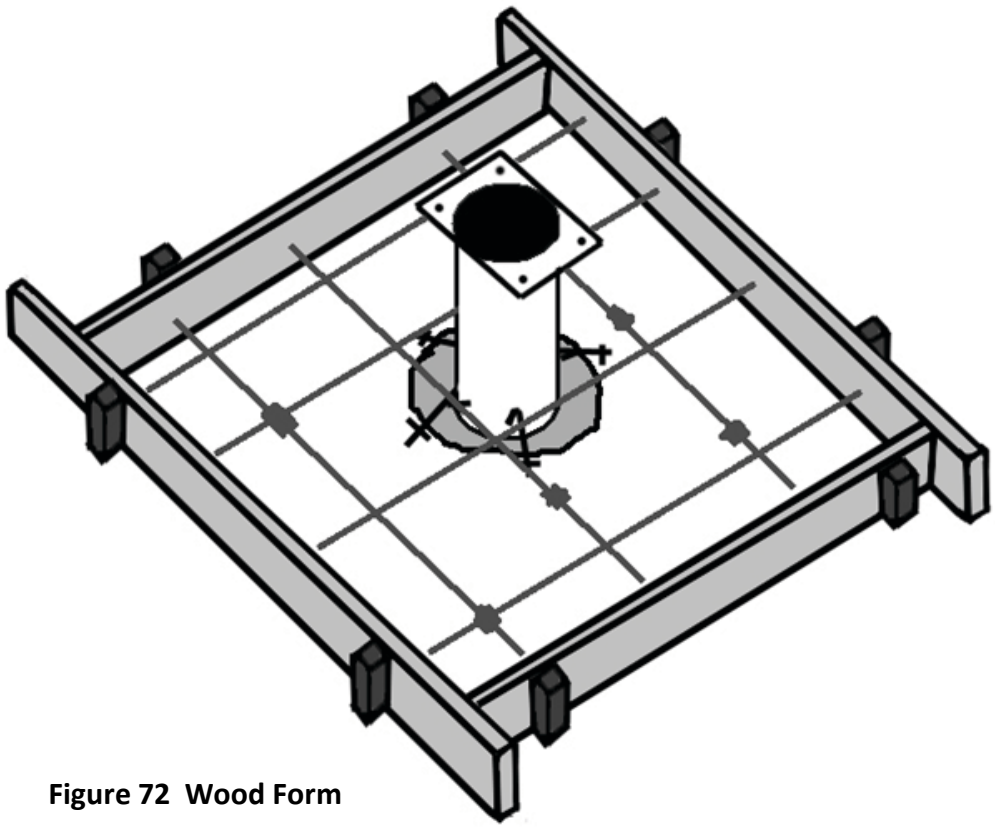


Figure 72 Wood Form

Brick Form

If bricks or cement blocks are readily available in the area, they can be used to make a form for the pump pad. Lay the bricks in a circle with a radius of 1 m (3') centered on the pump base, as shown in Figure 73. (Use a stick tied to a string to mark a good circle.)

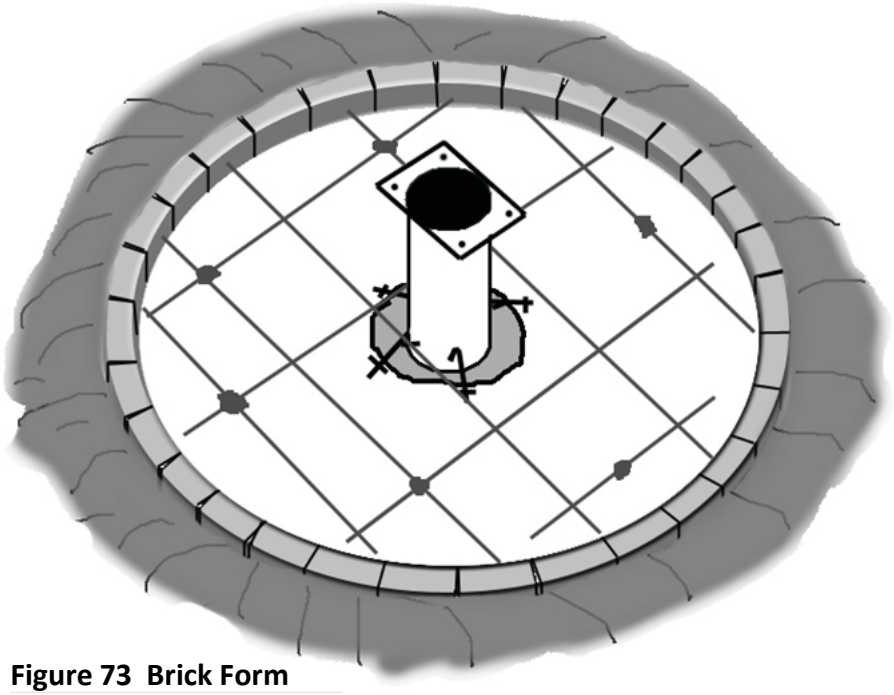


Figure 73 Brick Form

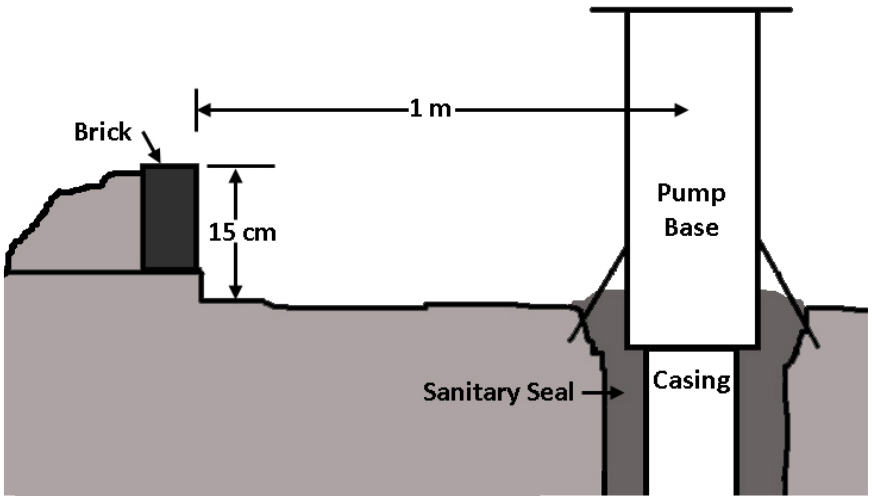


Figure 74 Brick Form Cross-Section

If the bricks are less than 15 cm (6") high, then it will be necessary to dig the pad area to get a thick enough pad, as shown on Figure 74.

The base for the bricks must be level and smooth or it will be difficult to get the pad level. Bricks will not be heavy enough to hold back the wet concrete, so dirt must be piled up against the bricks to hold them in place. An alternative to piling dirt is to tie a strong rope around the circle of bricks.

Lay the rebar or wire mesh (raised with rocks to put it in the center of the concrete), mix and pour the concrete, level and float it, then finish the concrete surface. After the concrete has started to set, remove the dirt or rope from around the bricks. To make a curb, lay a second course of bricks around the edge on top of the green concrete, and then cover these bricks with a thin layer of concrete. Use the same procedure to form a drain channel.

Steel Form

The most efficient way to make a pump pad is with a steel form. These are more expensive than wood or brick and may not be available everywhere. But they will last for many years (if cleaned after each use) and can form the pad, curb, and drain line in a single pour. Procedures for assembling and using a steel form will vary depending on the form design. The form shown in Figure 75 is just one example (the sections of this form have not been connected yet).

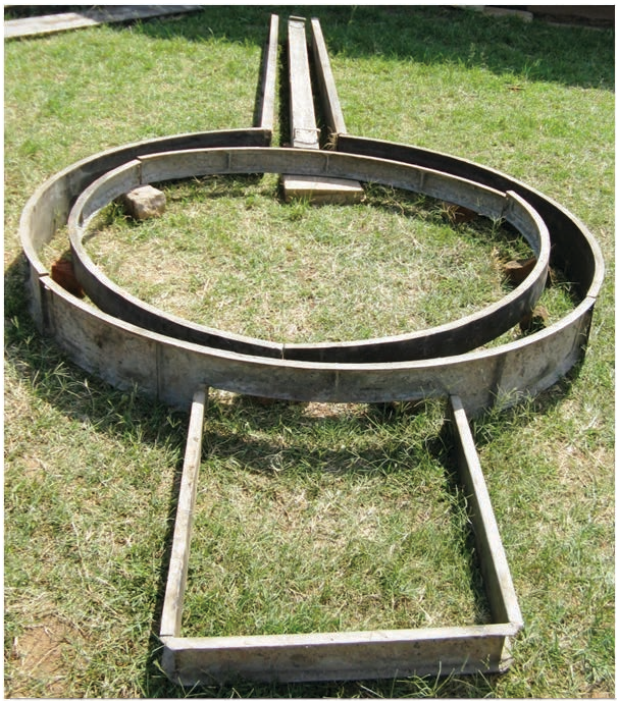




Figure 75 Steel Form and Resulting Pad

With any of the different concrete forms, the soil around the borehole should be compacted so it does not settle and caused the pad to be undermined. If the soil is sandy and can't be compacted, then it may be necessary to make the outer edge of the pad thicker. Figure 76 shows how to do this.

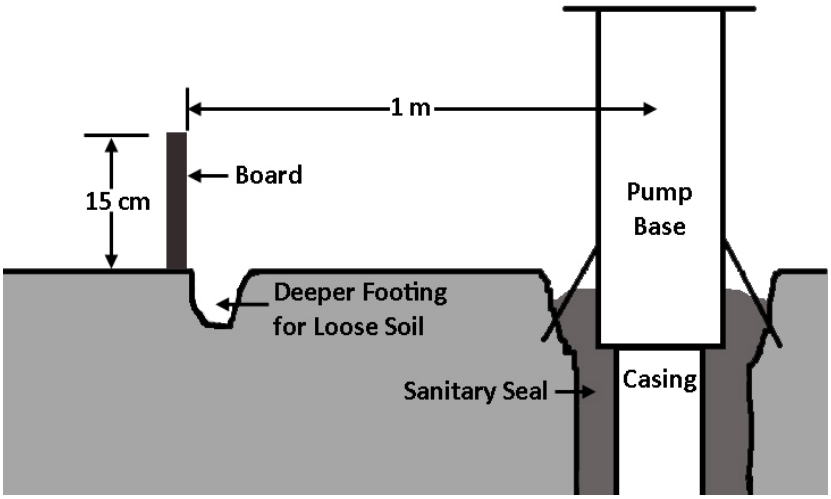


Figure 76 Footing for Loose Soil

5. Making Good Concrete - 20 minutes

Concrete is made from cement, sand, gravel and water.

- To make strong concrete these ingredients should usually be mixed in a ratio of 1:2:4:0.5 to achieve maximum strength. That is 1 part cement, 2 parts sand, 4 parts gravel, and 0.5 part water. (A "part" means a unit of measure. Technically, it should be based on weight but in practical use the unit of measure will be a volume such as a sack, a bucket, or a shovel full.)
- If not enough cement is used, then the result is called "sandcrete" and the pad will eventually fall apart. Sometimes, a different cement:sand:gravel ratio such as 1:2:3 is printed on a sack of cement as a guideline for making a concrete slab. It is best to use the ratio printed on the sack, but if none is given use 1:2:4. The 1:2:4 ratio assumes good quality cement is being used. More cement might be required if the quality is doubtful. (A ratio of 1:2:3 is recommended for a latrine slab because a higher strength is required.)

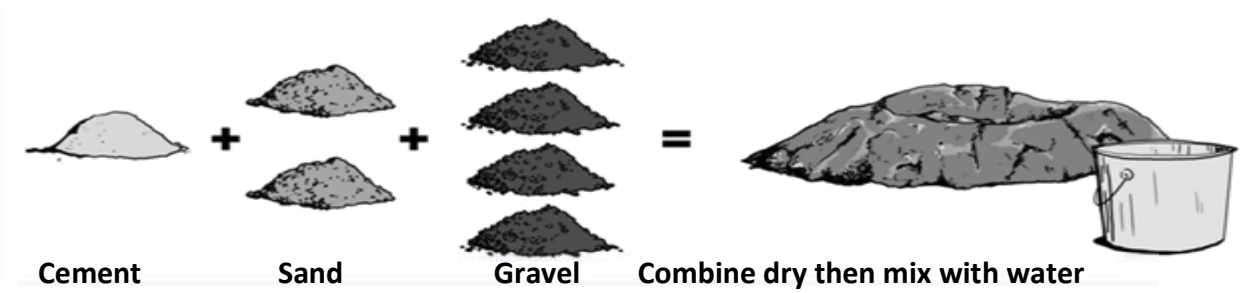


Figure 77 Making Good Concrete

- If there are several grades of cement available, always use the best grade. Cheap cement does not hold up to heavy use so a pump pad made with cheap cement will soon have to be replaced. So cheap cement will not save money in the long run.
- Cement must be stored in a dry place. If it is exposed to moisture it will begin to cure. Cement that has hard lumps in it has been exposed to water and should not be used.
- For best results, the sand and gravel should be angular, not rounded or smooth. The gravel should have a maximum diameter of about 2cm (3/4").
- It is very important to use clean sand and gravel. Even small amounts of silt, clay, or vegetation will weaken the concrete.
- The amount of water used to mix the ingredients is the most important factor in determining the final strength of the concrete. Use the least amount of water that will still give a workable mix. Too much water weakens the concrete and leads to cracking. The 1:0.5 cement:water ratio noted above is merely a guide for estimating.
- First mix the cement, sand, and gravel then slowly add water. It is best to sprinkle the water rather than pour it. The water must be clean and fresh, not salty.

For mixing a large volume of concrete, as will be needed for a pump pad, a cement trough is a very useful tool. The trough shown in Figure 78 is approximately 1.2 m wide by 2 m long (4' x 6') and 30 cm (12") deep. Clean the trough after each use before the concrete sets, or it will become difficult to use and heavy to move.

It is best to mix in a single batch the full volume of concrete that will needed. However, this may not always be possible so the batches should be mixed as closely together as possible and then finished together.



Figure 78 Cement Trough



Figure 79 Cracked Pump Base

It takes time for concrete to cure. After a week concrete has gained most of its strength but it takes about a month to cure to full strength. Therefore, it is very important to let the concrete harden for at least a week before doing anything that will bump or move the pump base. If work is done on the pump before the concrete hardens, then the bond between the concrete and the metal will be weakened. This might not show up right away, but after time the base can begin to separate from the concrete, as shown in Figure 79. This is a serious problem because it allows contaminated surface water to seep directly into the well.

When installing or repairing a hand pump, NEVER leave a well casing open and unattended! Children, and even some adults, may drop rocks down it to hear the interesting sound the rocks make as they fall. In this way the well casing can be quickly filled with rocks which will destroy the well. Therefore, whenever the well is left unattended before the pump installation has been finished, secure the opening in the pump base. Bolting a plate where the pump head will be attached is an effective method. (See lesson 6.4 Fishing and Appendix 9 for a tool to remove rocks from a well casing.)

Lesson 4.9 Building a Pump Pad – Part 3

Purpose

To examine standards and practices for pump pad construction.

Objectives

By the end of this lesson, participants will have

- Practiced calculating the volume of a pump pad
- Practiced calculating the volume of concrete components and final mix
- Practiced making a concrete pad (optional)

Materials

- Boards and stakes to form small concrete pads (optional demo)
- Cement, sand, gravel, water (optional demo)
- Concrete mixing and finishing tools (optional demo)

Preparation

- Study lesson ahead of time

Time

60+ minutes

Steps

1. Calculating Concrete Volume
2. Calculating Concrete Components
3. Finishing Concrete
4. Concrete Practice (optional)

1. Calculating Concrete Volume- 20 minutes

Figuring out how much concrete will be needed for a pump pad requires good measurements, a little math, and experience. It is not unusual for concrete quantity calculations to result in too much or too little concrete being mixed. It is better to have a little concrete left over than to have to mix additional concrete to finish the job. Even when making the same sized pad each time, there will be variations in the amount of concrete needed. For example, Figure 76 shows a cross-section of a 15 cm (6") thick circular pad with a radius that extends 1 m (3') from the pump base. But the area around the pump base is lower and there is a footing dug around the edge of the pad. The volume of these areas can be difficult to calculate, so it may be necessary to estimate how much addition concrete will be needed above the calculated amount. A common practice is to mix 5% more concrete than calculated from the measurements of the pad.

Circular Pad Volume

The volume of a circular pump pad is calculated using the formula for a cylinder, $V=\pi R^2 H$ where V is volume, π is 3.14, R is the radius (distance from the center to the edge), and H is the height or thickness of the pad. For a pad with a radius of 1 m (about 3') and a thickness of 15 cm (0.15 m or 6") the formula would be:

$V=\pi R^2 H$

$V=3.14 \times 1^2 \times 0.15 = 0.47\ m^3$

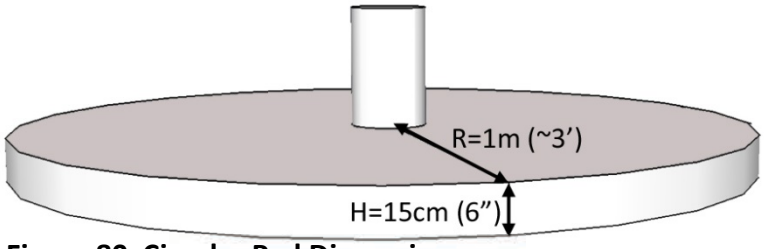


Figure 80 Circular Pad Dimensions

Adding 5% to 0.47 cubic meters ((0.47 x 0.05)+0.47) and rounding off gives a concrete volume of 0.5 m^3 (18 cubic feet). A cubic meter is 1,000 liters so this pump pad volume is 500 liters.

Square Pad Volume

The volume of a square pump pad is calculated using the formula for a cube, V=LWH where V is volume, L is the length, W is the width and H is the height or thickness of the pad. For a pad with a length and width of 2 m (about 6') and a thickness of 15 cm (0.15 m or 6") the formula would be:

$V=LWH$

$V=2 \times 2 \times 0.15 = 0.6\ m^3$

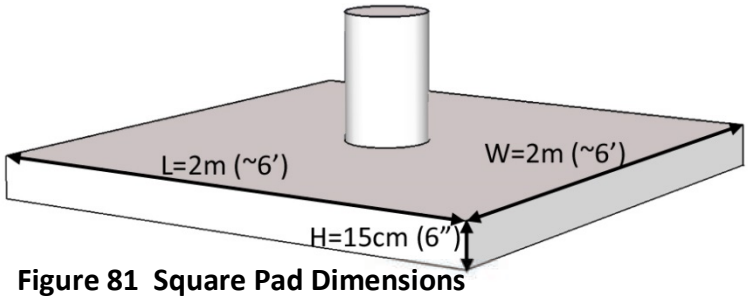


Figure 81 Square Pad Dimensions

Adding 5% to 0.6 cubic meters ((0.6 x 0.05)+0.6) and rounding off gives a concrete volume of 0.65 m^3 (23 ft^3), or 650 liters.

In these examples, there is no footing around the edge of the pad. If the pad has one, then its volume would be calculated by multiplying the length, width and depth and adding that result to the pad volume. The volume of the drainage channel also needs to be calculated and added to the pad volume. Assuming the channel is 2m long by 0.3m wide and 0.15m thick (6' x 1' x 0.5') gives a volume of 0.09 m^3. Adding 5% gives a drainage channel volume of 95 liters (3 ft^3).

2. Calculating Concrete Components- 30 minutes

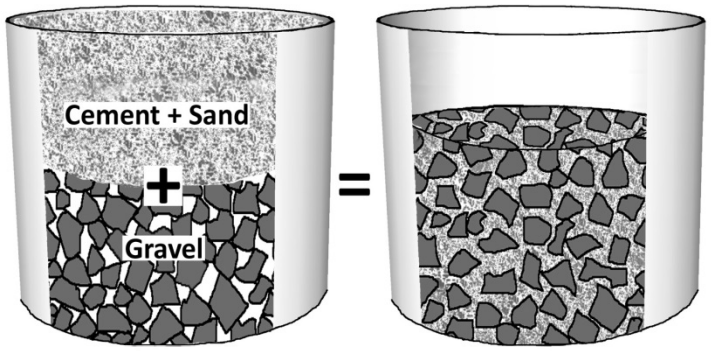


Figure 82 Volume Reduction

After the volume of concrete needed has been calculated, the next step is to determine how much cement, sand, gravel, and water is required to make up that volume. Because the small grains of sand and cement fill in the spaces between the gravel, the final volume of concrete is less than the sum of the individual parts. Although 1 part cement plus 2 parts sand plus 3 parts gravel plus 0.5 part water adds up to 6.5 parts, the actual volume when the ingredients are mixed together will be about **2/3** of that sum. (http://www.cement.org/tech/faq_cement.asp). This is illustrated in Figure 82.

To show how this works out in practice, start with a 50 kg (110 pound) sack of cement as the unit of measure or "1 part." This size sack, which is the standard sold in most countries, has a volume of around 33 liters (1.2 ft^3). If the cement sack has a different weight, obtain its volume by multiplying the weight of the sack in kilograms by 1.51 kg/liter (or weight in pounds by 94 lb/ft^3), which is the density of cement powder. [In the US, a standard sack of cement weighs 94 pounds (43 kg) so it has a volume of 1 cubic foot (28 liters)].

Mixing one 33 liter (50 kg) sack of cement with 2 sacks of sand , 3 sacks of gravel and 1/2 sack or 16.5 liters of water gives 6.5 sacks. If each sack has a volume of 33 liters, then 6.5 sacks times 33 liters equals 214.5 liters. Because the small grains fill the spaces between the gravel, the actual mixed volume will be 2/3 of this. So 2/3 times 214.5 liters equals 143 liters. We will call this volume a "batch" of mixed concrete.

If you start with a different volume of cement as "1 part," or use a different ratio of components, then the size of the batch will be different, but the procedure for calculating the end volume of concrete will be the same; the sum of the parts in liters (or cubic feet) times 2/3.

The total concrete volume needed for the circular pad and drainage channel calculated above was 595 liters. Dividing 595 liters by the volume of one batch (143 liters) gives 4.2 batches of concrete. It is wise to mix more than is needed, so you would mix 4.5 batches of concrete for this pad and channel.

The concrete mix to make a curb for this pad would depend on how the curb was made. If the curb was made by coating bricks with cement, then use a "mortar mix" of 1:3 cement:sand. Otherwise, make up a standard cement mix after the form for the pad was removed.

The calculations in this lesson are based on volume. But cement, sand, and gravel are sometimes sold by weight (kilogram or pound) rather than by volume (liter or cubic foot). To find out what weight of each component to purchase, multiply the total volume of each component by its density (weight per unit volume). The following table gives the average densities of concrete components.

Table 3 Density of Concrete Components

Component	kg/liter	lb/ft^3
Cement	1.51	94
Dry Sand	2.56	160
Dry Gravel	1.52	95

The circular pad in the example above had a volume of 595 liters which requires 4.5 batches of concrete. The weight of the individual components may be calculated as follows:

Cement: 1 sack (33 liters) x 4.5 batches = 148.5 liters x 1.51 kg/liter = 224 kg
Sand: 2 sacks (2x33 liters) x 4.5 batches = 297.0 liters x 2.56 kg/liter = 760 kg
Gravel: 3 sacks (3x33 liters) x 4.5 batches = 445.5 liters x 1.52 kg/liter = 677 kg

Exercise:

Using the procedures described above, determine the total volume of concrete and the volume and weight of cement, sand, gravel, and water needed for a square pump pad with a drainage channel and curb. Show your calculations.

Pad:
- Length = 2.2 meters
- Width = 2.2 meters
- Thickness = 15cm

Channel:
- Length = 2.5 meters
- Width = 30cm
- Thickness = 15cm

Solid concrete curb around pad and channel:
- Length (sum of pad and channel sides) =_____cm
- Width = 8cm
- Thickness = 6cm

Total volume of concrete required = _____ m^3 x 1000 = _____liters

"Batches" of concrete (based on a 50 kg cement sack) = _____

Sacks (33 liters) of components needed to make the pad, channel and curb:
- Cement = _____ sacks = _____ kg
- Sand = _____ sacks = _____ kg
- Gravel = _____ sacks = _____ kg
- Water = _____ liters

3. Finishing Concrete - 10 minutes

The purpose of finishing is to remove air bubbles from the concrete which will weaken it, to push gravel down, to bring water up to aid in curing, and to give the surface an attractive appearance. The sequence of finishing steps and the tools used in the process are described in section 3, above. These are screed, float, trowel, and edging. It is not difficult to understand the process when you see it done, but it takes practice to master. Finishing concrete is an art.

Once the concrete has been finished and has begun to set so that it can't easily be dented, the pad must be kept moist for several days in order for the concrete to become strong. Cover the pad with cloths or grass and frequently sprinkle it with water. It is also helpful to cover it with a sheet of plastic to keep the surface from drying out. Remember, concrete does not "dry" it "cures" and the presence of water is necessary for that curing reaction to take place. The pad should be kept covered like this for at least one week. After that, it can be walked on to install the pump.

4. Concrete Practice (optional) – 60+ minutes

Depending on the time available and the students' prior experience working with concrete, show the principles of concrete construction by making a small demonstration pad, or have each student team make their own small practice pad. If a working well is to be completed as a class exercise, then pour a proper pump pad at the appropriate stage of well construction.

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Lesson 4.10 Well Closure

Purpose

Examine the reasons for closing a well and the proper way to do it.

Objectives

By the end of this lesson, participants will have

- Considered ways an unused well can be a problem and examine methods to properly close a well

Materials

- Flip chart and markers

Preparation

- Study lesson ahead of time

Time

30 minutes

Steps

1. Ways to Properly Close a Well.
2. The Risks of an Improperly Abandoned Well.

1. Ways to Properly Close a Well - 15 minutes

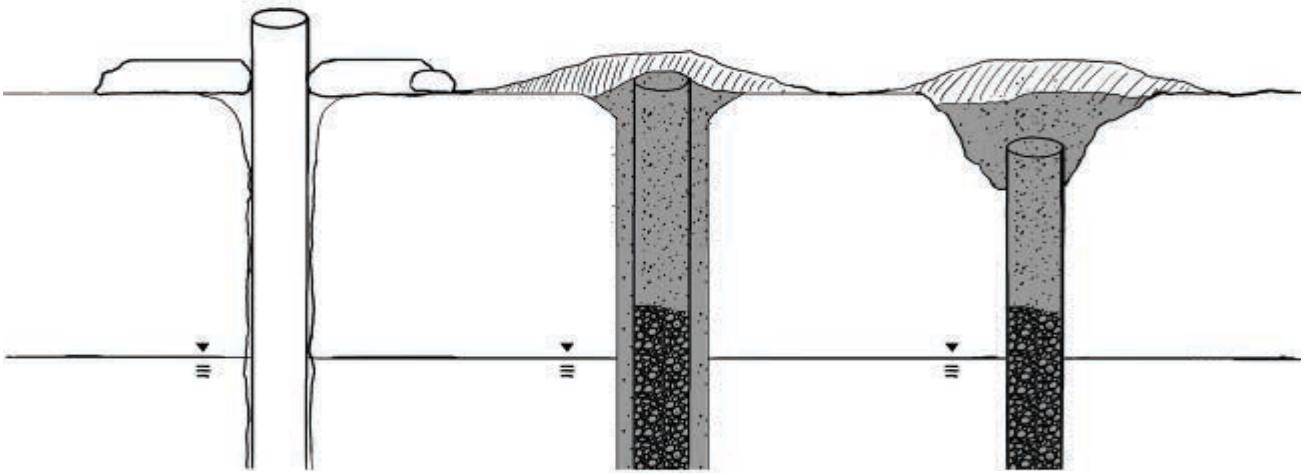
There are several circumstances when it may be necessary to permanently close a borehole or a well. If the borehole can't produce water, or if it is an older well that has run dry or has become obstructed and can't be put back into productive service, then it must be properly closed. Sometimes the term "abandoned" is used, but this implies just walking away from it which must not be done!

In your teams, study these well closure methods and be prepared to discuss them with the rest of the class.

1. If it is a new borehole with only a casing and gravel pack then it might be possible to pull out some or all of the casing to use again.
2. If it is a completed well with a pump pad, break it up and remove the concrete.
3. If there is a good sanitary seal around the casing, then cut off the casing at the top of the sanitary seal. Fill the casing with clean sand or rock to within about 2 meters from the top. Fill the remainder of the casing with cement. Backfill any low spots with soil.
4. If there is no sanitary seal around the casing, then dig a hole around the casing about 1 meter deep and about a half meter in diameter. Cut off the casing above the bottom of the hole. Fill the casing with clean sand or rock to within about 2 meters from the top.

Fill the remainder of the casing and two-thirds of the hole with cement. After the cement sets, backfill the hole with soil.

5. If there is a well construction report available for this well, then add to it a note providing the date and reason the well was abandoned and the procedure used to seal it.



Improperly Closed
No sanitary seal

Properly Closed
With sanitary seal

Properly Closed
No sanitary seal

Figure 83 Well Closure Examples

2. The Risks of an Improperly Abandoned Well - 15 minutes

In your teams, **discuss** and make a **list** of the problems that could be caused by a well that is left open.

One bad well can ruin others

"See to it that no one comes short of the grace of God; that no root of bitterness springing up causes trouble, and by it many be defiled." Hebrews 12:15

- What is the most important thing to do when closing a well?

- We have been discussing boreholes. How might you close a hand-dug well?

Lesson 5.1 Operational Principles of Hand Pumps

Purpose

To introduce the fundamentals of hand pump cylinder operation, including common wear points, and to standardize the names of cylinder parts.

Objectives

By the end of this lesson, participants will have

- Developed a working vocabulary for pump repair
- Understood the contribution of each part of a hand pump
- Considered ways in which a pump cylinder may fail

Materials

- Buckets of Water
- Clear plastic Mark II cylinder for demo (if available)
- One functional Mark II cylinder for each team
- Posters: Cylinder Operation and Cylinder Parts
- Markers

Preparation

- Fill buckets with water
- Ensure cylinders are assembled and work properly

Time

60 minutes

Steps

1. Cylinder Operation
2. Identify the Parts
3. Experiment with the Cylinders
4. Identify Failure Points

1. Cylinder Operation - 10 minutes

All hand pumps have a "pump cylinder" that is operated by a handle to lift water to the surface. The most common type of pump cylinder is illustrated here.

Study these drawings to see how a cylinder functions. Then observe the facilitator using a hand pump cylinder.

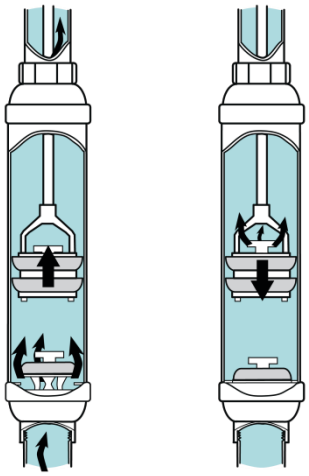


Figure 84 Cylinder Operation

2. Identify the Parts - 10 minutes

Draw a line connecting the name to the component. Quiz your partner on the names of the cylinder parts.

Riser Main

Pump (Connecting) Rod

Upper Cap

Cylinder Barrel

Piston (Plunger) Assembly

Piston (Traveling) Valve

Piston Seals

Foot Valve

Lower Cap

Tail Pipe

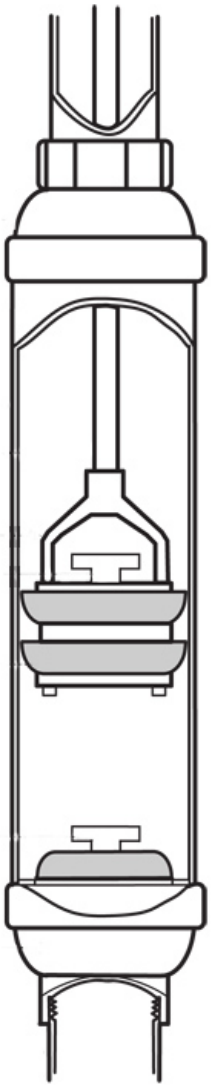


Figure 85 Cylinder Parts

3. Experiment with the Cylinders - 20 minutes

Get into groups of two or three and each of you take apart your pump cylinder by unscrewing the end caps and removing the plunger. Locate and identify each part. Experiment with it to see how it works. After you put it back together, try pumping water from the bucket.

4. **Identify Failure Points -** 10 minutes

With heavy use, even good pumps can break as often as every six months. Considering what you have just learned about the parts of a pump cylinder, let's try to identify what can go wrong with a hand pump.

Which parts of a cylinder do you think are most likely to require repair or replacement? Why and how do you think that part is likely to fail?

Using the spaces below, write a brief description of all the possible cylinder failures you can think of and then draw a line to the affected cylinder part:

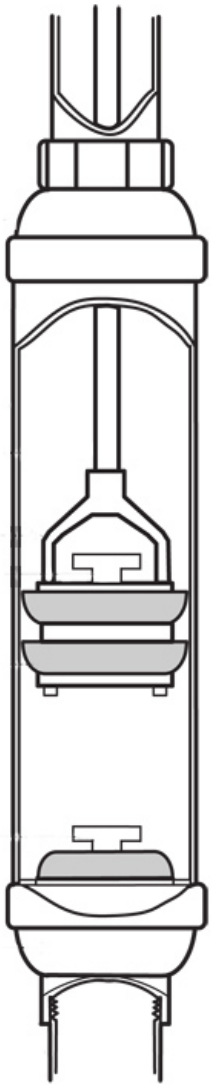


Figure 86 Cylinder Failure

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Lesson 5.2 Common Pump Types

Purpose

To identify the different families of hand pumps and introduce the principles of VLOM, Preventative Maintenance, and Standardization.

Objectives

By the end of this lesson, participants will have

- Classified pump types and identified the principle differences between them
- Examined diagrams of common pump models
- Discussed the concepts of VLOM, Preventative Maintenance, and Standardization

Materials

- Poster of deep well pumps
- Flipchart and markers

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. Hand Pump Families
2. Introduction to VLOM Pumps
3. Preventative Maintenance
4. Standardization

1. Hand Pump Families - 30 minutes

"Public Domain" hand pumps can be categorized into three main families, or types: **Suction**, **Direct Action**, and **Deep Well** pumps.

The following summaries are just a sampling of the most common designs of pumps that can be manufactured and sold by anyone. There are many other proprietary models licensed only to one company. Some of these are similar to the ones described here and others are quite different. Whenever an unfamiliar pump is found, do not attempt to work on it without a specific installation and maintenance manual.

Refer to Appendix 7 for a chart of recommended operation depths for different models of hand pump.

Suction Pumps

Suction pumps are the most simple. These pumps consist of an above-ground "cylinder" in which water is literally sucked up by the motion of the piston seals into the pump head and out the spout.

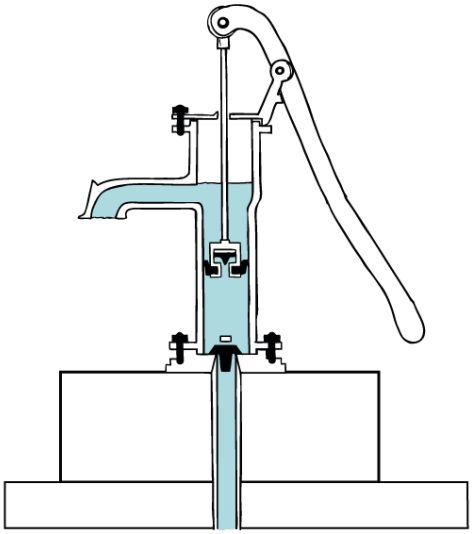


Figure 87 Suction Pump

Construction and Maintenance

Suction pumps are typically made of cast metal and most of the parts last a long time. The parts that wear out are easily accessible for replacement.

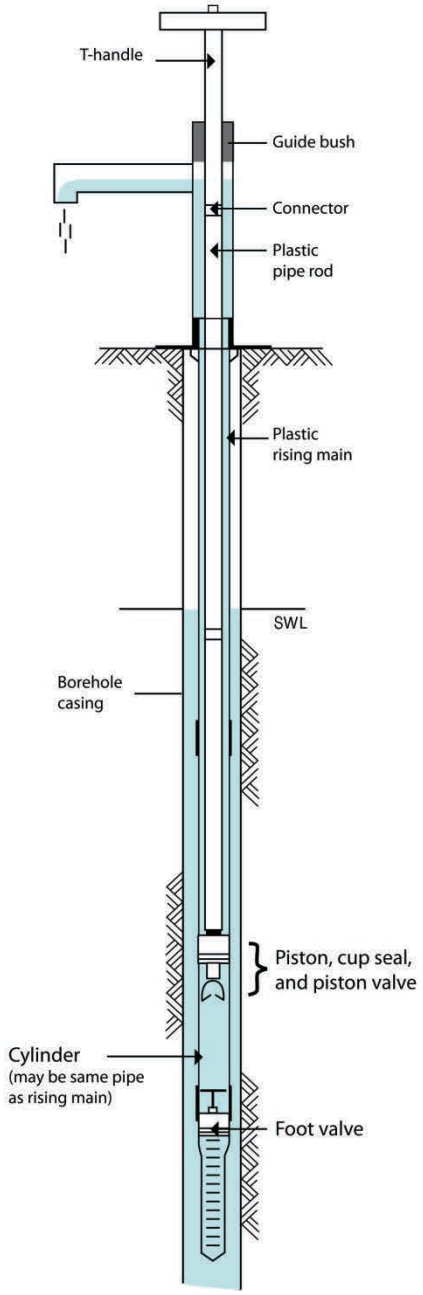


Figure 88 Direct Action Pump

Suction pumps have a maximum lift of 7-8 meters.

➢ What limits this lift?

Direct Action Pumps

Direct Action pumps have a below-ground cylinder and are usually operated by a 'T'-bar handle. Some Direct Action pumps bring water to the surface on the up-stroke AND the down-stroke! The major pumping action takes place when the T is pushed down. When this happens, the extension of the T-bar, an empty and capped PVC pipe, is pushed into the water in the riser main. The volume of this PVC pipe displaces water, and because the foot valve is closed, the water is "pushed" up the riser main. When the T-bar is released, the buoyancy of the empty PVC helps lift the T-bar back up.

The Direct Action pump has a maximum lift of 15–25 meters.

➢ What do you think limits this lift?

Construction and Maintenance

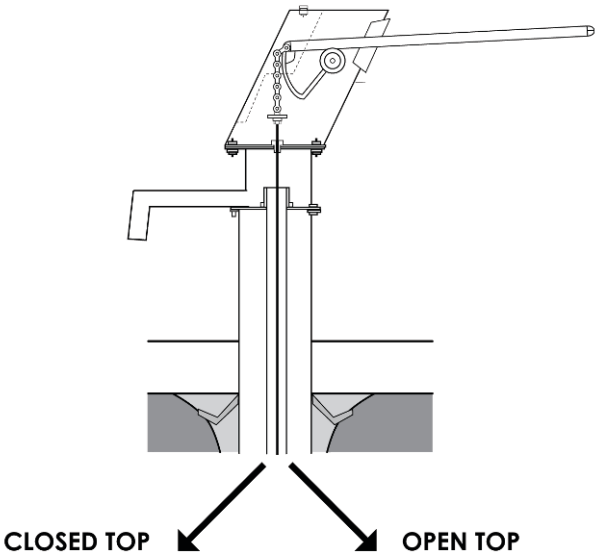
Direct Action pumps are typically made of PVC and some designs can be built from off-the-shelf PVC components with a minimum of fabrication. With such simple construction, these pumps are usually easy to repair.

Deep Well Pumps

Deep Well pumps have a cylinder that works like a suction pump, but the cylinder is placed below-ground beneath the water table. They are equipped with a handle that provides mechanical assistance to lift the water. The Deep Well pump has a metal pump rod attached to the traveling valve instead of PVC pipe pushing water up, like the Direct Action pump.

With special adaptations, some Deep Well pumps can lift water from as deep as 80 meters below ground.

- What is limiting the lifting height?



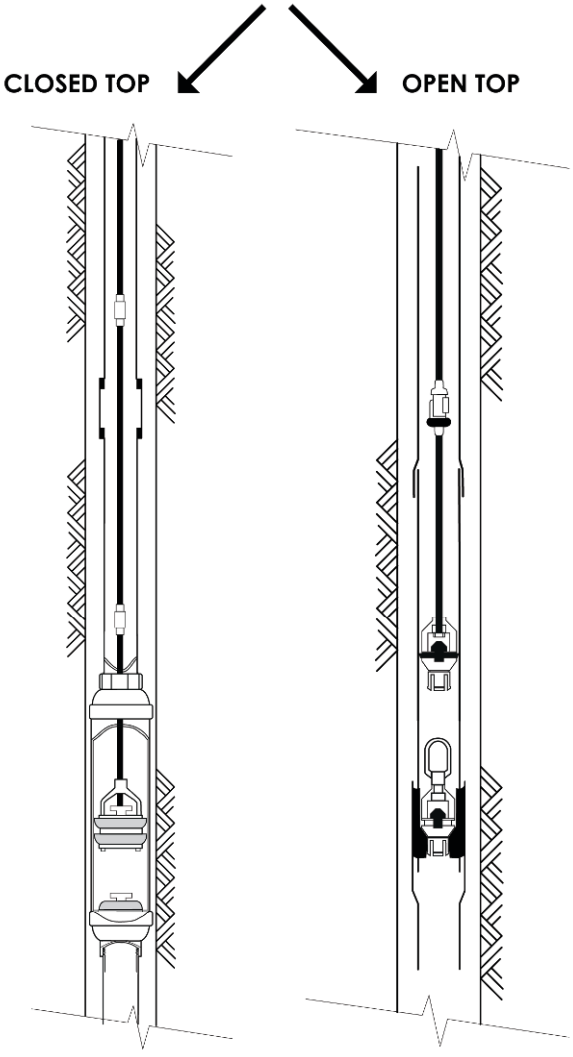


Figure 89 Deep Well Pumps

Construction and Maintenance

Deep Well pumps come in a variety of designs. Some may only be manufactured by one company, while others are "public domain" and are made by many companies. The India Mark II and Afridev pumps are common public domain pumps. Most Deep Well pumps have cast or machined steel parts. This heavy-duty construction is necessary because of the wear caused by constantly lifting heavy columns of water.

The most important difference between types of Deep Well pump is how the pump piston and foot valve are serviced. On "closed-top" pumps, which were developed first, the entire riser main and cylinder must be removed. The India Mark II is a common example of a closed-top pump.

With an "open-top" pump, the cylinder is the same diameter as the riser main so only the pump rods need to be pulled out to service the piston and foot valve. Open-top pumps were designed for Village Level Operation and Maintenance, or VLOM. The Afridev is a common example of an open-top pump. The India Mark **III** is also an open-top pump.

2. Introduction to VLOM Pumps - 10 minutes

VLOM stands for Village Level Operation and Maintenance, and is used to describe a hand pump that:

- can be operated by a small child;
- can be installed and repaired by a team of two or three persons;
- is durable against corrosive groundwater; and
- can have its quickly worn parts easily purchased and replaced.

Why are VLOM pumps needed? Many hand pump projects have failed because of:

1. The absence of a sustainable system of hand pump maintenance and repair;
2. The installation of pumps which were not suitable for the heavy usage they received;
3. The use of pump components which were damaged by corrosive groundwater; and
4. A lack of community involvement in important aspects of the project planning.

The careful choice of a VLOM hand pump can help solve the first three of these problems, but unless the community is involved from the beginning in all elements of the water project – planning, design, construction, and maintenance – it is unlikely that the hand pump will be sustainable.

The Afridev (lesson 5.3) is one of the most common VLOM hand pumps. The India Mark II pump (lesson 5.4) is not a VLOM pump, but the Mark III is.

3. Preventative Maintenance - 10 minutes

Preventative maintenance, as opposed to corrective maintenance, is the routine work done on a pump and its surrounding area to ensure that major breakages or contaminations do not occur. The capacity of the village to do routine maintenance on their pump will often determine the success of the water projects for that village. Below is an outline of a preventative maintenance schedule. When training village maintenance crews, it is critical to include a schedule of tasks aimed at preventing major pump problems:

Weekly:
Lubricate moving parts.
Check and tighten nuts and bolts.
Make sure the pump is firmly set in the base.

Monthly:
Check pump flow (discharge) rate.
Check and repair condition of concrete base and apron.

4. Standardization - 10 minutes

"Standardization" refers to the government deciding to limit hand pump choices to a few models. The idea is that if only a few hand pump types are used in the country, then it is easier for hand pump repair technicians to learn how to repair them. Also, suppliers do not need to stock many different kinds of spare parts. It is hoped that this standardization would stimulate self-sufficiency and eventually create a stable market for spare parts and tools.

However, the results of standardization have not always turned out as hoped. The availability of spare parts continues to be a problem. Worse, standardization can lead to the creation of a monopoly (few distributors) which typically results in the price of a pump to be inflated.

Whether or not standardization has been adopted in a particular country, when selecting a pump it is important to make sure that there are trained repair technicians and a supply of spare parts.

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Lesson 5.3 The Afridev Hand Pump

Purpose

To introduce the components of and installation procedures for the Afridev hand pump.

Objectives

By the end of this lesson, participants will have

- Reviewed the parts and manner of operation of the Afridev pump
- Installed an Afridev pump in a new well

Materials

- Posters of Afridev pump head and cylinder
- Markers

Preparation

- Study lesson ahead of time
- Gather demonstration parts if an installed pump is not available

Time

45 minutes

Steps

1. Afridev Parts
2. Afridev Installation
3. Afridev Pump Rod Adjustment

1. Afridev Parts - 5 minutes

Study this drawing of an Afridev pump head and label these parts:

Cover
Handle
Handle bearing
Pump rod
Rod hanger
Riser main.

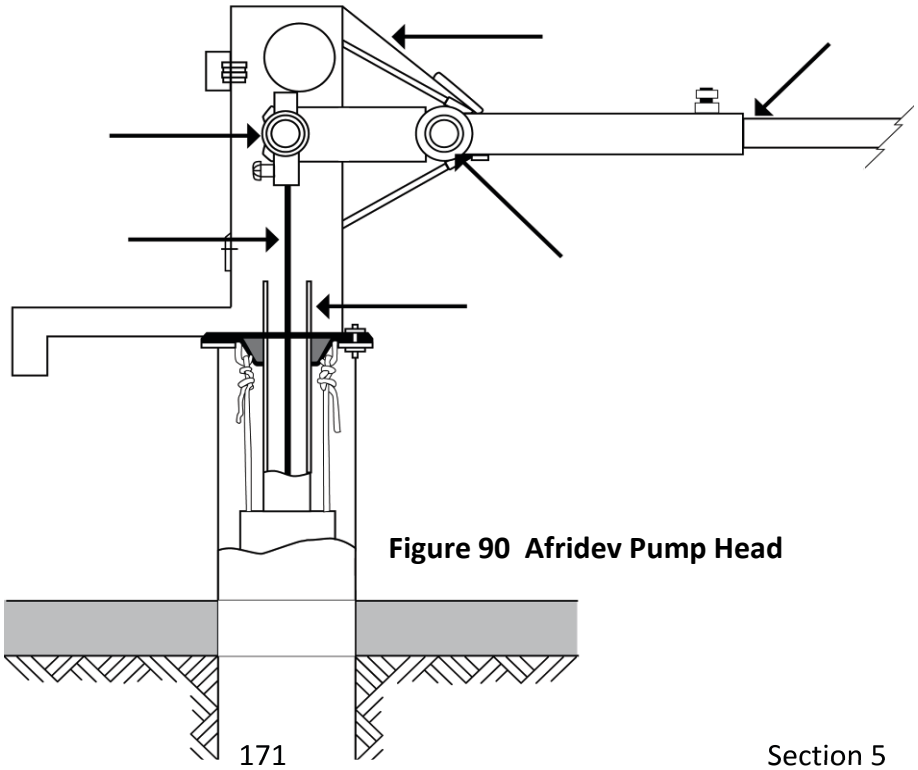


Figure 90 Afridev Pump Head

Study this drawing of the Afridev pump cylinder. Draw lines from the part names to the correct spot on the drawing.

Riser Main

Pump Rod

Piston (Plunger)

Traveling Valve

Piston Seal

Cylinder Barrel

Foot Valve Retriever

Foot Valve

O-Ring

Suction Pipe

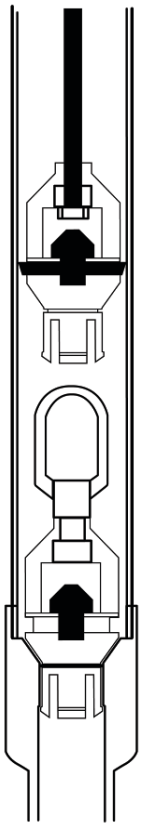


Figure 91 Afridev Cylinder

The "Deep Well" Afridev

The standard Afridev piston and foot valve are made of sturdy plastic. These parts are inter-changeable, which reduces the cost of manufacturing. The standard Afridev is designed for wells no deeper than 45 meters (150 feet). It has been found that in deeper installations the weight of the water causes the plastic to fail or the piston seals to fold over. So a "deep well" version has been developed that uses brass pistons and foot valves and larger piston seals (or two seals). On this design the bottom of the piston has threads that screw into the top of the foot valve, so the foot valve can be retrieved after the rod hanger has been removed from the handle. A separate foot valve retrieval tool is not needed. A deep well Afridev usually has an identifying tag on the pump base.

2. Afridev Installation - 5 minutes

The base of the Afridev pump should be set when the pump pad is constructed (lesson 4.7). After the concrete has hardened for a week, the pump cylinder, riser main, and pump head can be installed. The detailed procedures for installing an Afridev pump are found in the "Installation and Maintenance Manual for the Afridev Handpump" (Appendix 15).

The following are key points to remember when installing an **Afridev** pump:

- Attach a new, clean nylon safety rope through the bottom of the pump cylinder.
- Place a large rubber centralizer on at least every other section of riser main and thread the safety rope through the grooves on the centralizer.
- Thoroughly clean and dry each joint before applying solvent cement.
- When joining the riser main sections, allow the PVC solvent cement to dry for at least 5 minutes. Some brands of solvent cement may take longer to dry.
- Do not move or twist the joint while the solvent cement is drying.
- Tie the safety rope to the loops provided on the bottom of the riser attachment plate.
- Add a small rubber centralizer to each pump rod joint. This prevents the joints from rubbing on the riser main and cutting it.
- If using threaded pump rods, use a lock nut to secure each joint.

3. Afridev Pump Rod Adjustment - 15 minutes

The distance that the piston moves up and down in the pump cylinder is called the "pump stroke." The length of the pump stroke is determined by the distance that the front end of the pump handle travels with each stroke. The upper and lower limits are set by stops built into the pump housing.

The pump rod is connected to the handle, so the length of the pump rod determines the section of the pump cylinder in which the piston moves up and down.

If the rod is too short, the piston moves in the upper portion of the cylinder. The piston might travel above the cylinder where the seal is not as tight so that some water will get past the seal on each stroke. If the rod is too long, the piston moves in the lower portion of the cylinder. In this case the piston might hit the foot valve and damage it.

It is necessary to cut the top pump rod to the proper length so that the piston stays inside the pump cylinder and does not hit the foot valve. For this reason, Afridev pumps are usually supplied with one pump rod that does not have an "eye" coupling on one end.

On a new pump installation, the length of pump rod should be set so that the piston is operating in the lower section of the cylinder. This way, if the cylinder becomes worn the pump rod can be shortened so that the upper portion of the cylinder is being used.

To determine where to cut the pump rod:

1. Install the foot valve and piston and let the piston rest on the foot valve.
2. Grasp the pump rod even with the top of the riser main.
3. Without moving your finger from that spot, get some help to lift the rod so that you can place a permanent mark there.
4. Pull out the top section of rod and cut it at the mark with a hack saw.
5. Re-attach the pump rod to the rod hanger.

When the pump rod is attached to the rod hanger it will be lifted up several centimeters above the foot valve.

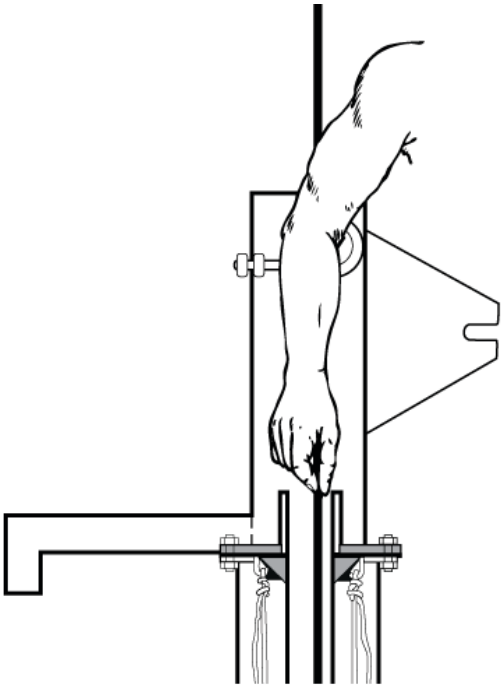


Figure 92 Afridev Adjustment

Lesson 5.4 The India Mark II and III Hand Pumps

Purpose

To introduce the components of and installation procedures for the Mark II hand pump.

Objectives

By the end of this lesson, participants will have

- Reviewed the parts and manner of operation of the Mark II pump
- Installed a Mark II pump in a new well

Materials

- Poster of Mark II head
- Mark II cylinders, at least one for each team

Preparation

- Study lesson ahead of time.
- Gather demonstration parts if an installed pump is not available

Time

60 minutes

Steps

1. India Mark II and Mark III Pump Head
2. Mark II versus Mark III
3. Mark II Installation
4. The Purpose of a "Lock Nut"

1. India Mark II and Mark III Pump Head - 5 minutes

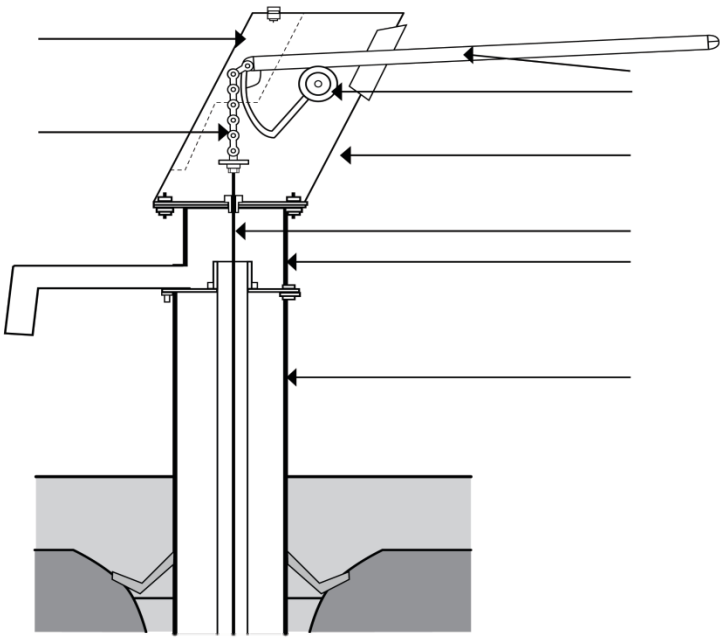


Figure 93 Mark II/III Pump Head

Study this drawing of an India Mark II/III pump head and **label** these parts:

Handle

Handle Axle

Cover

Chain

Top Head

Water Tank

Pump Rod

Pedestal

The parts of the India Mark II and Mark III cylinder were presented in lesson 5.1.

2. Mark II versus Mark III - 40 minutes

The India Mark II pump is one of the most widely used hand pumps around the world. But it is not suited for village level operation and maintenance (VLOM) because, being a closed-top cylinder, the riser main and cylinder have to be pulled out of the well to service the piston seals and other components that tend to wear out over time.

In response to this problem, the India Mark III pump was introduced. The Mark III pump is identical to the Mark II except, like an Afridev, the Mark III riser main is PVC and is the same diameter as the pump cylinder. Two different cylinder/riser main diameters are available; 50 mm (2") and 65 mm (2.5"). Of these, the 65 mm is more popular. [When first introduced, the Mark III came with 76 mm (3") steel riser main but it was much too heavy.]

Of the pump head parts, only the Mark III water tank is different from the Mark II, but they have the same bolt spacing. Therefore, it is easy to convert an existing Mark II pump into a VLOM Mark III pump by replacing the water tank and riser main. With a proper top cap some Mark II cylinders can also be converted to an open-top design (but the foot valve can't be easily removed).

The PVC riser main for both cylinders can be attached to the pump head with an adaptor plate and rubber ring nearly identical to that used on the Afridev pump. There is also a threaded coupling to which a galvanized steel riser main can be attached.

3. Mark II Installation - 40 minutes

The base of the Mark II (or Mark III) pump should be set when the pump pad is constructed (lesson 4.7). After the concrete has hardened for a week, the pump cylinder, riser main, and pump head can be installed. The detailed procedures for installing this pump are found in the "Mark II Hand Pump Installation and Maintenance Manual" (Appendix 15).

The following are key points to remember when installing a **Mark II** pump:

- Insert the pump rod into the riser main before connecting to the pump cylinder or another section of riser main.
- Always secure the pump rod with a "T" handle so it can't drop into the well. Secure the riser main with a pipe clamp whenever it is not being lowered or lifted.
- Always keep a coupling on the upper end of the riser main and the upper end of the pump rod in case they slip through the clamps. (Keep extras couplings in the tool box for this purpose.)
- Wrap steel riser main that is exposed to corrosive water with tape (lesson (6.3)

- Steel riser main can be safely handled with "C" lifting wrenches to a depth of 18 meters (60 feet) but much below that depth a tripod with block and tackle should be used to lower or raise the pipe.
- Use lock nuts (see below).

The following are key points to remember when installing a **Mark III** pump:

- Attach a new, clean nylon safety rope through the bottom of the pump cylinder.
- Place a large rubber centralizer on at least every other section of riser main and thread the safety rope through the grooves on the centralizer.
- Thoroughly clean and dry each joint before applying solvent cement.
- When joining the riser main sections, allow the PVC solvent cement to dry for at least 5 minutes. Some brands of solvent cement may take longer to dry.
- Do not move or twist the joint while the solvent cement is drying.
- Tie the safety rope to the loops provided on the bottom of the riser attachment plate.
- Add a small rubber centralizer to each pump rod joint. This prevents the joints from rubbing on the riser main and cutting it.
- If using threaded pump rods, use a lock nut to secure each joint.

4. The purpose of a "Lock Nut" - 10 minutes

Sometimes, after being shaken and jolted around, a nut will become loose and slowly unscrew itself from the threads of a bolt. That is why we often try to tighten nuts firmly, hoping that it will be harder for the threads to start unscrewing. However, there is a better way that you might already be very familiar with.

By placing another nut, called a "lock nut" or "jam nut" onto the bolt, and tightening it to the other nut, the nuts cannot become unscrewed from normal jolting and shaking, but are still easily unscrewed with the proper tools. Using a lock nut ensures that the bolts will not unscrew themselves.

Always place a lock nut in the following **3** places:

1. On the threads of the piston rod, where it meets the pump rod.
2. On the threads of two connecting pump rods.
3. On the top pump rod, where it meets the chain assembly.

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Lesson 5.5 Well Disinfection

Purpose

To learn how to properly calculate the amount of chlorine needed to effectively disinfect a well after installing the pump.

Objectives

By the end of this lesson, participants will have

- Learned how to determine the proper amount of chlorine to use to disinfect a well

Materials

- Poster of Disinfection Table
- Bottle of locally-obtained chlorine bleach

Preparation

- Review the calculations for yourself

Time

60 minutes

Steps

1. Why Disinfect?
2. How Much is Enough?
3. Practice

1. Why Disinfect? - 10 minutes

It is likely that the dirt around a pump pad contains ground-up feces which harbor dormant, disease-causing bacteria. These can remain alive for a long time and can cause diseases after they get into a well. For this reason, always place the pump rods, riser mains, and pump cylinder on blocks of wood so that they do not touch the ground. But even with this precaution, installing a hand pump can introduce contaminants into the well. So it is necessary to always disinfect the well by adding chlorine to it.

The three most important things to remember for well disinfection are:

1. The amount of chlorine required depends on the volume of water in the well and the concentration of the chlorine source. Water volume is calculated from well depth, water level and borehole diameter (well casing plus gravel pack). The concentration recommended for “shock chlorination” is 250 milligrams per liter.

2. The chlorine should be mixed thoroughly in the well casing, pumped until you smell chlorine in the outflow, and then left in the well casing and inside the pump overnight.

3. The chlorine **must** be completely pumped out before people drink from the well.

2. How Much is Enough? - 25 minutes

The question, "How much chlorine to use?" must be answered using some mathematics, but the calculations can be simplified. This lesson presents a table that provides a "disinfection Rate" for use with a borehole. (The formulas by which those numbers were calculated are described in Appendix 8.)

To determine how much chlorine to add to a well, it is necessary to know three things:

- Diameter of the well casing (see note below for hand-dug wells).
- Depth of water in meters (to convert feet to meters, divide feet by 3.28).
- Concentration of chlorine in your source (either 3.5%, 5% or 70%).

Four easy steps:

1. Determine the depth of water in the well. Measure the well depth and then subtract the distance from the surface to the water level. [The Well Disinfection Table is based on meters, so to convert feet to meters, divide feet by 3.28.]
2. Find the row in the Well Disinfection Table that describes the source of chlorine that you have. Most liquid bleach sold in the market for cleaning or for washing clothes is 3.5% chlorine. The label on the bottle usually gives the concentration. Chlorine powder is normally 70% chlorine.
3. On the row in the table for your chlorine source (either row 1, 2, or 3), read to the right until you come to the column that represents the diameter of your casing. The number in that square is your "Disinfection Rate." This is 0.08 when using 3.5% bleach in a 4-inch casing.
4. Multiply the appropriate "Disinfection Rate" by the meters of water in the well.

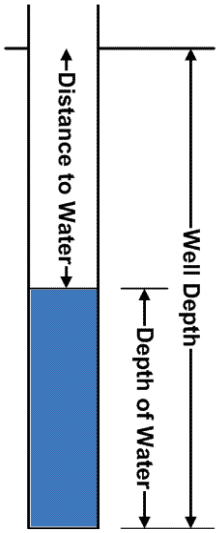


Figure 94
Well Depth

Table 4 Well Disinfection[1]

Row	Disinfection Rate / Casing Diameter[2]	75mm (3")	100 mm (4")	125 mm (5")	150 mm (6")
1	Liters of 3.5% liquid bleach per meter of water	0.05	0.08	0.11	0.16
2	Liters of 5% liquid bleach per meter of water	0.03	0.05	0.08	0.11
3	Tablespoons of 70% Powdered Chlorine[3] per meter	0.21	0.33	0.48	0.66

Notes

1. The Disinfection Rate is calculated assuming that the well has a good gravel pack about 50 mm (2") thick. If the well does not have a gravel pack, then the rates shown in this table will exceed the necessary chlorine concentration by about 25%. Since it will usually not be known if a gravel pack is absent, it is not necessary to make any adjustment in the disinfection rate.

2. The Well Disinfection Table is intended only for use with a borehole. A hand-dug well typically has a diameter of a meter or more. Even if there is only two meters of water in the well, it would take 11 liters of 3.5% bleach to disinfect it. And then it would require many hours of pumping to reduce the chlorine to a safe drinking level. After working on a pump in a hand-dug well, use a bleach solution (1 part bleach to 10 parts water) to wash the pump cylinder, pump rods, and riser main before putting them back into the well.

3. "Powdered Chlorine" is usually Calcium Hypochlorite. Some "swimming pool disinfectants" contain powdered chlorine but they also have chemicals for controlling algae that are unsafe for use in drinking water. Always read the label to be certain that what you are using is intended for treating drinking water. The amount of powder to add is typically stated in grams but a scale is not often available in the filed so grams of powder have been converted to the volume of a large soup spoon or "tablespoon" as a more convenient measurement.

Caution: All forms of chlorine can be dangerous if not handled carefully. But powdered chlorine is very hazardous because of its high concentration. It can cause chemical burns, especially on wet skin, and blindness if the powder gets into your eyes.

3. Practice - 25 minutes

Working together as a team, study the two well disinfection examples. Then use Table 4 Well Disinfection to solve the well disinfection problem on the next page. Write out your calculations.

Well Disinfection Example #1: A 100 mm diameter well casing is 30 meters deep and the distance from the surface to the water level is 15 meters. So the well has 15 meters of water. It is believed that the borehole was about 150 mm in diameter and a gravel pack was installed. A bottle of laundry bleach was found in a store and the label shows that it has 3.5% chlorine.

Find the row in the Well Disinfection Table that says, "Liters of 3.5% liquid bleach per meter of water" and then read the number in the column labeled "100 mm" – that is 0.08. Then multiply 0.08 liters of bleach per meter by 15 meters of water to get 1.2 liters of bleach. Pour this amount into the well before re-installing the repaired pump, and then pump a little water just until you smell chlorine. Lock the well for 24 hours, and then pump until no more chlorine can be smelled. The well is now safe to use.

Calculations:

Water Depth: 30 meters - 15 meters = 15 meters

Chlorine Dose: From Table for 3.5% Bleach and 100 mm casing,

0.08 liters bleach /meter of water x 15 meters water = 1.2 liters of bleach

Well Disinfection Example #2: A 75 mm diameter well casing is 18 meters deep and the distance from the surface to the water level is 12 meters. The well has 6 meters of water (18 m minus 12 m). The government water office provided a package of powdered chlorine. The label does not show the percentage chlorine, so we must assume it is 70%, since that is the normal chlorine concentration of calcium hypochlorite.

Go to row 3 in Table 4 Well Disinfection that says, "Tablespoons of 70% Chlorine Powder per meter of water" then read the number in the column labeled "75 mm" – that is 0.21. Then multiply 0.21 tablespoons of powder per meter by 6 meters of water to get 1.26 tablespoons.

So in this example you would dissolve about 1-1/4 tablespoons of powder into several liters of water in a bucket and pour that into the well before reinstalling the repaired pump. Then pump a little water just until you smell chlorine. Lock the well for 24 hours and then pump until no more chlorine can be smelled. The well is now safe to use.

Calculations:
Water Depth: 18 meters - 12 meters = 6 meters
Chlorine Dose: From Table for 70% Powder and 75 mm casing,
0.21 tablespoon/meter of water x 6 meters water = 1.26 tablespoons of powder.

Well Disinfection Problem:

Well casing diameter: 125 mm
Borehole diameter: 175 mm (there is a gravel pack)
Total well depth: 34 meters
Ground surface to water level: 21 meters
Chlorine source: Laundry bleach believed to be 5%

- How much bleach should be added to disinfect the well? _____ Liters

Your calculations:

Lesson 6.1 Working With PVC Pipe



Purpose

To gain knowledge and skills required for the proper use of PVC pipe.

Objectives

By the end of this lesson, participants will have

- Practiced cutting and gluing PVC riser main pipe
- Seen other uses for PVC pipe

Materials

- Bell & socket PVC pipe or straight pipe with couplings
- Tools: hack saw, fine sandpaper, PVC cement

Preparation

- Study lesson ahead of time
- Lay out pipe and tools for each team

Time

90 minutes

Steps

1. Choosing the Right PVC Pipe
2. Handling PVC Pipe
3. Other Uses
4. Practice

1. Choosing the Right PVC Pipe– 30 minutes

PVC pipe has advantages over galvanized iron (GI). It is less expensive, much lighter, very easy to work with, and does not rust. The main disadvantage is that PVC is not as strong as GI pipe. But when properly joined, the advantages of PVC outweigh this disadvantage. (PVC and uPVC are similar, but uPVC tends to be more rigid and have better resistance to sunlight.)

For well construction, it is important to always use strong PVC (or uPVC) pipe for the casing or, with a VLOM hand pump, for the riser main. Never try to use thin-walled drain pipe in a well because it can not withstand the pressures and will collapse or break.

Several grades of PVC (or uPVC) are available in most countries. “Schedule” is the universal term used to describe PVC pipe strength. Thin-walled drain pipe, not suitable for use in a well, is rated Schedule 20 or lower. Heavier-walled PVC that is suitable for use in a well is rated Schedule 40. PVC pipe designed for high pressure applications is rated Schedule 80. It is not necessary to use Schedule 80 PVC pipe in a shallow well

Some suppliers do not use the "Schedule" system, but instead rate their PVC pipe according to the amount of pressure that it can hold. If neither the Schedule nor the pressure rating is known, then wall thickness can be used as a guide to PVC pipe strength. The following table lists these different strength ratings for Schedule 40 PVC pipe in three common diameters. ("Nominal diameter" refers to the inside diameter of PVC pipe; diameter may have been rounded off for convenience.)

Table 5 Schedule 40 PVC Strength Ratings

Nominal Diameter	Pressure Rating	Wall Thickness
50 mm (2")	19 bar (280 psi)	4 mm (0.15")
65 mm (2.5")	20 bar (300 psi)	5 mm (0.2")
100 mm (4")	15 bar (220 psi)	6 mm (0.24")

A supplier may carry two grades of PVC in the same size, with each grade having about the same wall thickness. The only apparent difference is the price. If there is no other indication of the pipe's strength rating, then purchase the more expensive grade. This will be a bargain in the long run, because it is usually impossible to repair a well if the casing has collapsed. A well can supply safe water to many people for a very long time, so it is wise to use the best available materials in its construction.

The countries that manufacture PVC pipe use different measurement standards. In the United States, English units are used. Most of the rest of the world uses metric (SI) units. The difference in pipe diameters between these two systems is not simply the conversion between millimeters and inches (25.4 mm=1"). There may be several millimeters difference between pipes of the same nominal diameter. This difference can be critical if one is trying to join two pipes from different sources, or fit a pump designed for one system into a casing made under the other system. The following table is a helpful guide when looking for a specific dimension of PVC pipe.

Table 6 Metric & English Schedule 40 uPVC Pipe Sizes

	Metric Standards		***English Standards***	
Nominal inch diameter	Outside Diameter	Approx Inside Diameter	Outside Diameter	Approx Inside Diameter
1.5"	40 mm	33 mm	48.1 mm	40 mm
2"	63 mm	55 mm	60.2 mm	52 mm
2.5"	75 mm	65 mm	75 mm	65 mm
3"	90 mm	80 mm	88.7 mm	78 mm
4"	110 mm	98 mm	114.1 mm	102 mm
5"	125 mm	116 mm	140 mm	130 mm
6"	160 mm	148 mm	168 mm	154 mm
8"	225 mm	210 mm	219 mm	204 mm

Adapted from: "Drilled Wells" Peter Ball, SKAT, 2001

2. Handling PVC Pipe – 20 minutes

Storing. Both PVC and uPVC pipe are damaged by being stored in open sunlight for long periods of time. Therefore, either store the pipe under a roof or cover it with a tarp. Support the pipe on boards, using at least one board for every meter of pipe. Stack the pipe neatly, in no more than 4 layers so that the lower pipes are not damaged.

Cutting. PVC and uPVC pipe may be easily cut using a common hand saw. A hack saw will also work, but pipe larger than 2" in diameter will need to be rotated to cut all the way through. Keep the saw blade straight to get a flat end. Support the pipe on boards to keep it clean.

Cutting PVC produces a lot of scraps inside the pipe. Most can be removed by wiping the edge with a clean cloth or by tipping the pipe and shaking them out. When cutting well screen, it is necessary to "swab" the inside of the pipe using a clean cloth tied to a rope. Pull the cloth back and forth until all of the scraps have been knocked loose. If not removed, these scraps can cause the pump to malfunction.

Joining. PVC pipe is sold in either straight sections or with a "bell" end. Straight pipe requires a coupling to be added at one end. Bell end pipe has a coupling built into one end. When purchasing bell end pipe, it is wise to also purchase a few couplings so that short sections of pipe without a bell can be joined.

Cleaning. Before gluing PVC pipe it is very important to thoroughly clean the surfaces that will be glued. Lightly sanding the surfaces with fine sandpaper will make a stronger connection. Some PVC glues work best if a "primer" is applied first.

Gluing. The technical tern for PVC glue is "solvent cement." This is because the "glue" actually dissolves the surface of the PVC where it is applied. When it dries, the joint can be stronger than the original PVC. The surfaces to be joined must be clean and completely dry before applying glue.

Before applying glue, check the fit by inserting the straight end into the coupling or bell end. They should be very tight. If you can easily insert the pipe all the way into the back end of the coupling or bell, without glue, then the fit is too loose to be joined. This can happen if the PVC came from different sources.

Apply a light coat of solvent cement to the inside of the coupling or bell and to the end of the straight section. Then quickly push the two pieces together, giving them a ¼ turn as you push. The glue will lubricate the pipe so that it will go in farther than when it is dry.

This should be done by two people, pushing against each other. Remember to quickly screw the top of the glue can back on tightly or the glue will evaporate or get spilled.

Drying. Once the PVC pipe has "bottomed-out" in the bell or coupling, do not move it. Hold it still for at least 5 minutes. Some solvent cement requires a longer drying time.

3. Other Uses – 10 minutes

PVC is a very useful material since it is easy to cut and it can be softened with heat and shaped. If the shape is held until the PVC cools it will hold that shape. A 4-inch diameter PVC pipe has a wall thickness of around 6 mm (1/4"). Flattened out, it will be around 35 cm (14") wide.

To get a flat piece of PVC, cut off a section of pipe and then cut along its axis. Slowly heat the pipe over a fire and as it softens, gently open it up flat. Holding it too close to the fire and heating it too fast will burn the PVC and make it brittle. Once it has been opened up, place it between two boards and set heavy rocks on top or clamp the boards together. It will stay flat after it cools.

This flat piece of PVC can be used to make a lot of things. For example, use a hole saw to make the round disk that is part of a bailer (Appendix 6) or supports for the piston seal on a home-made pump cylinder.

4. Practice – 30 minutes

Working in your teams practice cutting, cleaning, and gluing two pieces of PVC pipe. If time and circumstances allow, practice making a flat piece of PVC.

Lesson 6.2 Cutting and Threading Steel Pipe

Purpose

The ability to cut and thread steel riser main is essential to the capacity to fix a broken hand pump.

Objectives

By the end of this lesson, participants will have

- Practiced cutting and threading steel riser main pipe
- Considered cutting and threading pipes of other material than steel

Materials

- Riser main pipe
- Tools: Pipe vise, pipe cutter, pipe threader (handle & 1.25" die), reamer or round file
- Electrical tape

Preparation

- Cut 2 ft. segments of pipe

Time

105 minutes

Steps

1. Cutting Pipe
2. Threading Pipe
3. Other kinds of Pipe
4. Protecting Pipe from Rust

1. Cutting Pipe – 30 minutes

Pipe Vise

The pipe vise is used to securely hold the piece of pipe being cut. Place the practice pipe in the pipe vise, leaving enough room at the end for the cutting tool to rotate. Notice how the hook at the end allows you to open the vise completely. This is very handy when working with a long piece of pipe. Tighten the vise so the pipe will not rotate.

Some versions of the Mark II tool kit include a riser main clamp that can be mounted on the pump base (after removing the pump head) as a pipe clamp. When using the pump base in this way, be sure to cover the pump base so that metal shavings and oil do not fall into the well.



Figure 95 Pipe Vise

Pipe Cutter

Working with your team, take out the pipe cutting tool from your tool box. Turn the handle to see how it raises and lowers the guide wheels. Tightening the handle presses the pipe against the cutting wheel. You cut pipe by rotating the tool around the pipe, tightening the knob a small amount each turn.

Mark the pipe a short distance (about 5 cm) from the end. Practice lining up the cutting tool on the mark where you want to cut.



Figure 96 Pipe Cutter

Practice Cutting

Now practice cutting the pipe where you marked it. Don't try to cut too fast; it will probably take ten or more turns to cut the pipe. Adding a small amount of oil to the cut will make it work easier. Take turns so that each team member makes a cut.

When the piece of pipe has been cut off, look into the ends. Notice that a ridge has formed inside the pipe at the cut point, so that the walls are no longer smooth. This ridge is called a "burr" and it is important to remove it. This is done either with a de-burring tool (also called a reaming tool) or with a file. Practice de-burring the section of pipe held in the vise.



Figure 97 De-Burring Tool

2. Threading Pipe - 60 minutes

Examine the pipe threading tool. Notice that it has two main parts; the handle and the "die." The die can easily be removed from the handle. Notice the teeth inside the die. These are what cut threads in the pipe; the teeth can be replaced when they get dull.

- With the pipe firmly held in the vise, fit the threading die over the end of the pipe. The unthreaded side of the die goes onto the pipe first, as a guide. Make sure the die is square, not at an angle to the pipe.

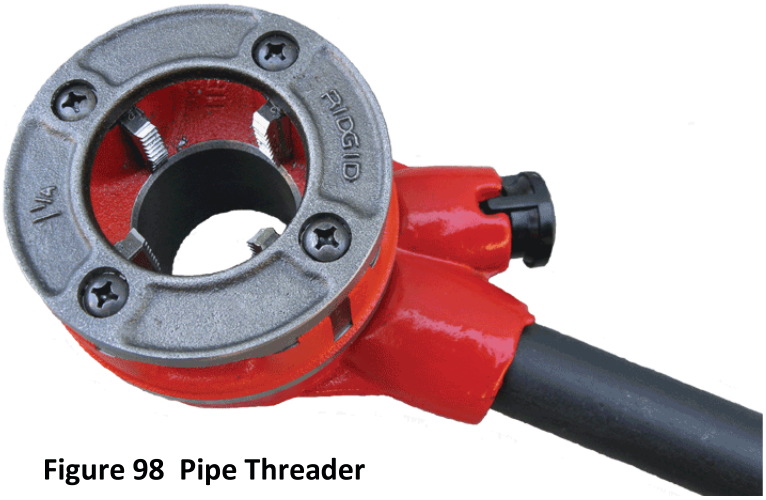


Figure 98 Pipe Threader

- Add cutting oil to the teeth then slowly turn the die handle clockwise. After about half of a turn, back the die up a little bit so the cuttings can drop out.

- Continue cutting, backing off every half-turn, and frequently adding a few drops of oil. Stop cutting thread just short of the width of the die.

- Back the die off of the pipe, wipe off any oil, the remove the pipe from the vise and knock out any cuttings from inside the pipe.

Let every team member have a turn at threading the pipe.

3. Other Kinds of Pipe

The pipe cutter, threader, and reamer used in this lesson are designed for steel pipe. They will not work on PVC pipe or copper tubing because these types of pipe have thin walls and are much weaker than steel.

4. Protecting Pipe from Rust - 15 minutes

When a section of riser main needs to be replaced it is often because it has holes or pits from rust (corrosion). If this is the case, then the replacement pipe should be protected from rusting so the same thing does not happen to it.

The easiest way to protect steel pipe from rusting is to wrap it with tape. Two types of tape will work. Plumbing supply shops often carry a wide, black PVC tape that is made for wrapping pipe. If that tape cannot be found, then plastic electricians' tape will also work. Electrical tape is available in most hardware shops.

Wrapping the pipe keeps water from getting to it, so it can't rust. Rust normally starts from the outside and works in. So wrapping the outside of the pipe is enough to protect it. The tape should cover the entire riser main that is under water. Because couplings are usually thicker than pipe, they do not need to be wrapped but the tape should overlap the coupling to protect the pipe threads.

PVC pipe wrapping tape comes in many different widths but electrical tape is usually about 3/4 inch (19 mm) wide. The tape should be wrapped so that each layer overlaps the one above it by about 4 or 5 mm.

It will take about 9 meters of electrical tape to wrap one meter of standard 1-1/4 inch riser main (about 6.6 feet of tape per foot of pipe). That works out to about 27 meters of tape needed to cover a 3-meter length of riser main. This is about 3 small rolls of electrical tape.

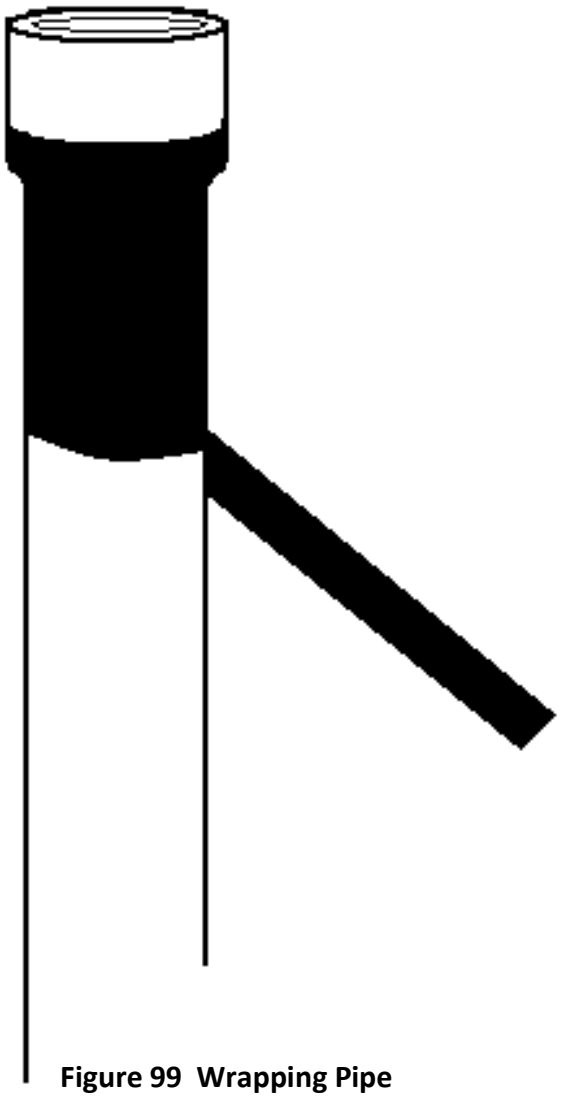


Figure 99 Wrapping Pipe

Prices will vary from country to country, but electrical tape is a tiny fraction of the cost of riser main. So this is a very economical way to protect riser main from rusting.

Lesson 6.3 Cutting and Threading Pump Rod

Purpose

Practice cutting and threading steel pump rod to obtain straight threads.

Objectives

By the end of this lesson, participants will have

- Practiced the correct techniques for cutting and threading steel pump rod
- Evaluated the option of protecting pipe from harsh water

Materials

- Pump rod for each group
- Tools for each team: hack saw, die and handle, file, pump rod clamp

Preparation

- Have one set of materials handy for a quick demonstration of the technique
- Set out materials for each team to collect

Time

60 minutes

Steps

1. Cutting and Beveling Pump Rod
2. Threading Pump Rod
3. Practice Cutting and Threading

1. Cutting and Beveling Pump Rod - 10 minutes

When it becomes necessary to cut and thread a steel pump rod it usually involves a length adjustment where the rod connects to the pump handle. It is necessary to first install the rod in the well to get the proper length. By raising and lowering the pump piston, you can set the rod length so the piston does not hit either the bottom or the top of the pump cylinder. The steps to follow are:

1. Mark the rod at the proper length for the pump. This will depend on the type of pump and cylinder.

2. With the rod still in the well, secure it tightly with a rod clamp and secure the clamp to the pump housing. Pack rags around the clamp so that tools, metal shavings, or oil can't fall into the well.



Figure 100 Rod Clamp

3. Using a hack saw cut the rod at your mark. It is very important that the cut be level, or the threads will not come out straight.



Figure 101 Hack Saw

4. Using a metal file, bevel the end of the rod as shown in the drawing on the right. The threads will not come out straight if the bevel is not even all the way around the rod. It will take time to get it right so work carefully.

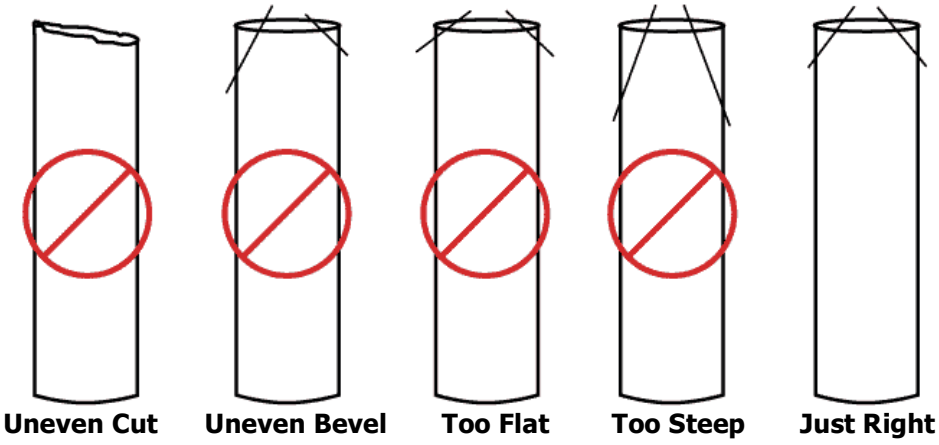


Figure 102 Proper Rod Bevel

2. Threading Rod - 10 minutes

The threading tool has two parts; the handle and the die. The handle can hold several different sizes of die depending on the rod diameter and thread size.

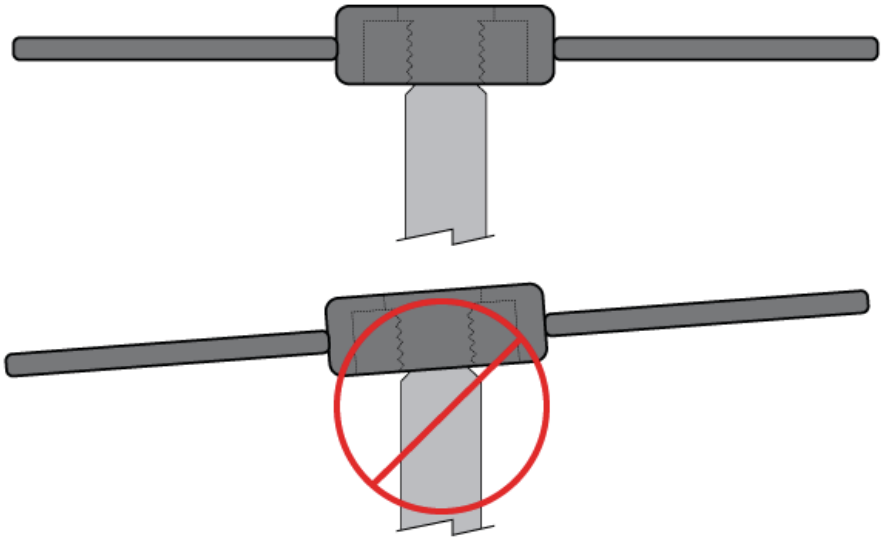


Figure 103 Rod Threader Alignment

It is very important to make the threads even. This is achieved by keeping the threading tool perfectly perpendicular to the rod.

Having crooked threads on a pump rod is not good:

- It causes one side of the rod to be stressed which could cause it to break.
- It causes a bend at the coupling which could rub against the inside of the riser main and make a hole in it.

Rod Threading Procedure:

1. Look at the way the die sits on a ledge in the handle. Hold the die against the rod so that when you press down, the die is pushed against that ledge, not away from it.
2. Slowly rotate the threading tool around the rod while exerting downward pressure. Keep the tool perpendicular to the rod.
3. When the cutting teeth begin to "bite" add a few drops of oil.
4. After every 2 or 3 full turns of the tool, back up about half a turn to clear out the cuttings. Add a few more drops of oil each time you back up. Repeat this.
5. Keep cutting threads until the end of the rod begins to come out the top of the die then back the tool off of the rod.
6. Inspect the depth of thread all around; if one side is deeper than the other side, then the threads are not straight. It is easiest to see if they are crooked by looking at the base of the threads. Crooked threads will be cut in deeper on one side of the rod, leaving a shoulder. Straight threads will not have such a shoulder. Even slightly crooked threads can cause the pump rod to eventually break.
7. If the threads are too crooked, cut off the threaded section and try again. If this causes a problem with the stroke length, then a new section of rod might be needed.

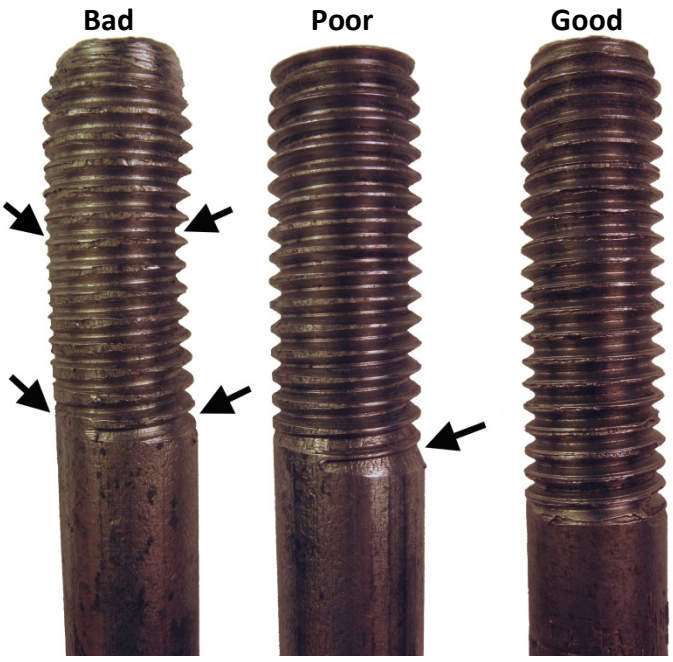


Figure 104 Good vs Bad Threads

3. Practice Cutting and Threading - 40 minutes

In your teams, take turns cutting and threading a short piece of pump rod. In this exercise, we won't be working over a well so someone will need to hold the rod clamp to keep it steady. Keep practicing until you can get the threads straight.



Lesson 6.4 Fishing

Purpose

Introduce the principles for getting a fallen tool or pump part out of a well.

Objectives

By the end of this lesson, participants will have

- Distinguished what to do if a tool or pump part falls down an open borehole
- Practiced common "fishing" techniques

Materials

- Sample fishing tools
- Tools, pump rod, and riser main as "fish"
- Mock well for each team – 4" PVC casing with a bottom cap and lashed to the side of a pickup truck

Preparation

- Gather the fishing tools
- Set up "mock wells"
- Gather tools as "fish"

Time

90 minutes

Steps

1. Four Keys to Success
2. Equipment
3. Practice

1. Four Keys to Success - 15 minutes

"Fishing" – as applied to well drilling – is the art of retrieving a tool or a pump part that has fallen into the well. Fishing is an essential well drilling skill.

1. Know your fish. The first key to successful fishing is to know something about your fish. What is down there, and what does it look like? Is there a coupling or a nut, exposed threads, or a clean break? Look at the remaining end of the rod or riser pipe. Which end of the tool is pointing up? These clues will tell you what kind of fishing tool is likely to work. If there is an unknown object in the well, use soft wax attached to the end of a pump rod to make an impression of it.

2. Have Patience. When it seems like you will never get it out and are about to give up, consider how much work went into drilling the well. Until you put that much effort into retrieving whatever has been dropped into the well, you have not tried hard enough.

3. Be Creative. A good driller makes his own fishing tools. It is possible to purchase commercially-made fishing tools. However, most well drillers and pump repairmen make their own fishing tools to meet the current need using whatever is available. Some basic tool types are introduced in this lesson but they are just a start. Never throw away a fishing tool that you have made; you will probably need it again.

4. Think it through. The fourth key to successful fishing is using your head. If you can't retrieve the fish, consider if there is enough water in the well so that a new pump can be installed above it. However, if the lost part will rust or cause other problems with the well, then keep fishing.

2. Equipment - 15 minutes

Examine the sample fishing tools or study the pictures below. Try to imagine how they are used, and write what pump parts or tools could be retrieved with each fishing tool.

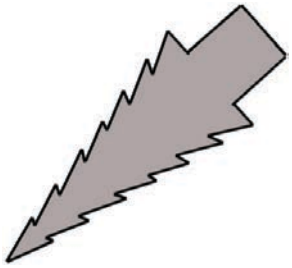
- If you have made a successful fishing tool, describe for the class how it worked.

There are many different kinds of fishing tools. The following are samples of some common types.

Figure 105 Types of Fishing Tools

Name	Picture	Description and Uses
Overshot Trap		A cylinder that is open at the bottom and attached to a pump rod (or riser main). Inside is a "trap" that slips over the end of a separated riser or a pump rod that allows movement in only one direction. But if the fish can't be pulled out of the well, there is no easy way to disconnect this tool.
Bell		Top of a 2-liter plastic bottle with a rod coupling fitted into the cap. Good for threaded rod with no end nut. The "bell" shape directs the threaded rod end into the coupling.

Half-Moon		A metal disk with a slot cut in to it that starts wide and gets narrower. Attaches to a pump rod. When the lost rod is leaning against the casing wall, rotating this fish will grab the rod. Stainless steel rod is more difficult to catch unless there is a nut or exposed threads. A larger version can be made for fishing out a broken riser.
Corkscrew		A spring attached to a rod coupling. Rotating the pump rod twists the spring into the fish. Very useful for retrieving tools such as a pipe wrench.
Hook		A steel rod bent to a sharp hook and welded onto a pipe or rod coupling. Useful in many situations. Can catch the lower lip of a pipe coupling or hook into a tool. Can also be pushed into a pipe.
C-Hook		A design based on the way a wrench "bites" into a riser pipe when used for lifting. It is lowered over the riser with the white rope. Because it is not rigidly attached, it easily slides over the riser. When in place, pulling up on the black rope causes the hook to firmly grip the pipe. Stronger rope can be used for a heavy lift.
Magnet		A magnet will attach to any iron or steel object that has fallen into the well.

Spear		Piece of flat steel cut with notches that can catch on the threads of a coupling or the rough inside edge of a pipe. Usually attached to a pump rod.
Well Cleanout Tool		A 36" (1m) section of 3" (76mm) diameter steel pipe fitted with a plunger connected to a rope. Lowering the tool on top of rocks in a well casing and pulling up on the plunger sucks rocks into the pipe where they are held by "fingers" and shelves. See Appendix 9 for fabrication instructions.

3. Practice - 60 minutes

In your teams, take turns using the different fishing tools to retrieve riser pipe, rods, and tools in the practice well casings.



Lesson 7.1 Doing All Things Well

Purpose

To develop an attitude of striving for godly excellence

Objectives

By the end of this lesson, participants will have

- Considered what it means to be a "professional"
- Listed positive qualities of a professional driller

Materials

- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

45 minutes

Steps

1. What is a "Professional"?
2. Excellence

1. What is a "Professional"? - 20 minutes

➢ What does the word "professional" mean to you? List the ideas that come to mind.

Looking through these different ideas of "professional" would you say that it has a positive or a negative meaning in your culture?

➢ What do you think might be the reason for this attitude toward the word?

2. Excellence - 25 minutes

Imagine for a moment that you are a property owner who plans to hire someone to drill a well. List all of the qualities that you would like to see in that well driller:

Almost everyone has heard of the "Golden Rule"

> **Matthew 7:12**
> "So in everything, do to others what you would have them do to you, for this sums up the Law and the Prophets."

- In what ways do you think this principle might apply to your work as a well driller?

One word that especially applies to the idea of being a professional is "**excellence**." This means doing the absolute best that you can do and not giving up when the work gets hard. A professional does not say, "I could have done it better, but this is good enough for these people."

> **Colossians 3:23-24**
> "Whatever you do, work at it with all your heart, as working for the Lord, not for men, since you know that you will receive an inheritance from the Lord as a reward. It is the Lord Christ you are serving."

A Christian professional keeps in mind the One for whom he is really working:

When we finish our work, whether it is drilling a well, building a pump pad, or living our life, we want to hear, "**Well done, good and faithful servant**." Matthew 25:21



Lesson 7.2 Planning and Mobilization

Purpose

To emphasize the importance of preparation before going out to drill a well.

Objectives

By the end of this lesson, participants will have

- Considered the consequences of inadequate planning
- Developed a well drilling "mobilization checklist"

Materials

- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. Time is Money
2. Planning
3. Mobilization

1. Time is Money - 20 minutes

In America there is a saying, "Time is Money." This means that if a worker who is paid by the hour wastes time then he is also wasting money because he is not working. It also applies to the person who owns his own business because when he does things that do not help the business then that time is costing him money.

Taking this principle to an extreme can lead to the idea that money, and therefore time, is more important than anything else, even relationships. This is clearly not what the Bible teaches us. However, we are instructed to "make the most of our time":

Ephesians 5:15-16

"Therefore be careful how you walk, not as unwise men but as wise, making the most of your time, because the days are evil."

- As well drillers who are trying to be "excellent" in all that we do, what are some ways that we can be wise in our use of time?

2. Planning - 15 minutes

Have you ever heard the ancient saying, "For lack of a nail"? It goes like this:



For lack of a nail the shoe was lost.
For lack of a shoe the horse was lost.
For lack of a horse the rider was lost.
For lack of a rider the battle was lost.
For lack of a battle the kingdom was lost.
And all for the lack of a horseshoe nail.

This proverb teaches that not paying attention to small things – like a single nail – can have serious consequences.

- How might this proverb apply to your preparations for drilling a well in a distant village?

3. **Mobilization -** 25 minutes

To **mobilize** is "to prepare for action." Mobilization is getting ready to do the job right.

- What is a word or phrase in your family language that means "to prepare for action"?

  Write it here:_____

- How can we best prepare to go out and drill a well and install a hand pump?

_____

_____

_____

_____

_____

_____

Most well drillers find it very useful to make checklists. A checklist is simply a written list of every item that needs to be packed and every task that needs to be completed before leaving for the drilling site. If you have a good checklist – and use it – then you never need to hear, "Sorry! I forgot to pack that tool." An example of a Well Construction Checklist is shown on the following page (and in Appendix 2). Your drilling crew might have a few different tools, so make a checklist that meets your needs. Appendix 2 also lists typical quantities of materials used in constructing a well.

Professional drillers assign the different members of the crew responsibility to complete a checklist related to their area of work. For example, the Driller would make sure all of the rig parts and its tools were working and packed. The Mud Engineer would ensure that enough bentonite and other items he uses were ready to go. The Crew Chief would then inspect each man's checklist to verify that all equipment and material had been loaded.

There is another saying that fits this subject:

"A place for everything and everything in its place."

Every tool should have a spot where it is always kept and everyone who uses that tool always returns it to that place. You should not have to look in many places to find that tool. This just wastes time. It may be necessary to make boxes or trays to carry and store some of the tools that come with the drill rig. This is an important part of getting organized. A professional knows the value of being organized.

Table 7 Mobilization Checklist for Well Construction

Drill Rig Parts

- ☐ Mast and mounting bolts
- ☐ Mast handle
- ☐ Mast tie-down ropes
- ☐ Mast tie-down stakes
- ☐ Drill motor and mounting bolts
- ☐ Winch handle
- ☐ Swivel and quill
- ☐ Spare swivel seals
- ☐ Drill pipe
- ☐ Drill bits
- ☐ Drill table
- ☐ Stabilizer legs
- ☐ Drill pipe slip
- ☐ Well casing slip
- ☐ Hoses
- ☐ Spare hose washers
- ☐ Casing flush tool
- ☐ Pipe wrenches
- ☐ C-Wrenches
- ☐ Swivel wrench
- ☐ Flushing tool
- ☐ Pipe lifting adaptor
- ☐ Tripod head
- ☐ Drill rig tool box (separate list)

Other Tools

- ☐ Gravel pack sifting screens
- ☐ Riser and pump rod threading tools
- ☐ Files
- ☐ Hammer, claw
- ☐ Hand saw, wood
- ☐ Adjustable wrenches
- ☐ Hack saw and spare blades
- ☐ Knife, utility
- ☐ Wire cutter
- ☐ Shovels
- ☐ Pick or mattock
- ☐ Safety perimeter rope
- ☐ Stakes for safety perimeter
- ☐ Boards or tarp to lay tools on
- ☐ Boards to place under drill table legs

Mud Mixing and Monitoring

- ☐ Water transfer pump, hoses, foot valve
- ☐ Water storage & mud mixing drums
- ☐ Buckets
- ☐ Marsh Funnel
- ☐ Bentonite
- ☐ Polymer
- ☐ Soda Ash
- ☐ pH Strips
- ☐ Strainer for mud samples
- ☐ Cuttings sample bags and marking pen
- ☐ Cuttings layout board or PVC gutter

Well Construction Tools and Supplies

- ☐ PVC casing
- ☐ Pre-cut PVC well screen
- ☐ PVC couplings
- ☐ PVC caps
- ☐ PVC cement
- ☐ Bailer and rope
- ☐ Gravel pack
- ☐ Pump riser main
- ☐ Riser main couplings
- ☐ Pipe wrap tape
- ☐ Pump cylinder
- ☐ Pump rod
- ☐ Rod couplings and jam nuts
- ☐ Pump head assembly
- ☐ Pump safety rope
- ☐ Bleach for disinfecting
- ☐ Cement for surface seal and well pad
- ☐ Sand for concrete mix
- ☐ Gravel for concrete mix
- ☐ Boards or bricks to form well pad
- ☐ Rebar or steel reinforcing mesh
- ☐ Concrete finishing tools

Fuel and Lubricants

- ☐ Fuel for rig and mud pump
- ☐ Oil for rig and mud pump
- ☐ Funnels for fuel and oil
- ☐ Grease for swivel
- ☐ Pipe joint compound



Lesson 7.3 Record Keeping

Purpose

To instill a sense of the importance of good record-keeping and reporting.

Objectives

By the end of this lesson, participants will have

- Practiced completing a daily drilling report

Materials

- Copies of Daily Work Report and Well Completion Report
- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. Why Keep Records?
2. Daily Work Report
3. Well Completion Report

1. Why Keep Records? - 10 minutes

When you drill a well and install a pump there usually are many villagers watching. Their presence is very obvious – perhaps annoying at times. But many other people, who might not be able to come to the drill site, are interested in the work you are doing:

- The Village Water Committee and other village leaders.
- Your supervisor and, in a larger organization, other people to whom he or she reports, including the financial manager who keeps track of labor and other costs.
- The government agency responsible for water development.
- Donor organizations that contributed money for your tools, training, and the cost of well construction.
- A pump repair technician who will repair that pump some time in the future.

All of these people need to know different things about the well that you are drilling. But, unlike the villagers, they are not able to watch so you need a way to tell them what you did. This communication is the purpose of the "Daily Work Report" and the "Well Completion Report." Because so many people rely on this information, it is important to complete these reports accurately.

2. Daily Work Report – 30 minutes

A professional driller MUST keep track of costs. If you spend more money than you receive then you will not be able to keep working. This fact of life is discussed in more detail in lesson 7.6. In this lesson, we look at the information that drillers must report to their supervisor so that the cost to drill a well can be accurately calculated.

The "Daily Work Report" in Appendix 10 is a way to answer four very important questions:

- How long did you work today?
- What work did you do today?
- How far did you drill today?
- What supplies did you use today?

These questions are answered for the drilling crew as a group, rather than for each individual member. The crew chief is responsible for completing this report at the end of every day spent on a particular drilling job. By signing the report the crew chief promises that the report is true in every detail. Without honest reporting, it is not possible to accurately determine the cost of the job.

Always describe any problems that were encountered during the day. By keeping a good record of what actually happens on a drill site, future cost estimates for a drilling job can be made more accurate.

It is especially important to ask for and keep receipts for all purchases made. In some countries, to ask a merchant for a receipt may be regarded by the merchant as an insult. But this can be overcome, by apologizing to the merchant and explaining, "I'm sorry, but my boss requires it." An official receipt form is not needed; it is enough to show the date, the name of the store, a description of the purchase, and the amount on a piece of paper.

➢ Review the Daily Work Report in Appendix 10. List any items that are not clear to you so they can be discussed in class.

3. Well Completion Report – 30 minutes

The Daily Work Report is for use within your organization. The Well Completion Report (sometimes called a well log or a well record) is for the village leaders and government agencies to have.

A Well Completion Report is only filled out if the borehole produces water and a pump is installed. A "dry hole" is reported on the Daily Work Report.

In some countries, the agency responsible for water resources has developed their own form for the Well Completion Report. If the country where you are working does not have one, then use the Well Completion Report form in Appendix 11.

A well completion report contains the following information:

- Well location; including village name, latitude and longitude (GPS coordinates).
- Name of the organization and crew chief that drilled the well.
- Boring log showing sediment types and drilling notes
- Water level, screened interval, and pump depth.
- Well construction details such as type and amount of casing, screen placement, gravel pack, backfill and sanitary seal details.
- Well development method and time spent
- Well yield test method and results.
- Well disinfection method.
- Water quality test results.

➢ Review the Well Completion Report in Appendix 11. List any items that are not clear to you so they can be discussed in class.

_____

_____

_____

Your organization will establish procedures for submitting your Well Completion Report to the different people who want the information that it contains. As a minimum, copies should be provided to:

- The Village Water Committee
- The responsible government agency
- Your Supervisor
- A donor who sponsored the well

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Lesson 7.4 Equipment Maintenance

Purpose

To introduce basic maintenance procedures for the LS100/200 drill rigs

Objectives

By the end of this lesson, participants will have

- Considered the value of preventive maintenance
- Practiced basic LS100/200 maintenance procedures

Materials

- Markers and flip chart
- Quill, wrenches, rags, and grease

Preparation

- Study lesson ahead of time
- Set up drill rig for demo. For an advanced class, have transmission & pump ready for maintenance demos

Time

60 minutes (plus time spent demonstrating procedures)

Steps

1. Preventive Maintenance
2. Drill Rig Maintenance
3. Tool Maintenance
4. Vehicle Maintenance
5. Maintenance Record

1. Preventive Maintenance - 10 minutes



"If it is not broken, why fix it?"

➢ Is this an attitude that is found in your country? If it is, list reasons why you think people might feel this way:

_____

_____

_____

Preventive maintenance is what we do to avoid an equipment failure. It is a fact of life that equipment wears out. And when equipment stops working, whether it is an automobile or a drill rig, bad things are likely to happen. Preventive maintenance gives us control over breakdowns; we can prevent them before they happen.

Preventive maintenance simply means frequently looking for - and then correcting - equipment problems before they get serious. It is much easier to do this than to deal with the bad things that happen when equipment fails.

2. Drill Rig Maintenance - 15 minutes

Detailed manufacturers' operation and maintenance manuals are supplied with the LS100/200 drill rigs. Always consult these before attempting to repair the equipment. The following paragraphs describe procedures for common maintenance and repair tasks.

Daily Drill and Mud Pump Engine Maintenance. At the beginning of the day, always:

- Make sure the engine oil is at the full level on the dip stick;
- Make sure there is sufficient oil in the drill transmission (level with the fill hole);
- Make sure the air filters are clean; and
- Make sure the fuel tanks are full.

The drill and mud pump engines, and the drill transmission use either **SAE 30** or **10W30** motor oil (detergent oil is preferred).

At the end of each day of drilling, wipe down the drill motor and mud pump to remove any mud that has collected on them. Empty out the mud pump housing and flush the pump housing and the hoses with clear water so drilling mud does not settle in them. If left long enough, the drilling mud will dry inside the hose and clog it. Always keep a "clean machine."

Engine and Transmission Oil Changes. An engine will not last long without proper lubrication. Replacing oil is very cheap compared to the cost of replacing an engine! The small engines and transmission used on the LS100/200 experience much more wear and tear than an automobile engine. Therefore, the oil in the drill and mud pump engines, and the oil in the drill transmission, should be **replaced after every 25 hours of operation**.

For example, if the rig is operated for 8 hours per day for three days, then replace the oil in the engines and transmission at the end of that third day of drilling. If it is only run for 6 hours per day then replace the oil after 4 days.

NEVER pour used oil on the ground! This dishonors God's creation and harms other people by polluting the groundwater and nearby surface waters. Use a funnel to transfer the oil to a large can and then take it to a garage or other facility that has proper methods of recycling or disposing of used oil. The used oil has been "stressed" by the small engines so it is not good to use it in an automobile - except in an emergency.

Regular Lubrication. Oil and grease are a well driller's best friends because they keep his equipment working properly. The routine lubrication points include:

- The quill must be greased throughout the day whenever drilling mud begins to seep through the seals. "Zerk" fittings to which a grease gun will attach are provided for this purpose.
- Zerk fittings are provided for greasing the pulleys over which the drill motor chain rides.
- The chain itself should be lightly oiled every few days, or whenever it has been washed.
- A light coat of grease on the male and female hose fittings will make it easy to attach and detach the hoses.
- The winch also requires an occasional shot of grease.

Daily Quill Maintenance. The quill on the LS100/200 drill rigs can very quickly develop grooves that will cause uncontrollable leakage. It is miserable to try drilling while mud is constantly spraying in your face. These grooves develop when drilling mud is allowed to seep past the swivel seals. Fine sand carried by the mud acts just like sandpaper. A quill can be ruined this way in just a few hours, as shown in the photo below.

This quill had been stored after drilling without first cleaning and greasing it, so that it is also badly rusted. A rusty surface like this will quickly tear up the rubber swivel seals.

Every day of drilling, either at the start or the end of the day, remove the swivel and quill from the drill motor, completely remove the quill from the swivel housing, and clean all of the parts. Carefully inspect the quill for signs that grooves may be developing. Inspect the swivel seals for wear and clean out their small holes so grease can get through to the quill. Re-grease the quill



Figure 106 Worn Quill

and reassemble the unit. Details of quill maintenance are found in Appendix 12.

If grooves are starting to form on the quill, adjust the position of the quill in the swivel so the

seals are resting on a non-grooved surface. Then consider if the mud pits are large enough, or the drilling mud thin enough so that sand can drop out and not be circulated through the quill. Also remember to keep the quill greased and the compression caps properly tightened during drilling.

After the borehole has been finished, always clean and grease the quill before putting the drill rig away. Otherwise, it will rust like the quill in Figure 106.

Quill Re-facing. When a quill has become so grooved or rusted that no flat, smooth surface remains on which the seals can rest, then it is necessary to re-face the quill. This is done at a machine shop, using an arc welder to fill the grooves, then a lathe to restore the diameter and roundness of the quill. The surface of the quill is then polished and hardened. A skilled machinist can restore a quill to nearly its original quality. An unskilled machinist can easily ruin a quill.

Drill Clutch Replacement. The clutch on the LS100/200 allows the drill pipe to stop rotating when the motor speed is reduced to idle. If the drill pipe continues to rotate when the motor is at its slowest possible speed, then it is time to replace the clutch. A clutch should last for many hundreds of meters of drilling, but there are two things that can prematurely wear it out:

1. Applying too much downward pressure while drilling. Let the bit advance at its own speed; don't force it.
2. Encountering a rock or other obstruction when rotating at high speed. If the throttle is not immediately reduced, or the motor shut down, the clutch will be ruined.

The LS100/200 is provided with one spare clutch. Detailed instructions for replacing the clutch are given in Appendix 12.

Mud Pump Impeller Replacement. It is wise to inspect the mud pump impeller after about every 50 hour of operation to determine if it is getting worn. If the mud pits are too small, or the drilling mud so thick that cuttings can't drop out, then a large amount of sand will be moved through the pump. This will wear down the impeller blades and reduce the output of the pump. This can get so bad that the pump is unable to generate enough force to bring cuttings out of the borehole.

Instructions for removing and replacing the impeller are provided in Appendix 12. Figure 107 illustrates how to loosen the impeller from the motor shaft by protecting the impeller blades with a piece of wood. It just takes just one quick rap with a hammer to loosen the impeller (right-hand rule).



Figure 107 Removing the Impeller

Figure 108 compares a new and a worn pump impeller. The worn impeller had been in use for about 20 hours with mud pits that were too small. The three signs of wear are: 1) the plate on which the blades are attached has a thin edge, 2) the blade tips have been worn back almost 2cm (3/4”), and 3) the blades are almost half their original thickness. This impeller has some life remaining in it, but not if it continues to pump sand as it has been doing.

Mud Pump Shaft Seal Replacement. There is a seal located on the motor shaft between the pump housing and the motor that keeps fluid from leaking out of the pump housing. This seal will normally last for hundreds of hours of pump operation. However, if the pump is run without the pump housing first being filled with water or drilling mud, then the shaft seal will be ruined within a few minutes. The LS100/200 mud pump must always be “primed” before starting it.

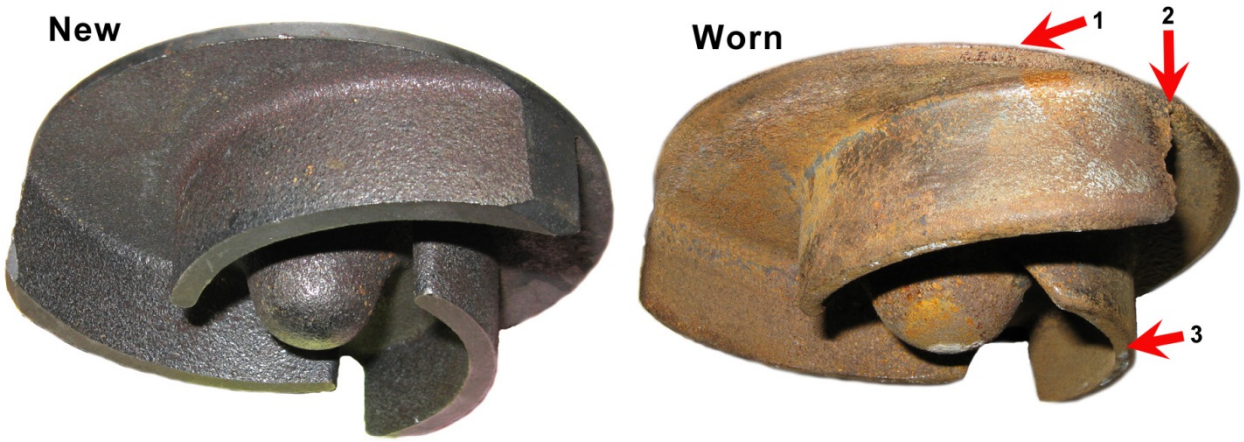


Figure 108 New vs Worn Impeller

When fluid begins to leak out between the pump housing and the motor, the shaft seal must be immediately replaced. The pump may appear to be working, but it will not be able to generate suction with even a small shaft seal leak. One spare mud pump shaft seal is included in the LS100/200 tool box. The impeller must be removed to replace the shaft seal, as described in Appendix 12.

There are two parts to the shaft seal as shown in Figure 109; a metal spring-loaded housing and a white ceramic ring in a rubber cup. The shaft seal is installed with the rubber cup facing toward the motor and the spring toward the pump impeller. The glassy smooth face of the ceramic ring runs against a raised ridge of equally smooth hardened graphite that is held in the metal housing. The spring keeps the two parts pressed against each other so that fluid can't leak past them. Fluid in the pump housing cools and lubricates the shaft seal.

When the mud pump is run dry, the shaft seal overheats which weakens the graphite. With no fluid to lubricate the face of the seal, the graphite very quickly wears down to a point where the spring can no longer apply sufficient pressure to hold back water or drilling mud. In a new seal, the graphite sticks up above the metal housing. In a damaged seal, the graphite is worn down below the edge of the housing. (In some older seals the graphite is not surrounded by the housing, but it is still easy to see the wear.) Figure 109 compares new and a worn seals. Note the discoloration of the metal housing on the worn seal caused by being overheated.



Figure 109 New vs Worn Shaft Seals

3. Tool Maintenance - 15 minutes

A professional takes very good care of his tools, because he knows that without them he can't work.

If a tool is not available because somebody borrowed it to fix their motorbike, then the entire well construction project might be delayed. Here are three rules that are suggested so that the tools designated for well drilling are always available for well drilling.

1. The tools that you are using are not your personal property. They are the property of the organization for which you are working so treat them with care and respect. Always keep them clean and in good working condition.
2. Never loan the tools, especially for purposes not related to well drilling. If someone in authority asks to borrow a tool, you might not be able to refuse them. In that case, go with the tools. You can help with the task and you can guarantee that you get all of the tools back.
3. Always know where your tools are. Maintain and inventory of the tools and check it often. Keep them in a safe place on and off the job site.



Figure 110 Drill Motor Stand

The tools provided with the LS100/200 drill rig are very high quality and if properly used and cared for, they will last a very long time. At the drill site, have a tarp or a board on which tools are laid after use. Never drop a tool in the mud! At the end of the day, wipe any dirt off, dry the tools, and lightly oil them so they do not rust. Always store the tools in a secure, dry place.

Besides keeping them clean, professionals take care of their tools by making storage and carrying boxes for them. Throwing everything in the back of the truck is a quick way to loose or damage tools. But if the tools are in sturdy boxes, then it is easy to find them and easy to inspect to make sure all of the necessary tools are present. A tool box can be simple or fancy, as long as it works.

Inexperienced drillers sometimes make the serious mistake of running their drill rig without oil. This happens because the oil has to be drained out of the engine in order to lay it down in the drill rig shipping box. The next time they take it out, they forget to refill it with oil. The solution is to make a stand so the engine can be transported and stored upright as shown in Figure 110. It can be made out of wood but welded rebar will last longer. (If the quill is removed for storage then the stand can be made lower.)

A good way to protect the mud pump is to build a frame around it as shown in Figure 111. This also makes it very easy to move the pump. Without good handles like these, there is a temptation to move the pump by pulling on one of the hoses, which will break the hose. A frame like this also guards against someone brushing against the hot muffler.

Anything that will help the equipment last longer is worth the effort!

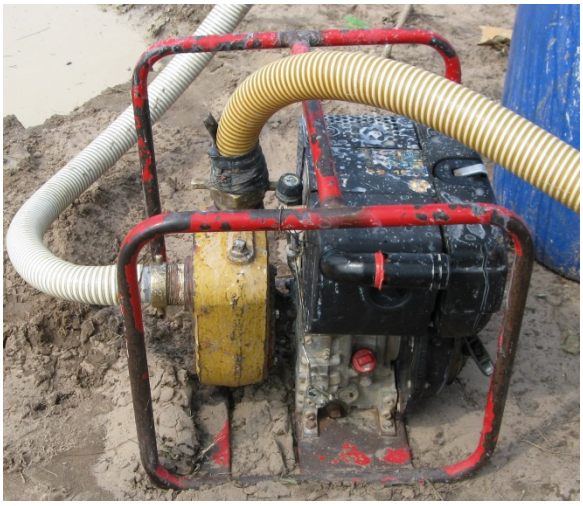


Figure 111 Mud Pump Frame

4. Vehicle Maintenance - 15 minutes

Finally, any discussion of maintenance must also include vehicle maintenance. If the vehicle you use to transport your drill rig breaks down, you can't bring safe water to a community no matter how well your drill rig works. Regular vehicle maintenance should include, as a minimum, the following:

- Maintain the proper oil level.
- Change oil, oil filter, and air filter every 5,000 km (or 3,000 miles).
- Maintain proper tire pressure.
- Replace tires before they blow (#1 cause of single-vehicle accidents).
- Grease where fittings are provided every 5,000 km (or 3,000 miles).
- Inspect the brakes every 5,000 km (or 3,000 miles).
- Replace brake pads before they wear out.

5. Maintenance Record - 15 minutes

It is wise to keep a record of maintenance and repairs performed on each piece of equipment. Have a sheet of paper where the equipment is stored that lists the date, work performed, and cost. This will show when it is time to replace a piece of equipment. It also makes it easier to determine how much is being spent on maintenance.

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Lesson 7.5 Safety

Purpose

To instill a habit of safety awareness on the drill site

Objectives

By the end of this lesson, participants will have

- Evaluated their personal attitudes toward safety
- Considered three areas of safety concern

Materials

- Poster of drill site
- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

45 minutes

Steps

1. Personal Safety
2. Visitor Safety
3. Equipment Safety

1. Personal Safety - 15 minutes

There are two main reasons why we have a daily "safety briefing" in this class:

- Help the students become aware of hazards that they might not anticipate.
- Create a "culture of safety" on the well drilling crew.

It does not take long to learn the hazards of well drilling. These include:

- Rotating machinery
- Hot mufflers
- Electrical shock
- Mud pits
- Head knocks
- Heavy lifting
- Slipping or tripping
- Exposure to dust
- Dehydration & sunstroke

The bigger problem is becoming too familiar with these hazards. When that happens, we tend to stop being careful and that's when accidents occur.

To have a "culture of safety" on a well drilling crew means that everyone is not only looking out for their own interests, but they are also looking out for each other (Philippians 2:4). The daily safety briefing is not only for this class. It should become a habit every day of work.

Where there is a "culture of safety" there is no shame given or received by pointing out a safety problem to a team member. Instead, it is a demonstration of love – "I do not want you to get hurt, my brother!"

It is helpful to adopt some basic safety rules:

- Always wear a hard hat on the drilling site.
- Keep the drilling site clean: put tools away, control water, and pick up trash.
- Lift properly; bend knees and lift with the legs when picking up heavy objects.
- Be cautious of other people when moving drill pipe.
- Drive safely at all times! Too many people are killed on the highway, so take it easy.

➢ What are some other safety rules you would like your drill crew to adopt?

_____

_____

_____

_____

2. Visitor Safety - 15 minutes

➢ How many potential accidents can you count in this photo? List what you see:

_____

_____

_____

_____

_____

A scene like Figure 112 suggests that this drilling crew does not care whether these children get hurt or not. They are so focused on their work that they are missing a chance to demonstrate love for these children by protecting them. It is not necessary to chase visitors away; simply put up a safety rope and instruct them to stay behind it.



Figure 112 Unsafe Visitors

3. Equipment Safety - 15 minutes

Safety hazards are often the result of behavior – doing something unsafe or not taking proper precaution, like failing to wearing a hard hat. But another category of safety concerns relates specifically to the drilling equipment, such as:

- Tie down the drill rig mast before attaching the shuttle and motor.
- Never fuel an engine while it is running.
- Be cautious of mufflers, as they get very hot.
- Do not wear loose clothing that can be caught by the rotating drill pipe.
- If the drill engine does not already have an emergency "kill switch," tie a cord to the spark plug wire so the engine can be quickly stopped in an emergency.
- Do not lay tools where they can be kicked into the bore hole.

➢ What other equipment-related safety measures can you think of?

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Lesson 7.6 Counting the Cost

Purpose

Explore ways to pay for the cost of constructing a well

Objectives

By the end of this lesson, participants will have

- Established cost factors to determine what a well costs
- Discussed different market-based approaches to providing safe water

Materials

- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

120 minutes

Steps

1. Introduction
2. Drilling and Well Construction Expenses
3. Elements of a Business Plan
4. Market-based Approaches

1. Introduction – 15 minutes

The Planning and Mobilization lesson introduced the idea that "time is money." Most people agree that to be obsessed with money is not a good thing. But the ability to handle money wisely and in a way that honors God is a sign of spiritual maturity. It is also a sign of a professional.

Consider this Scripture:

Luke 14:28

Suppose one of you wants to build a tower. Will he not first sit down and estimate the cost to see if he has enough money to complete it?

- In what ways do you think this verse might relate to well drilling?

2. Drilling and Well Construction Expenses - 60 minutes

Whether you are running a business that charges customers to construct a well for them, or you are operating a ministry that gives wells at no cost to the users, it is absolutely necessary to know what a well costs you to construct. A water well is your "product" – it is what you have to "sell." You will either sell it to a customer or to a donor agency who then gives the well away. In either case, if you spend more money making a well than you receive for that well you will go broke. A business or a ministry that loses money cannot survive.

What we will develop in this lesson is a cost per meter (or foot) for constructing a well. So if you know, for example, that the water table is at 35 meters then you can calculate with a degree of reliability what it will cost to drill that borehole and install a pump. Because the cost of the items that make up a well vary from country to country, it is not possible to develop a single cost factor. So this lesson will help you discover how to put all of the pieces together.

First, list all of the drilling and well construction costs you can think of in the category of **labor.** This includes everything related to maintaining the drilling crew, not just salaries. Include as many actual costs as you can for the area where you work. Also include the time period; whether it is per hour, per day, week or month.

Labor Costs

Job Description or Activity	**Cost**	**Per:**

Next, list all of the costs for the materials that are used up by drilling a borehole and constructing a well. Include as many costs as you know for your area plus the rate at which that item is consumed; either per meter (or foot) of borehole, per hour, or per well. The rate of fuel consumption, for example, would be listed as liters (or gallons) per hour.

Materials Costs

Item	Unit Cost	Per:

- Who do you think is responsible for keeping track of these expenses?

There are two other expense categories that are important to understand. These are **overhead** and **depreciation.** What goes in the **overhead** category are all of the expenses of running a well drilling operation that cannot be charged directly to a specific project. Examples include the Director's salary and office rent. List all of the overhead costs that you can think of, including actual amounts if you can and whether it is a monthly or an annual expense:

Overhead Costs

Item	Unit Cost	Per:

Depreciation is an accounting concept that simply means the cost of replacing a major piece of equipment, divided by the life span of that equipment. For example, if your drill rig costs $20,000 and will last (with proper maintenance) for 10 years, then the depreciated cost of that rig would be $20,000/10 years = $2,000 per year. List all of the major equipment items that you can think of, including replacement cost and life span in years, and then divide the cost by the life span to get depreciation cost per year:

Depreciation Costs

Equipment	Replacement Cost	Life (years)	Per Year

- If you have not already listed transportation to and from the drilling site, where do you think this expense fits into these cost categories?

Labor and materials costs can be charged directly to a specific well drilling project, so they are called “direct costs.” This is evident in the way they are used up; for example, three days of labor to drill a well, 40 meters of casing installed, one pump installed.

Overhead and depreciation can be thought of as “indirect costs” because they are not related to a specific drilling project. For example, rent on the office or warehouse must be paid whether wells are being constructed or not. But these expenses are a necessary part of the cost of constructing a well, so we must have a way to charge them to a specific drilling project.

Each of the four cost categories can be related to one of these three questions:

1. How may meters of borehole can the crew drill and ream, on average, per day?
   -Relates to crew labor costs.
2. What are the per meter costs and the fixed costs of constructing a well?
   -Relates to materials costs and some depreciation costs.
3. How many wells per year can the organization construct?
   -Relates to indirect costs (overhead and depreciation)

When all of the costs are gathered, and the calculations are completed, everything will be reduced to a **cost per meter** (or foot) of drilling plus a **fixed cost per well**. Here are steps you can take to reach that goal:

1. Gather actual materials costs. Go to the stores where drilling supplies are sold and make a list of the prices you will have to pay. Determine how much of each material is used in a 30-meter (100 foot) well then divide the total by the depth to get cost per meter.
2. Determine how many meters the crew can drill (pilot hole plus reaming) per hour. Divide labor cost per hour by meters drilled per hour to get labor cost per meter.
3. Determine materials used by the hour (like fuel). Divide hourly materials costs by meters drilled per hour to get materials cost per meter.
4. Add up all of the per-meter costs to get a total cost per meter.
5. Determine the cost of materials that are used on a per well basis (like the pump head). Add up all of these costs to get a total per well.
6. Convert all of the monthly overhead costs into annual costs then add them to get an annual overhead cost. Divide this amount by the number of wells drilled in one year to get the total overhead cost per well. This will be a fixed cost.
7. Look through the equipment on your depreciation list. The life span of some items can be expressed in meters drilled. The LS100 and LS200 drill rigs will drill a total of at least 1,500 meters (or approx. 5,000 feet) and the mud pump should last for about 750 meters (or approx. 2,500 feet). So the replacement cost of this equipment would be

divided by those drilling depths to give a cost per meter. Other items, like a vehicle, need to be replaced after a given number of years, so divide their cost by the years and then divide that by the number of wells drilled per year. This would be added to the other per-well fixed costs.

8. Finally, add up all of the expense factors according to either cost per meter or cost per well.

This might seem like a lot of work. It is! But it is necessary. It is how a professional driller sits down to "count the cost."

For a start-up drilling operation, it will be necessary to make a lot of estimates. The materials list in Appendix 2 can be used as a guide. But the most accurate information will be obtained from the actual costs recorded on the Daily Work Reports (lesson 7.3). The estimated drilling costs will need to be adjusted as soon as actual costs can be calculated from the Daily Work Reports.

3. Elements of a Business Plan - 15 minutes

A business plan is a way to determine what it will cost to operate a business and how much should be charged for the services that are provided. If it costs more to operate a business than the money received, then the business will fail.

At its most simple level, a business plan for well drilling considers three calculations:

1) Total Expenses ÷ Number of Wells Constructed = Expense per Well

2) Total Projected Revenue – Total Projected Expenses = Profit

3) Expense per Well + Profit per Well = Amount Charged per Well

For a start-up drilling operation, total expenses must be estimated through the procedure described above. The financial records of an existing operation will tell what the expenses were for the year - if they keep good records.

- What are the sources of revenue (income) for your well drilling operation?

_____

_____

_____

Do you know if more money is coming in as revenue than is going out as expenses? If expenses are greater than revenue, then your well drilling operation cannot succeed, either as a business or as a ministry.

Profit is the money remaining after all of the expenses have been paid. If the profit goes into the business owner's pocket then he has made money. But if that profit is put back into the business then it is called an investment. In most countries, a non-profit organization is allowed to show a profit as long as it is invested back into the work.

- How much profit (as a percentage) do you think would be fair to charge on a well drilling project and why?

Other parts of a business plan include how you will advertise your services, samples of contracts that you will use, and methods by which you may help customers pay for their well.

4. Market-Based Approaches - 30 minutes

The idea behind a "market-based approach" is simply that the people who benefit from a service like safe water should pay for it. Water from heaven is clean and free, but it costs money to store it and once it becomes contaminated it costs money to make it safe again. So we can think of safe water as a commodity that has a price.

- Is it right to ask a community to pay all of the cost of a well?

- If a community says they can't afford to pay any part of the cost of a well, what should you do?

- What are some methods by which you may help customers pay for their well?

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Lesson 8.1 Encouraging Village Water Committees

Purpose

Develop and rehearse ways to help a Village Water Committee do a better job.

Objectives

By the end of this lesson, participants will have

- Explored ways to keep a pump working by encouraging the community to take ownership of their well and responsibility for its routine maintenance

Materials

- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

90 minutes

Steps

1. Keeping the Pump Working
2. Village Water Committees
3. Pump and Well Maintenance
4. Encouraging a Village Water Committee

1. Keeping the Pump Working - 10 minutes



Figure 113 Village Market

Every community has resources that are available to the people year after year. These resources include environmental conditions (air, water, soil), human inventions (roads, electricity, machines), and social institutions (churches, schools, markets, festivals).

In most cases, what keeps these resources available for the community is a commitment by the community to take responsibility for them. For example, the entire community benefits from a weekly market so the community members (sellers and buyers) work together to keep it going. Even resources for which the government has the main responsibility, taxes or fees collected from the community makes its work possible.

List examples of resources (environmental, human, or social) that are found in your community and that are sustained by the efforts of the community.

2. Village Water Committees – 10 minutes

Experience has shown that a Village Water Committee (or Water and Sanitation Committee) is the most effective way to keep a hand pump operating for the benefit of the community.



Figure 114 Water Committee Meeting

- In the area where you work, what responsibilities do Village Water (and Sanitation) Committees have?



Here are some characteristics of an effective Village Water Committee:

- It includes representatives of various groups in the village, especially women.
- It takes a lead in identifying the community's water and sanitation problems.
- It helps educate the community on water, sanitation, and hygiene issues.
- It promotes water, sanitation, and hygiene projects in the community.
- It takes responsibility for operating and maintaining water and sanitation systems and for collecting and managing the money needed for this work.
- It establishes rules (such as fees and hours of operation) for the water pump.
- It resolves disputes over the community's water and sanitation systems.

➢ What characteristics on this list are not true for Water Committees in your area? Why?

3. Pump and Well Maintenance - 25 minutes

No matter what type of pump a community has, there are some maintenance and repair operations that will be easy for them to do and some that will be hard for them.

➢ What are some things that can go wrong with a hand pump and well area that may be prevented (or delayed) by simple, routine maintenance that most communities could do themselves?

➢ What are some things that can go wrong with a hand pump or the area around the well that probably require training or special tools?

4. Encouraging a Village Water Committee - 45 minutes

In your work, imagine that you find the following situation:

> A community in the area where you are working has a Water Committee, but they are not doing many of the things that we decided were helpful for a Water Committee to be doing. The evidence for this is obvious: the one pump they have has been broken for a long time, the pad is cracked from neglect, they have collected no money for repairs, and they are blaming each other for the problems.

Your assignment is to help this Water Committee understand their role and do a better job at it. In the culture where this committee lives, to lecture them as an "expert" would be highly offensive and they would simply not listen to you. Therefore, important messages like this are communicated through story-telling, song, dance, or drama.

Working with your team, develop a story, song, dance, or drama that will help this Water Committee understand their role. You will make your presentation to the rest of the class as if we were that Water Committee. If you think more than one session with the committee is needed, then just make your first presentation and explain what else you would do.

- What would you do differently if the community did not have a Water Committee?



Lesson 8.2 Pump Maintenance and Repair

Purpose

To introduce basic hand pump maintenance procedures.

Objectives

By the end of this lesson, participants will have

- Reviewed weekly and monthly maintenance tasks

Materials

- Poster of Good Pump Pad
- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

30 minutes

Steps

1. Preventive maintenance

1. Preventive Maintenance - 30 minutes

Preventative maintenance, as opposed to corrective maintenance, is the routine work done on a pump and its surrounding area to ensure that major breakages or contaminations do not occur. The capacity of the village to do routine maintenance on their pump will often determine the success of water projects for that village. When training village maintenance crews, include a schedule of maintenance tasks such as:

Weekly:

- ☐ Lubricate moving parts.
- ☐ Check and tighten nuts and bolts.
- ☐ Make sure the pump is firmly set in the base.
- ☐ Keep well pad and area around the well clean and neat.

Monthly:

- ☐ Check pump flow (discharge) rate and record results.
- ☐ Repair concrete base and apron as needed.

There are other maintenance and repair tasks that a hand pump requires, but they depend on the type of pump and the specialized tools and training that the community has been given. Refer to Lifewater's "Hand Pump Repair" manual for details.

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Lesson 8.3 Hygiene and Sanitation

Purpose

To introduce healthy hygiene and sanitation behaviors.

Objectives

By the end of this lesson, participants will have

- Reviewed common disease pathways
- Examined disease-blocking practices

Materials

- Markers and flip chart

Preparation

- Study lesson ahead of time

Time

60 minutes

Steps

1. Diarrheal Disease
2. Handwashing
3. Keeping Water Safe
4. Safe Fecal Disposal
5. Your Role

1. Diarrheal Disease - 10 minutes

One of the most common health problems in a rural community, especially among children, is diarrhea. The dehydration that results from diarrhea can lead to death in a very short period of time. The germs that cause diarrhea are transmitted through contact with feces. We get sick when those feces get into our mouth. There are many ways this can happen; contaminated water, soiled hands, and flies are common pathways. Figure 115 shows some of these pathways.

Safe water is one way to reduce the spread of diarrheal disease. Good hygiene and sanitation practices are also necessary to better block all the pathways for disease transmission; not only for diarrhea, but for many other diseases as well.

It takes education - and time - for a community to recognize behaviors that increase the risk of getting sick and to begin changing those behaviors. For this reason, Lifewater has developed a full training program aimed at promoting good hygiene and sanitation practices. These training manuals include; “WASH Promotion,” “Handwashing at Critical Times,” “Keeping Water Safe,” “Safe Fecal Disposal,” ”Sanitation: Latrine Design and Construction,” and “WASH in Schools.”

This lesson provides a summary overview of some of the key principles covered in these manuals.

It is possible to reduce disease in a community by blocking these disease transmission pathways by washing hands, covering food, avoiding open defecation, protecting water from fecal contamination, and many other simple practices.

Therefore, in addition to drilling wells, an effective water development program will also teach the community good hygiene and sanitation practices. Without these, safe water can easily become contaminated and the benefits of safe water will be greatly reduced.

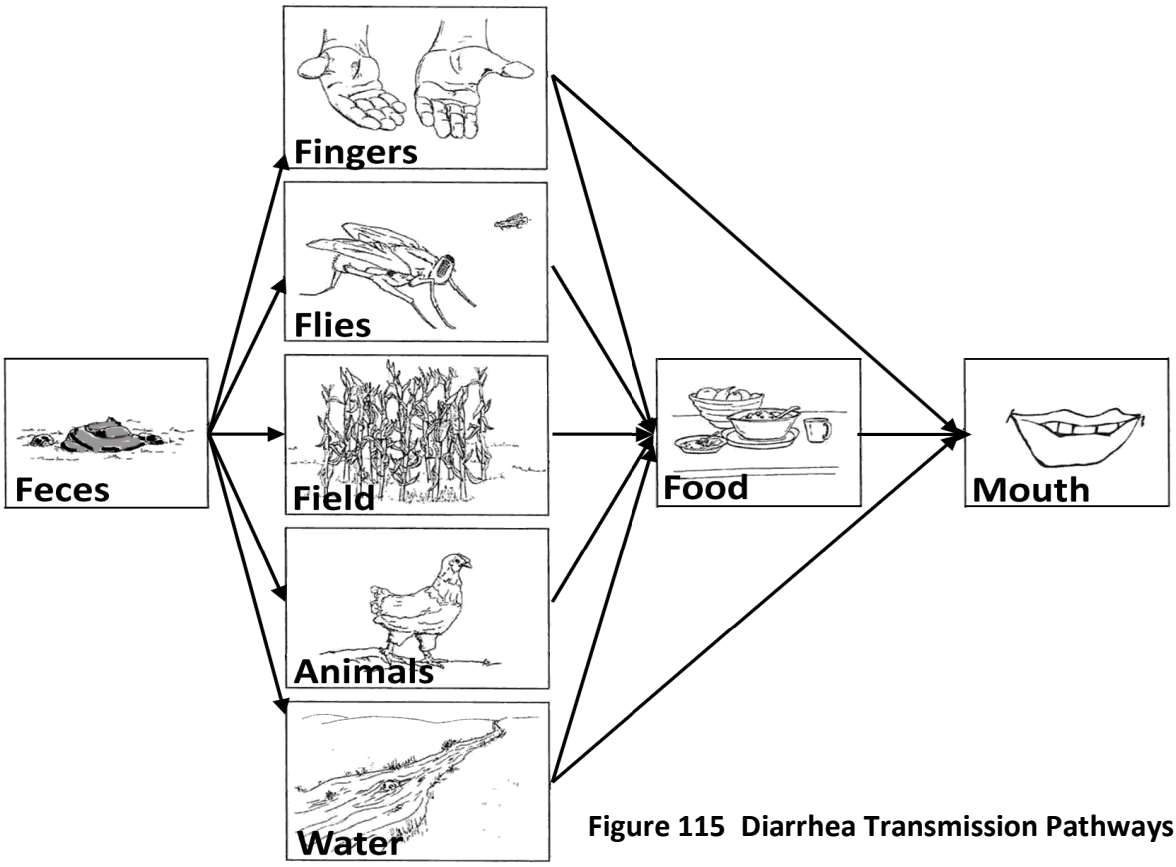


Figure 115 Diarrhea Transmission Pathways

2. Handwashing - 10 minutes

Washing our hands is the first line of defense against disease. There are two times when it is critical that we wash our hands:

- AFTER contact with feces.
- BEFORE handling food.

There are many ways to wash our hands, but the most effective is with soap and water. A very simple device for this can be made using a plastic jug. It's called a Tippy-Tap and is illustrated in Figure 116. Put up a Tippy-Tap by the latrine and near where food is prepared and eaten to remind people to wash their hands.



Figure 116 Tippy-Tap

3. Keeping water safe - 10 minutes

As well drillers, you are in the community to provide a safe source of water. All of the well construction procedures – especially installing a deep sanitary seal, building a strong pump pad, and disinfecting the well – are designed to keep the groundwater from becoming contaminated. But what if people carry their water in a dirty bucket? Or leave the bucket uncovered at home?

Some simple practices for keeping water safe include:

- Wash the water bucket with soap and water.
- The bucket used to collect water is only used for that purpose.
- Keep the water bucket covered.
- Avoid touching water in the water bucket; dip it out with a clean cup.
- If using a hand-dug well, cover the well and install a hand pump.
- Protect water sources from feces by burying feces or using a latrine
- Use fences to keep animals away from safe water sources.

4. Safe Fecal Disposal - 15 minutes

The proper disposal of feces is probably the most important thing that a community can do to promote good health. This is so important, that God has commanded it!

Deuteronomy 23:12-14
Designate a place outside the camp where you can go to relieve yourself. As part of your equipment have something to dig with, and when you relieve yourself, dig a hole and cover up your excrement. For the LORD your God moves about in your camp to protect you and to deliver your enemies to you. Your camp must be holy, so that he will not see among you anything indecent and turn away from you.

This command was given to the Hebrews as they were travelling from Egypt to Canaan. It was given to promote their health, so it is equally important to us today. It might take time for a community to gather the resources to build a latrine. But if they are now practicing open defecation, then simply digging a small hole and covering their feces is something very simple that can be done. And the benefits will be great.

5. Your role - 15 minutes

As well drillers, you may not have many opportunities to instruct the community in good hygiene and sanitation practices. But you can be a good example.

- In what ways can a well drilling crew model good hygiene and sanitation behavior?

Appendix 1 LS200 Packing List

LS200 BRP-D LS200 BASIC RIG PACKAGE – HATZ DIESEL				
PART NO	**DESCRIPTION**	**QTY**	**IN CRATE**	**AMT SHORT**
LS200 DP	M250 DRILL PIPE / BREAKOUT LUGS	40		
LS200HDRPUTA	ROTARY POWER UNIT WITH 2" SWIVEL - 4.8HP HATZ DIESEL	1		
LS200HDMPUA	2” MUD PUMP WITH 4.8HP HATZ DIESEL, BSGF-10	1		
LS200 TBA	REINFORCED TABLE BASE ASSEMBLY	1		
LS200 MWA	REINFORCED MAST WELDMENT ASSEMBLY	1		
LS200 SLPA	M250 DRILL PIPE SLIP ASSEMBLY	1		
LS100 SLT	STABILIZER TUBE	2		
LS200 RTBA-D	LS200 RIG TOOL BOX ASSEMBLY – DIESEL (contents page 2)	1		
LS100 HXW	18” HEX WRENCH	1		
FC 31025	18” RIDGID PIPE WRENCH	1		
FC 31030	24” RIDGID PIPE WRENCH	1		
LS200 3.875B	3-7/8” 3W STP ON M250 BOX - DRILL BIT	3		
LS200 5.875B	5-7/8” 3W STP ON M250 BOX - DRILL BIT	1		
LS200 5/875R	5-7/8” 3W STP ON M250 BOX TO PIN - REAMER	1		
LS200 7.00R	7” 3W STP ON M250 BOX TO PIN - REAMER	1		
RT 100PJC	PIPE JOINT COMPOUND	1		
NWS 3X36	3”X36” PVC BAILER	1		
LS200 BLTA	M250 BAILER TRIPOD ASSEMBLY	1		
LS200 FT4	4” CASING FLUSH TOOL WITH M250 BOX	1		
LS100 SLP4	4” CASING SLIPS	1		
LS200 MMA	2” MUD MIXER ASSEMBLY	1		
LO .375 HBR	3/8” X 100’ HOLLOW BRAID ROPE	1		
LS200 DHDHA	2” X 5’ DOWN HOLE DELIVERY HOSE ASSEMBLY	1		
LS200 DISHA	2” X 10’ DISCHARGE HOSE ASSEMBLY	2		
LS200 SUCHA	2” X 10’ SUCTION HOSE & FOOT VALVE ASSEMBLY	1		
GR 5X808	SAFETY HAT	4		
LS200 HBA	HOIST BRACKET ASSEMBLY	1		
LS200 HPA	HOIST PLUG ASSEMBLY	1		
LS200 INFO	LS200 RIG INFORMATION PACKAGE	1		
OPTIONAL ITEMS				
LS200QLA	LS200 QUILL, SPARE			
	LS200 WHEEL KIT ASSEMBLY; 2 WHEELS, AXEL & HANDLE			
EM25PG	POLY-SAL DRY POLYMER (GUAR GUM), 25LB PAIL			

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CONTENTS OF LS200 RIG TOOL BOX ASSEMBLY – DIESEL				
PART NO.	**DESCRIPTION**	**QTY**	**IN CRATE**	**AMT SHORT**
HD 991716	19” TOOL BOX	1		
THE FOLLOWING TOOLS GO IN THE BOTTOM OF THE TOOL BOX				
GR 4K601	12” ADJUSTABLE HACKSAW	1		
GR 2A637	3 LB. RIG HAMMER	1		
GR 6C178 – 8	8” ADJUSTABLE WRENCH	1		
GR 6CL78 – 12	12” ADJUSTABLE WRENCH	1		
DL 5560883	OIL CAN, 1 PT. FLEX SPOUT	1		
DL 5570023	GREASE GUN, LEVER TYPE	1		
GR 4ZF46	GREASE TUBE	1		
GR 3H385	WIRE BRUSH	1		
GR 1A421	LOCKING PLIERS	1		
GR 6C283	SCREWDRIVER, 6 PC. SET	1		
GE 3517	ROTOR / SHOE CLUTCH	1		
MA 438200	PUMP IMPELLER FOR BSGF-10	1		
LS200 TJ	M250 TOOL JOINT SET	1		
BA 1-39003	1-1/2” ROUND DIE STOCK	1		
HG CB1	CHAIN BREAKER	1		
GE 310-0101	TRANSMISSION GASKET	1		
MA 193930	PUMP HOUSING GASKET	1		
HD 25TD	1/4” X 25’ TIE DOWN ROPE	3		
THE FOLLOWING TOOLS GO IN THE TOP TRAY OF THE TOOL BOX				
GR 4L559	12” HACKSAW BLADES	3		
GR 2A500	FLAT FILE	1		
GR 5AI59	PIPE DOPE BRUSH	1		
GR 5X630	SLIP JOINT PLIERS	1		
GR 6A543	COMBINATION WRENCHES, 5PC. SET	1		
GR 6X995	TORPEDO LEVEL	1		
BA 31608	“T” HANDLE HEX KEY – 1/8”	1		
GR 1R313	MECHANICAL SHAFT SEAL FOR BSGF-10	2		
BA 1-927-10913	5/16” ALLEN WRENCH	1		
GR 4PZ45	3/4” COMBINATION WRENCH	1		
GR 6L092	#50 CONNECTING LINK	2		
BA 3830283	7/16” – 14 X 1-1/2” ROUND DIE	1		
BA 3830323	1/2” – 13 X 1-1/2“ ROUND DIE	1		
TE 7603SSS	SPARE SWIVEL SEALS	5		
	HOSE GASKETS	4		
	MUD PUMP SHIMS	2		
	TAPE MEASURE	1		
	POCKET KNIFE	1		

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Appendix 2 LLS100/200 Well Construction Checklist

Drill Rig Parts

- ☐ Mast and mounting bolts
- ☐ Mast Handle
- ☐ Mast tie-down ropes
- ☐ Mast tie-down stakes
- ☐ Drill motor and mounting bolts
- ☐ Winch handle
- ☐ Swivel and quill
- ☐ Spare swivel seals
- ☐ Drill pipe
- ☐ Drill bits
- ☐ Drill table
- ☐ Stabilizer legs
- ☐ Drill pipe slip
- ☐ Well casing slip
- ☐ Hoses
- ☐ Spare hose washers
- ☐ Casing flush tool
- ☐ Pipe Wrenches
- ☐ C-Wrenches
- ☐ Swivel wrench
- ☐ Flushing tool
- ☐ Pipe Lifting adaptor
- ☐ Tripod head
- ☐ Drill rig tool box (separate list)

Other Tools

- ☐ Gravel pack sifting screens
- ☐ Riser and pump rod threading tools
- ☐ Files, Set
- ☐ Hammer, claw
- ☐ Hand saw, wood
- ☐ Adjustable wrenches
- ☐ Hack Saw and spare blades
- ☐ Knife, utility
- ☐ Wire Cutter
- ☐ Shovels
- ☐ Pick or mattock
- ☐ Safety perimeter rope
- ☐ Stakes for safety perimeter
- ☐ Boards or tarp to lay tools on
- ☐ Boards to place under drill table legs

Mud Mixing and Monitoring

- ☐ Water transfer pump, hoses, foot valve
- ☐ Water storage & mud mixing drums
- ☐ Buckets
- ☐ Marsh funnel
- ☐ Bentonite
- ☐ Polymer
- ☐ Soda Ash
- ☐ pH Strips
- ☐ Strainer for mud samples
- ☐ Cuttings sample bags and marking pen
- ☐ Cuttings layout board or PVC gutter

Well Construction Tools and Supplies

- ☐ PVC casing
- ☐ Pre-cut PVC well screen
- ☐ PVC Couplings
- ☐ PVC Caps
- ☐ PVC Cement
- ☐ Bailer and rope
- ☐ Gravel pack
- ☐ Pump riser main
- ☐ Riser main couplings
- ☐ Pipe wrap tape
- ☐ Pump cylinder
- ☐ Pump rod
- ☐ Rod couplings and jam nuts
- ☐ Pump head assembly
- ☐ Pump safety rope
- ☐ Bleach for disinfecting
- ☐ Cement for surface seal and well pad
- ☐ Sand for concrete mix
- ☐ Gravel for concrete mix
- ☐ Boards or bricks to form well pad
- ☐ Rebar or steel reinforcing mesh
- ☐ Concrete finishing tools

Fuel and Lubricants

- ☐ Fuel for rig and mud pump
- ☐ Oil for rig and mud pump
- ☐ Funnels for fuel and oil
- ☐ Grease for swivel
- ☐ Pipe joint compound

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Well Construction Materials Quantities

Each 100-foot deep well typically consumes the following (some quantities depend on well depth and other factors):

- ☐ 4-6 sacks bentonite clay
- ☐ Drilling polymer
- ☐ 5, 7m (20 f t) lengths of PVC pipe, schedule 40, 4-inch (10cm dia.)
- ☐ 1, 7m (20 ft) length of well screen (commercially-cut PVC, hand-cut PVC, or stainless steel wire wrap)
- ☐ 8 PVC couplings for 4-inch pipe.
- ☐ 1 PVC cap or wooden point/end plug for 4-inch PVC pipe
- ☐ 1 liter each of PVC cement and primer.
- ☐ 5 liters bleach to disinfect the well. Dry bleach is OK.
- ☐ 4 sacks of cement for surface seal and well pad.
- ☐ 8 sacks of sand for concrete mix.
- ☐ 10 sacks of gravel for concrete mix.
- ☐ 3 sacks of washed, sieved coarse river gravel (2 to 3 mm diameter) for gravel pack. (Note: one "sack" = 1.1 cubic feet, or approximately 50 Kg, or 96 lb.)
- ☐ 4, 2m lengths of boards to build form for well pad (alt. use bricks for circular pad).
- ☐ 0.5 kg (1 lb.) nails, 10 cm long (4 inches) to build form for well pad.
- ☐ 15 meters (45 ft) 1 cm diameter reinforcement rod heavy gauge wire mesh for well pad.
- ☐ 40 liters (10 gallons) gasoline (petrol) for drill and mud pump engines.
- ☐ 4 liters (4 quarts) SAE 30 engine oil.
- ☐ 1 kg (2 pounds) heavy duty grease for drill pipe joints.
- ☐ 2 tubes grease for swivel seals
- ☐ 10'x12' heavy gauge plastic sheet to use as a liner for mud pits to prevent water loss.

Each hand pump to be installed requires (assuming a 100-foot deep well):

- ☐ 5, 20-foot lengths of 1.25 inch galvanized or schedule 40 PVC pipe (PVC will need centralizers)
- ☐ 12, PVC couplers (1.25 inch, male-thread with female-glue adapter).
- ☐ 12, PVC adapters (1.25 inch, female-thread with male-glue adapters).
- ☐ 10, 10-foot lengths steel pump rod (7/16 inch dia, 7/16 NC threaded ends. (Stainless steel preferred where water is corrosive).
- ☐ 12, steel couplings for the pump rod (matching thread).

Appendix 3 Step-By-Step Drilling with the LS100/200 Drill Rigs

When teaching the proper operation of the LS-100/200 drill rigs, take a novice crew through these well drilling steps slowly. Moving too quickly can result in frustration, accidents and perhaps injuries. Learning to drill a well is like learning a complex dance; each person has a different set of steps and must synchronize with the other dancers. It takes time for each crew member to learn their part. The different roles on a drilling crew are: Crew Chief, Driller, Assistant Driller, Mud Engineer, Helper, and Ambassador. Their roles change depending on what is happening.

Drilling is normally done in two stages; first with a small pilot bit, and then with a reaming bit that enlarges the borehole. The pilot hole identifies the different soil layers and the location of the aquifer. The borehole is then widened enough to allow approximately 2 inches of annular space between the casing and the borehole. Based on what is learned from the pilot hole, a well design is developed. While the hole is being reamed, the well components are being assembled so that they are ready to install as soon as the borehole is ready.

The major well drilling activities described in detail below are: setting up the drill site, drilling and making connections, removing drill pipe from the borehole (tripping out), securing the site overnight, installing well casing, flushing the well and placing gravel pack, developing the well, installing a hand pump, and demobilizing the drill site.

STEPS TO SETTING UP THE DRILL SITE

1. Drive stakes around the drill site and link them with a perimeter rope. Provide sufficient room in which to move and work, including storage space for tools and supplies that is out of reach by spectators.
2. Begin mixing drilling mud in a large trash can or 55-gallon drum. With water of the proper pH, it takes at least 30 minutes of vigorous mixing through the mud pump for bentonite to fully hydrate.
3. Dig two mud pits and a ditch leading from the borehole site. The pits should be large enough to settle out all of the drill cuttings. Place the pits no closer than 4 feet from the borehole so they do not interfere with the pump pad.
4. Assemble drill table with stabilizer tubes and position as directed by the Driller.
5. Use bubble level to ensure table is level. Adjust by digging out high spots.
6. Attach 3 tie down ropes to top of mast, erect mast & check vertical alignment.
7. Secure mast with three tie down ropes; space pegs to leave room for drill motor.
8. Attach drill motor (rotary power unit) to mast shuttle using hinge pins.
9. Position mud pump and lay out hoses to/from pump.
10. Prime pump with water and attach suction and discharge hoses, check gaskets.
11. Attach pump discharge hose to 3-way valve inlet on mast.
12. Attach short downhole delivery hose from 3-way valve to swivel.

13. Attach longer bypass hose to 3-way valve and to drill mud mixer.
14. Position the drill mud mixer discharge into the settling pit and drive in spike.
15. Check and fill drill motor with oil and gas (being careful to avoid spillage).
16. Attach short cord to spark plug cable as emergency drill motor "kill" switch.
17. Check drill motor and transmission oil and fill as required.
18. Grease swivel assembly and chain idler sprocket bearings with grease nipples.
19. Lubricate the winch, chain and sprockets, mast shuttle, and slip area with light oil.
20. Establish a secure position for all tools required to drill with the LS-100/200, including: 12" C-wrench, 24" pipe wrench, rig hammer, 3/16" "T" hex key, pipe joint compound (dope) and brush, wire brush, cleaning rags, oil can, fire extinguisher, tool box, sample bags, and marker pen.

DRILL CREW ROLES WHILE DRILLING AND MAKING CONNECTIONS

Crew Chief - Crew foreman who plans the work and does the paperwork.

- Maintains well construction report including; tally of drilled depth vs. time for each joint, depth of any changes in drilling conditions (vibration, color of mud, temperature change), and bags, washes and describes cuttings samples every 5 feet and when there is a change.
- Looks for early signs of problems (lost circulation, backflow, and equipment failure).
- Directs team's attention to problems and guides them in problem solving.

Driller - Responsible for operating the drill rig and making hole.

- Operates the drill motor, the winch and the 3-way valve.
- Controls primary drilling parameters; bit revolution and drilling time per joint.
- Controls drilling mud circulation with 3-way valve.
- Controls the connection procedure - amount of over-drill, circulation time, position of tool joint to break connection, height and speed of quill to make connection, steadies joint as he makes up the quill and then lifts pipe for Assistant Driller to pull slips.
- Looks for early signs of problems (lost circulation, backflow, and equipment failure).
- Directs Assistant Driller and Mud Engineer as needed to deal with problems.

Assistant Driller - Responsible for handling drill pipe and collecting samples.

- Ensures that the swivel assembly is serviced if any leakage is detected.
- Cleans pin & box connection of each drill pipe and dopes pin end.
- Sets drill pipe slip in table when Driller is ready to make a connection.
- Breaks connection with 12" C-wrench (with tap of hammer if required).
- Dopes the pin on the quill before adding the next joint.
- Pulls the slips once the Driller lifts the tool joint clear of the slips.
- Assists the Crew Chief by collecting cuttings sample for bagging.
- Re-fuels the drill motor as needed and protects the borehole from contamination.

Mud Engineer - Responsible for mixing mud and operating the mud system.

- Ensures an adequate reserve of water for drilling (from village water committee).
- Carefully monitors the level of fluid in the pits while drilling.
- Adds water to the pits on connections to maintain suction to the pump as hole drilled.
- Mixes bentonite to maintain mud viscosity (> 30 seconds Marsh Funnel viscosity).
- Fill barrels with water for use when needed during drilling and for development.
- Digs out settled solids from ditch, settling pit, and the suction pit.
- Skims any floating debris from the suction pit.
- Monitors return flow for signs of pump suction strainer clogging (lost circulation) and cleans pump suction hose strainer as needed.
- Monitors the mud pump unit and services or re-fuels it as needed (avoiding spillage).
- Maintains crowd control as needed to keep spectators outside the safety perimeter.

Helper – Assists where needed, may also be the driver.

Ambassador – Where appropriate interacts with spectators.

- Informs spectators about the work in progress and the motivation – the love of Jesus. Ideally, each crew member will be able to share their faith; but during drilling, they must attend to what is happening at the rig.
- Responsible for keeping spectators outside the safety perimeter.
- Helps the drill crew as needed, rotating to relieve other members.

STEPS FOR DRILLING AND MAKING CONNECTIONS

1. With a new joint made-up and the slip plate clear, Driller switches the 3-way valve to the horizontal position to direct drilling mud down the drill pipe.
2. Driller drills joint down with moderate rotary speed and lowers the joint with a winch handle speed of about ½ to1 revolution per second. (Only use the slip plate to help center the pipe on first joint until about half of the joint is drilled down, then remove the slip plate.)
3. Assistant Driller assists Crew Chief to take a cuttings sample when about half the joint drilled down, Crew Chief transfers it into sample bag marked with sample depth. Crew Chief records any indications of a change in drilling conditions, such as increased or decreased drill pipe vibration or a change in color or temperature of the returning mud from the borehole, and records the bit depth when these changes were seen.
4. Driller stops drilling down when the top of the drill pipe joint is about 2 inches below the top of the drill table. Driller stops the bit rotation by throttling back on the drill motor to idle.
5. Continue to circulate drilling mud into the drill pipe while Assistant Driller takes a cuttings sample for Crew Chief who transfers it into sample bag marked with sample depth.
6. After Assistant Driller confirms that no more cuttings are being returned (or one minute per 10 feet of pilot hole depth, whichever is longer), Driller raises tool joint to above the

table, Assistant Driller inserts the slip plate and Driller lowers the joint just enough to engage the lugs (weld bead below the joint) fully into the slip plate.

7. Driller switches 3-way valve to by-pass and directs drilling mud to the mixing jet. Then Assistant Driller uses large hex wrench to unscrew the quill from the top of the drill pipe (lugs on wrench rest on top of the quill hex). Right hand rule dictates correct direction to turn the quill to break out the joint.
8. When the quill is unscrewed sufficiently, the pipe joint should drop down onto the slip plate. If the joint will not drop free after the threads are disengaged this indicates that something is preventing the bit from going back to the bottom. Either all cuttings were not removed (and have slumped back to the bottom of the hole) or the hole has collapsed around the bit. Remedy is to quickly re-connect the quill and circulate/ream back to the bottom and repeat steps 6, 7 & 8 with extended circulation time.
9. Driller checks for drilling mud flowing out of the top of the drill pipe (back-flow). If back-flow occurs, this indicates that the fluid column in the borehole is heavier than the fluid column inside the drill pipe. Most often this is caused by insufficient circulating time before stopping to break the connection to remove all the cuttings from the borehole. Remedy is to quickly re-connect the quill and circulate/ream back to bottom and repeat steps 6, 7, 8 & 9 with extended circulation time (may also need to increase the viscosity of the drilling mud).
10. Proceed with adding new drill pipe joint. While doing this, Driller directs the Mud Engineer to add water to the pits as needed to keep the drilling mud level high enough to drill the next joint down. Additional bentonite mixed as needed to keep viscosity within target range of 30 – 35 Marsh Funnel seconds.
11. Driller increases throttle of drill motor until quill just begins to rotate. Assistant Driller applies small amount of pipe compound (dope) to the pin of the quill as Driller raises the drill motor to the top of the mast.
12. Assistant Driller checks to ensure the bore of the new drill pipe joint is clear and cleans pin & box threads with the wire brush. Assistant Driller dopes pin end thread only of new drill pipe joint.
13. Assistant Driller stabs pin end of new joint into the box end of the joint in the slips and makes-up the thread hand tight. Assistant Driller takes hold of the slip plate handle and prepares to pull it (once tool joint is lifted the plate is easy to pull).
14. With the Driller centering the top end of the new joint, Driller lowers the drill motor to engage the pin of the quill into the box end of the new joint. At slow rpm the pin end of the quill should start to engage into the drill pipe thread.
15. Before the quill threads are fully made up into the new joint, Driller begins raising the drill motor with the winch to lift the weight of the drill pipe off the slip plate.
16. When tool joint starts to lift off the slip plate, Assistant Driller pulls the slip plate out of the drill table.

17. When Mud Engineer confirms that any water addition and drilling mud treatment has been completed the crew is ready to repeat the process from Step 1 until the desired pilot hole depth has been reached or maximum of 100 ft drilled.

DRILL CREW ROLES WHILE TRIPPING OUT OF THE BOREHOLE

Crew Chief - Crew foreman who plans the work and does the paperwork.

- Develops detailed plan for well construction, including screen length and depth, volume of filter pack required, and length of hand pump riser main and pump rod required.
- Directs team's attention to problems and guides them in problem solving.

Driller - Responsible for ensuring pipe is not dropped while tripping out.

- Lead crew member using a C-wrench to lift pipe.
- Ensures Helper understands lift and hold instructions with C-wrench.
- Ensures Assistant Driller understands when to pull out slip plate and when to push in slip plate.
- Controls the lifting procedure – height of lift on each stroke, ensures good communication during lifting and ensures the lowest C-wrench is placed under the tool joint as it is set down on the slip plate to break out the next joint.
- Directs Assistant Driller and Mud Engineer as needed to deal with identified problems

Assistant Driller - Responsible for handling the slip plate and breaking out pipe joints.

- Pulls out slip only as required to allow passage of tool joint, otherwise keeps in place.
- Breaks connection with 24" pipe wrench (with tap of hammer if required).

Helper - Second crew member using C-wrench to lift pipe.

- Follows Driller's lift and hold instructions with C-wrench.
- Follows Driller's instructions re which C-wrench placed under the next tool joint.

Ambassador - Interacts with spectators.

- Keeps spectators outside the safety perimeter and answering questions.
- Rotates into the Assistant Driller's or the Helper's position as needed to spell them during tripping out.

STEPS FOR TRIPPING DRILL PIPE AND BIT OUT OF THE BOREHOLE

1. After circulating sufficiently to clear all cuttings, Driller lifts the pipe connection above the table and the Assistant Driller pushes the slip plate into the table. The Assistant Driller then inserts a C-wrench below the tool joint on top of the slip plate (this will allow the pipe to be lifted with the C-wrench once the connection has been broken out from the quill).
2. Driller switches 3-way valve to by-pass and directs drilling mud to the mixing jet. Then Assistant Driller uses hex wrench to unscrew quill from top of the drill pipe (lugs on

wrench rest on top of the quill hex). Right hand rule dictates correct direction to turn the quill to break out the joint.

3. When the quill is unscrewed sufficiently, the joint should drop down onto the C-wrench. If the joint does not drop free after the thread is disengaged this indicates something is preventing the bit from going back to the bottom. Either all the cuttings were not removed (and have slumped back to the bottom of the hole) or the hole has collapsed around the bit. Remedy is to quickly re-connect the quill and circulate/ream back to bottom and repeat steps 1,2 and 3 after some extended circulation time.
4. Driller checks for drilling mud flowing out of the top of the drill pipe (back-flow). If back-flow occurs, this indicates that the fluid column in the borehole is heavier than the fluid column inside the drill pipe. Most often this is caused by insufficient circulating time before stopping to break the connection to remove all the cuttings from the borehole. Remedy is to quickly re-connect the quill and circulate/ream back to bottom and repeat steps 1,2,3 & 4 after some extended circulation time (may also want to increase the viscosity of the drilling mud).
5. Driller stops the drill motor and raises it to the height where it can be swiveled above the 3-way valve and out of the way for tripping. After covering the borehole in case anything is dropped, Assistant Driller removes one of the hinge bolts. Driller and Assistant Driller swivel the rotary power unit assembly and secure it for tripping.
6. Mud Engineer stops the mud pump, finds the other C-wrench and prepares to help Driller with pulling the pipe.
7. With a straight back and bent knees, Assistant Driller lifts the pipe up off the slip plate with the C-wrench. Helper slips his C-wrench under the drillers C-wrench as soon as there is room to do so and helps lift the pipe. Together they lift only a short stroke by straightening their legs until Driller stops the lift by saying “hold!” (Don’t try to lift above this point by bending elbows!)
8. Crew member with C-wrench on top takes full weight and says “I have.”
9. At this signal, crew member with bottom C-wrench relaxes and bends his/her knees to slide the wrench down to get a new grip (without disengaging the wrench from around the pipe) and, when ready to take the full weight of the pipe, says “I have.”
10. At this signal, crew member with top C-wrench relaxes and bends his/her knees to slide the wrench down to get a new grip (without disengaging the wrench from around the pipe) and, when ready to take the weight of the pipe, says “lift.”
11. Together they lift only a short stroke by straightening their legs until Driller stops the lift by saying “hold!” (Don’t try to lift above this point by bending elbows!) Any extra resistance while lifting is reported to the Crew Chief as a tight spot.
12. Repeat steps 8 through 11 until the next tool joint is about to reach the slip plate. The Assistant Driller pulls the slip plate out of the way only when the tool joint can be lifted clear of the slip plate in one stroke. In this way the slip plate can be pushed back into place immediately after the tool joint is pulled above the table.

13. Crew member with C-wrench on top takes full weight and says “I have.”
14. At this signal, crew member with bottom C-wrench relaxes and bends his/her knees to slide the wrench down to get a new grip below the tool joint. (Must disengage the wrench from around the pipe to do this) and, when ready to take the full weight of the pipe, says “down.”
15. Together they lower the weight of the pipe onto the slip plate, with a C-wrench underneath it. (If the lugs on the pipe do not line up with the slip plate opening they will have to rotate their C-wrenches, pick up the weight together, and rotate the pipe until the lugs line up and then lower the pipe until the weight is on the bottom C-wrench.)
16. The Assistant Driller uses the 24” pipe wrench to break the threaded connection (with the aid of a sharp hammer blow if it is too tight).
17. The Crew Chief unscrews the joint by hand and lays it down separate from the other drill pipe in order to tally all of the pipe as it is removed.
18. Repeat steps 7 through 17 until all of the pipe (and the bit) is pulled from the borehole but with Helper and Assistant Driller taking the role dictated by whose C-wrench is the one sitting on the slip plate under the tool joint.
19. Remember to switch out crew members as they get fatigued and as necessary to give every crew member the opportunity to learn each role.

STEPS TO SECURE THE SITE AT THE END OF THE DAY’S DRILLING

1. The Driller and Assistant Driller remove all drill pipe from the borehole, clean it, and stack it on boards. If the hole collapses during the night, any drill pipe and bit left in the hole will probably be lost. If the hole is very unstable, then it may be necessary to work into the night to finish reaming, setting the casing and placing the gravel pack.
2. The Driller and Assistant Driller clean the rig, grease the swivel, and lubricate the chain, winch and idler sprockets. Lower the drill motor so the rig is not top-heavy.
3. The Driller covers the borehole and builds a dike to prevent rain water from flowing into it.
4. The Mud Engineer checks oil and fuel levels in the drill motor and mud pump motor, refilling as needed (taking care not to spill fuel or oil).
5. The Assistant Driller and Helpers clean and secure all tools, and cover any bentonite or cement sacks with plastic tarps.
6. The Crew Chief and Driller inspect the site for loose tools, uncovered equipment, and tripping hazards.
7. If the site is not secure, the Crew Chief posts a guard to protect the rig and supplies.
8. The Crew Chief completes the day’s drilling log and discusses plans for the next day with the crew.

STEPS FOR INSTALLING THE WELL CASING

1. After the pilot hole is finished, and before reaming begins, the Crew Chief and Driller develop a well construction plan based on the results of the pilot hole, as recorded in the Crew Chief's well log. The key decisions to be made include: the upper and lower depths of the aquifer, the static water level, the final depth of the well, how much well screen is to be used and where it will be placed, the volume of gravel pack needed, and where the pump cylinder will be placed.
2. Mud Engineer pumps out bentonite from the mud pits, refills the pits with water and mixes fresh polymer drilling mud. The Marsh Funnel viscosity should be at least 30 seconds. This drilling mud will replace the bentonite in the borehole. Using polymer instead of bentonite for reaming makes it easier to develop the well, since polymer breaks down with chlorine. However, polymer is not as dense as bentonite, so if the hole is very unstable there is a greater chance of it collapsing with polymer alone. This is a judgment call for the Crew Chief and Driller, weighing the chance of losing the hole versus more effort to remove all of the bentonite when developing the well. The choice becomes easier as more experience is gained drilling in a particular formation.
3. Ream the hole to about five feet below the final well depth. If there is a chance that the borehole walls may slough, allow more room below the bottom of the casing so the final well depth can be reached with the casing.
4. While tripping out the drill pipe and reaming bit, carefully note any zones where resistance is encountered. This could be a layer of swelling clay and it will need to be drilled out by making several passes. The well casing must not be forced past such a zone, since it may clog the slots in the well screen and will prevent the gravel pack from being properly placed around the well screen.
5. While the hole is being reamed, Assistant Driller and Helper prepare and clean the 4-inch PVC well casing, cut well screen, and glue on couplings as needed. Use a file to remove any burrs on pipe ends that would interfere with make-up. Mark on the top section of well casing where the ground level will be, leaving about 3 feet of casing to stick out of the ground.
6. Assistant Driller and Helper measure out the volume of sifted and washed gravel pack (coarse sand) as determined by the Crew Chief. Sifting and washing the gravel pack should be started at least a day before it is needed, since it can take a long time.
7. The casing and gravel pack must be ready before the reaming is completed, because it should be placed in the borehole soon after the reaming bit and drill pipe are removed, or else the borehole could collapse. Lay out the screen and casing sections on blocks of wood to keep them off of the dirt (that dirt will end up in the well.) Count the sections to ensure that they match the Crew Chief's well design.
8. After reaming is completed (all swelling clay zones opened up and all cuttings removed from the borehole) and the drill pipe and reaming bit have been tripped out of the borehole, remove the hinge pin from the side opposite the 3-way valve and swing the drill

motor out of the way. Do not completely remove the drill motor from the mast, since it may be necessary to go back into the hole to re-drill a swollen or collapsed section.

9. While the Driller and Assistant Driller are installing the casing, Mud Engineer fills three 55 gal drums with water to use for flushing out the borehole and removes all drilling mud from the mud pump and hoses. Pump out the mud pits so there will be capacity to receive the water used to flush the borehole.
10. Replace the 2-inch slip plate with the 4-inch slip plate that is designed to hold 4-inch PVC well casing.
11. The Assistant Driller secures a rope around the top of the first section of well screen and casing and the Driller and Assistant Driller lower the casing into the borehole, with the coupling (or bell) end up, until it rests on the slip plate. If a cap has been placed on the end of the casing, it will take time for the drilling mud to flow into the casing. Alternately, the casing can be installed without a cap and the bottom sealed later (see below).
12. Clean the inside of the coupling (or bell end) and the end of the next section of casing with a dry cloth. Apply PVC cement to the inside of the coupling and the end of the next section. [If the cement requires a primer, apply it first to both surfaces and allow it to dry.] Quickly slide the two sections together, making a quarter turn. Make sure the casing end is completely inserted into the coupling. Allow 5 to 10 minutes for the PVC cement to completely dry (depends on the cement and the weather).
13. For a well deeper than around 60 feet, the upper casing joints will carry a significant weight, especially if the water table is deep. So it may be necessary to use short self-tapping stainless steel screws in addition to the PVC cement to make sure the sections do not separate as they are being lowered. The screws should not extend into the casing. It is helpful to use a small hand drill to make a starter hole for the screws.
14. Once the PVC cement is thoroughly dry, re-tie the rope to the upper section of casing, pull the slip out to let the coupling pass, replace the slip, and then lower the casing into the borehole. Try not to let the casing hit the sides of the borehole. Repeat until the ground surface mark has been reached on the top casing section. Securely tie the casing to the rig so that it can't drop into the borehole. Proceed immediately to flushing the well and placing the gravel pack.

STEPS FOR FLUSHING THE WELL AND PLACING GRAVEL PACK

1. Screw the casing flushing tool onto the quill, swing the drill motor back in place and secure it with the hinge bolt. Place the lower end of the flushing tool over the casing, put the mud pump suction hose into one of the fresh water drums, and slowly begin to circulate water through the casing. (Bypass to a drum as needed so as not to waste water.) Pump clean water until the returns from the borehole are clear. This will flush the drilling mud out of the borehole. Use a plastic bag if needed to form a seal between the flushing tool and casing.

2. As the return water begins to clear, re-fill one or two barrels with water, add chlorine to them and mix thoroughly (use unscented laundry 5% bleach, not swimming pool chlorine powder). Use caution when handling chlorine, as it is a skin and eye irritant. Mix 1 gallon of unscented laundry 5% bleach in 100 gallons of water, or 2 liters in 200 liters (55 gallons) of water. A chlorine concentration of 500 mg/l (ppm) is required to break down drilling polymer (e.g. Polysal) and prevent it from promoting bacterial growth in the well water. Circulate the chlorinated water through the casing to break down the polymer.
3. While drilling mud and water is slowly flowing out of the borehole, carefully pour the gravel pack down the annular space between the borehole and casing. Pouring the gravel pack too quickly will cause it to hang up (bridge) between the casing and borehole wall. Gently shake the casing to keep the gravel pack settling to the bottom of the borehole. Use a bucket to measure the volume of gravel pack being placed.
4. If the casing was installed without a bottom cap, stop adding gravel pack when the end of the casing has been covered. Fill a small plastic bag with wet cement, seal the bag so there is no air in it, and drop the bag inside the casing. It should fall to the bottom and when the cement sets it will close off the end of the casing.
5. When about half the volume of gravel pack has been added, according to the Crew Chief's calculations, stop and measure the depth to the top of the gravel pack. If it is much lower than the mid-point of the well screen, then the borehole was either deeper or wider than anticipated. The amount of gravel pack needed to complete the well must be increased. If the top of the gravel pack is significantly higher than it should be according to the volume added, then there has probably been a bridge. Shake the casing while increasing the flow of water into the casing. Let the gravel pack settle then measure again. Repeat until the bridge has been broken up and the gravel pack settles to its proper position.
6. Continue adding gravel pack, measuring periodically, until the top of the gravel pack is about 3 feet (1 meter) above the top of the well screen. If it is late in the day, work can be stopped at this stage (after properly securing the drill site), but not until the gravel pack has been completed.
7. Disconnect the flushing tool, remove the drill motor from the mast, and place a cap over the top of the well. It is best to leave the drill table and mast in place.
8. Backfill the annular space using clean sand or cuttings up to a depth of 20 feet (about 6 meters) below the ground surface.
9. Fill the last 20 feet (6 m) of the annular space, up to the ground surface, with a concrete sanitary seal consisting of either neat cement (no sand or gravel) or bentonite. The concrete or bentonite should be wet enough to pour easily. Do not move the casing (don't start developing the well) until the seal has set at least 24 hours.
10. If the base of the pump that you will be installing needs to extend below the concrete pump pad, then the pump base should be set into the sanitary seal while the concrete is still wet. In this case, it will be necessary at this stage to build the form for the pump pad (see below) so the pump base can be placed at the proper height.

STEPS FOR DEVELOPING THE WELL

1. Attach three lengths of drill pipe (15 feet) to each leg of the tripod adaptor, attach a pulley to the adaptor, and thread a rope through the pulley. Raise the tripod and center it over the well casing.
2. Attach a bailer to the rope, taking care to use a secure knot that centers the rope.
3. Measure the static water level in the casing using the bailer or a sounding cord.
4. Continuously bail water from the well for about 15 minutes then measure to see how far the water table has been drawn down. Time how long it takes for the water level to recover. The recovery volume divided by the recovery time gives an approximate flow rate for the well. To calculate recovery volume, subtract the lower water level from the upper water level. A 4-inch casing holds 0.66 gallons per foot or 8.7 liters per meter.
5. Surge and bail the well for 5 to 10 minutes, working from the bottom of the well screen toward the top. Do not surge violently, as that may generate a suction that can collapse the well screen and destroy the well.

Repeat steps 1 through 5 until no further improvement in the recovery rate is seen and only clear water is bailed from the bottom of the casing. Three things must be accomplished for the well to be fully developed: (1) drilling mud removed from the borehole, (2) the wall cake that forms on the sides of the borehole broken down, and (3) flow paths establish through the aquifer into the well. It is relatively easy to remove the drilling mud but if you stop there, the well has not been developed. It normally takes a minimum of several hours and can possibly take a day or more to properly develop a well. It is not unusual for a well to take several hours, or even over night, to recover after the initial bailing. But with persistent development, a good flow can usually be developed if the aquifer is suitable.

STEPS FOR INSTALLING A HAND PUMP

1. Build a form for the concrete pad around the pump base. If using wood, a 6-foot by 6-foot square form is preferred. If the form is to be made using concrete blocks, bricks, or rocks, a circular design with a 6-foot diameter is easier to work with. In either case, the pad should be 4 inches thick and reinforced with steel rod or mesh. The pad should be elevated so it remains above water that may collect on the ground and it should have a cement trough or other means to direct spilled water away from the pump area. The concrete mix should have a ratio of X parts cement to x parts sand and x parts gravel.
2. There are several common designs for the pump base and each has different requirements for proper installation. In all cases, a portion of the pump base is securely set into the concrete of the pump pad. Once the pump base is secured and the pad has been poured and finished, the concrete should be allowed to set for several days before installing the pump. If the pump base is disturbed before the concrete sets, cracks may form that will weaken the base and could let contaminated water seep into the well.

3. The depth at which the pump cylinder is to be set was decided when the well was designed after completion of the pilot hole. But a more accurate static water level might be determined after developing the well; if this is the case, the pump depth may need to be revised. Ideally, the pump cylinder should be placed several feet above the top of the well screen so turbulence from the pump doesn't disturb the gravel pack. However, it is more important to place the pump cylinder deep enough in the well so that it will always be submerged, especially if the water table fluctuates.
4. Connect the first section of sucker rod to the pump piston. If it is a threaded sucker rod, use lock nuts against the coupling and tighten them securely. (Disconnected sucker rod is one of the most common causes of pump failure.)
5. Thread the first section of rising main into the top of the pump cylinder. Thread a coupling onto the upper end of the rising main. Attach a pipe clamp to the rising main and lower the cylinder and pipe into the well casing. Let the upper coupling rest on the small slip from the drill rig, placed over the pump base.
6. Connect the next section of rising main and sucker rod and lower it into the well, being careful to keep a pipe clamp securely attached to the rising main to prevent it from slipping into the well.
7. Depending on the depth of the well, it may be necessary to use the tripod and pulley to safely lower the pump assembly into the well.
8. When the pump cylinder is at the proper depth in the well, finish assembly of the linkage and pump handle. The procedure depends on the type of hand pump, but in each case care must be taken to properly adjust the stroke of the pump piston so that it does not hit against the upper or lower ends of the pump cylinder.
9. Add enough liquid or dry bleach to achieve a 250 mg/l (ppm) chlorine concentration in the well and let it sit 24 hours before pumping it out. When the water no longer has a chlorine smell or taste then it is safe to drink.
10. Collect a water sample and analyze it for the parameters in the Lifewater test kit.

STEPS FOR DEMOBILIZING THE DRILL SITE

1. Pump out the mud pits and then flush the mud pump and hoses with clean water.
2. Backfill the mud pits with cuttings from the borehole and the soil that was dug out of the pits. Level the drill site and remove all trash.
3. Drain fuel and used oil from the drill motor (do not drain transmission oil).
4. Service the swivel and then clean and pack up all tools, equipment and supplies.
5. Review with the village water committee their plans for maintaining the well.

Appendix 4 Drilling Mud Additive Amounts

The volume of drilling mud needed depends on the size of the mud pit and the final volume of the borehole. The channel mud pit design shown in Figure 52 has a volume of 650 liters (170 gal). Borehole volume depends on diameter and depth. When using 4 inch (100 mm) well casing, an 8 inch (20 cm) diameter borehole is recommended to allow a good gravel pack. This size of borehole has a volume of 32.4 liters per meter (2.6 gallons per foot). The volume of other size boreholes is shown in Table 2 (use the borehole bottom figures).

Borehole Size	Mud Pit Volume	Borehole volume	Total Volume
200 mm (8") x 30 M (100')	650 L (170 gal.)	970 L (260 gal)	1,620 L (410 gal.)
200 mm (8") x 60 M (200')	650 L (170 gal.)	1,940 L (520 gal)	2,590 L (690 gal.)

Bentonite

The amount of bentonite required for a borehole depends on the total mud volume needed as described above and on the viscosity of the mud required to lift cuttings. The standard rate is one 50-pound sack (23 kg) of bentonite per 100 gallons (378 L) of water. So in the above example with a 100 foot deep well, about 4 sacks of bentonite would be needed. Using a high grade of bentonite will require less powder to obtain a given viscosity than using a low grade of bentonite. Therefore, the actual amount of bentonite to use must be determined by adding a small amount at a time and checking the viscosity. It is wise to always have more bentonite on hand than the calculations suggest.

Measuring Additives

Measuring the proper amounts of soda ash and polymer is easy since there are only a few common vessels - like a bucket, large trash can, drum, or mud pit – that are used on the drill site. Take a standard soda can and cut it in half to use as a scoop for measuring. The following tables show the number of half soda can scoops to use for the common drill site vessels.



Soda Ash

Based on a rate of 60 gm per 100 liters (0.5 lb per 100 gal)

Vessel size	Liquid volume	Half a soda can scoop
Bucket	20 liters (5 gal)	handful
Large trash can	114 liters (30 gal)	1/2 scoop
Oil drum	190 liters (50 gal)	full scoop
Channel mud pit	650 liters (170 gal)	2-1/2 scoops

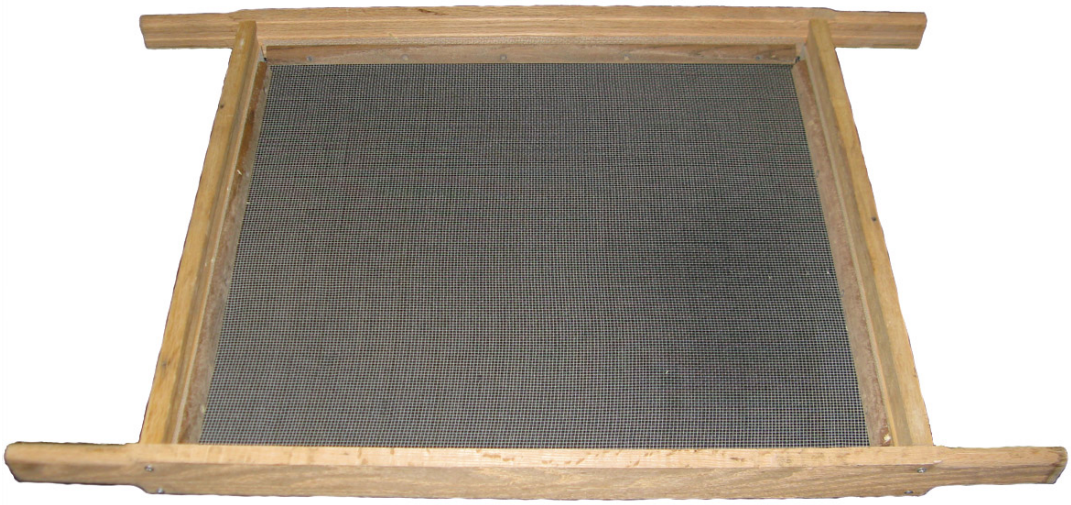
Dry Polymer added to Bentonite
Bariod “EZ-Mud DP” or WYO-BEN “Kwik-Vis D”
Based on a rate of 30 gm per 100 liters (0.25 lb per 100 gal)

Vessel size	Liquid volume	Half a soda can scoop
Bucket	20 liters (5 gal)	pinch
Large trash can	114 liters (30 gal)	handful
Oil drum	190 liters (50 gal)	1/4 scoop
Channel mud pit	650 liters (170 gal)	1 scoop

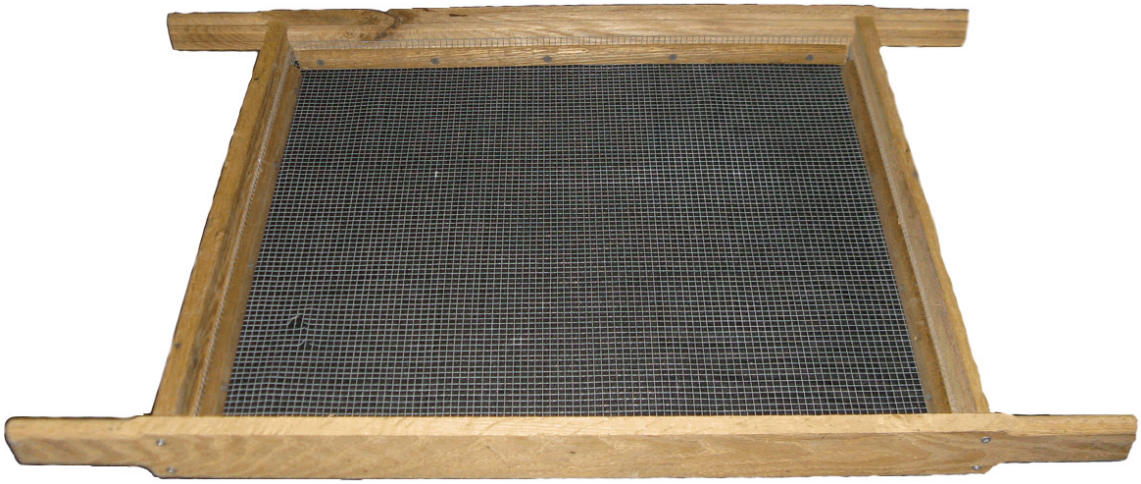
Dry Polymer used without Bentonite
Bariod “EZ-Mud DP” or WYO-BEN “Kwik-Vis D”
Based on a rate of 90 gm per 100 liters (0.75 lb per 100 gal)

Vessel size	Liquid volume	Half a soda can scoop
Large trash can	114 liters (30 gal)	1/2 scoop
Oil drum	190 liters (50 gal)	1 scoop
Channel mud pit	650 liters (170 gal)	2-1/2 scoops

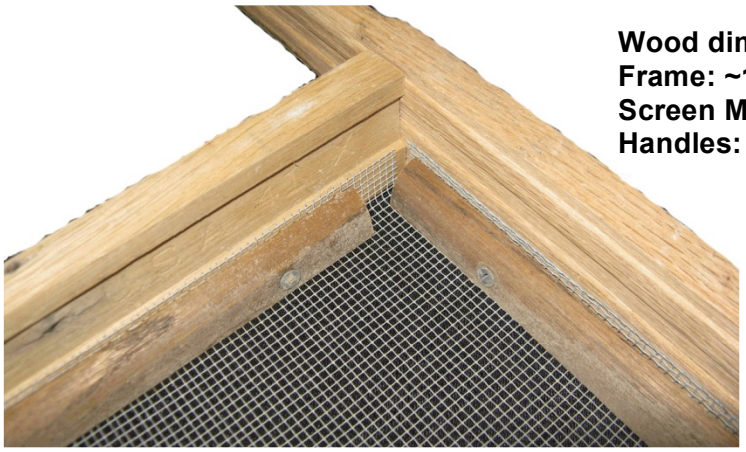
Appendix 5 Making Gravel Pack Screens



Small mesh: ~3 squares per cm (~8/inch)



Medium mesh: ~1.6 squares per cm (4/inch)



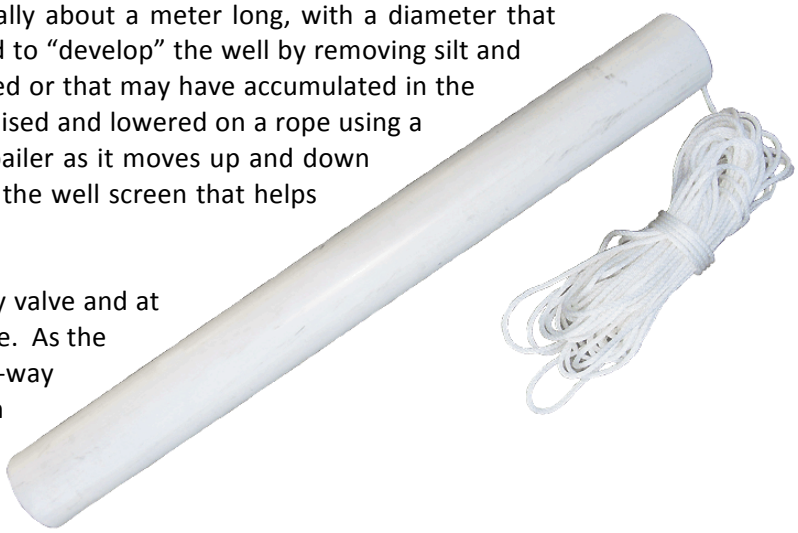
Corner Detail

Wood dimensions: ~2”x3/4” (5cm x 2cm)
Frame: ~16”x22” (40cm x 56cm)
Screen Material: ~18”x24” (46cm x 61cm)
Handles: 4” (10cm)

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Appendix 6 Bailer Construction

A "bailer" is a length of PVC pipe, usually about a meter long, with a diameter that easily fits into the well casing. It is used to "develop" the well by removing silt and sand that remains after the well is drilled or that may have accumulated in the well over time. The bailer is typically raised and lowered on a rope using a tripod and pulley. The motion of the bailer as it moves up and down under water creates a "surge" through the well screen that helps to improve well yield.

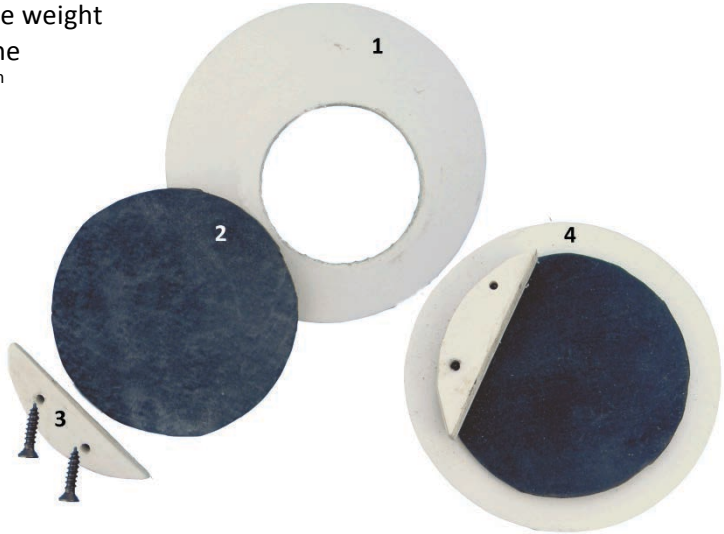


At the bottom of the bailer is a one-way valve and at the top is an attachment point for a rope. As the bailer is lowered into the well, the one-way valve allows it to fill with water. When the bailer is raised, the valve holds the water. The bailer is brought to the surface and tipped upside down to empty it.

Bailers can be purchased from drilling supply companies, but they are relatively easy to make. There are several different ways to make the one-way valve. One example is described below:

Step 1. Cut a disk out of plastic with a diameter that just fits into the bailer. (A flattened piece of PVC casing is a good material to use.) Cut a hole in the center of the disk that is about half the diameter of the disk. For a 3-inch (77 mm) diameter bailer, the disk should be 76 mm in diameter and the hole around 38-40 mm.

Step 2. Cut a disk out of a piece of heavy truck tire inner tube or similar rubber. This "flapper valve" needs to be flexible but thick enough so that the weight of the water can't push it through the hole in the plastic disk. The flapper should be around 3/4th the diameter of the plastic disk; that would be 58-60 mm for a 3-inch bailer. It should be larger than the hole by at least 5 mm on all sides.



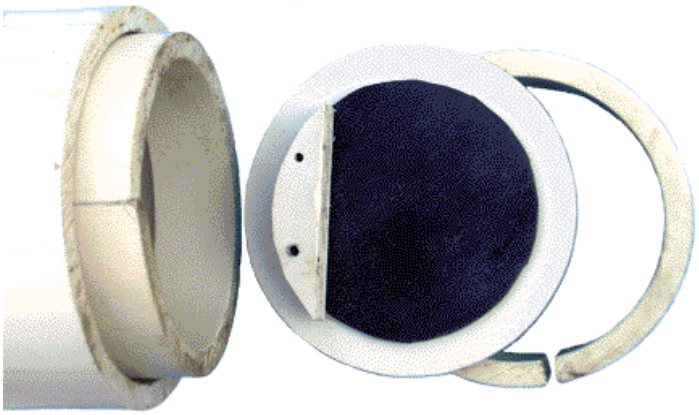
Step 3. Cut a shape out of PVC as shown and drill two holes in it slightly smaller than the diameter of a small wood or metal screw. Stainless steel screws are best since they will not rust like regular wood screws.

Step 4. Assemble the pieces as shown.

Step 5. Cut off two rings about 10-15 mm wide from the same diameter of PVC pipe that you are using for the bailer. Cut out a section from each ring about 30 mm wide. You should be able to compress the

rings and slide them into the bailer so they fit snugly. These rings will be the "keepers" for the disk and flapper assembly.

Step 6. Insert into the bailer one ring, the disk assembly (screw heads pointing out), and the second ring. Then remove them to make adjustments needed to ensure a snug fit. Once a good fit is obtained, put PVC cement on the inside of the pipe where the first ring will sit and then insert the first ring. Put a small amount of PVC on the end of the first ring, then press in the disk assembly. Finally, glue and insert the second ring to hold the disk tightly. The bottom edge of the second ring should be even with the bottom of the bailer.



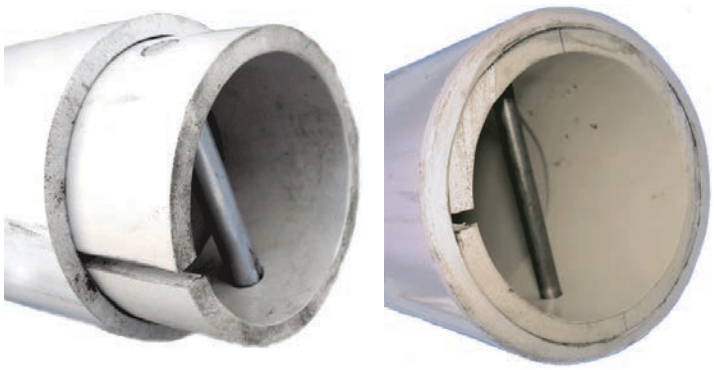


The bottom end of the bailer should look like this. Putting the screw heads on the outside makes it possible to replace the rubber flapper valve if it wears out. Round-off the outer edge of the bailer bottom so that it will not cause damage to the slots in the well screen.

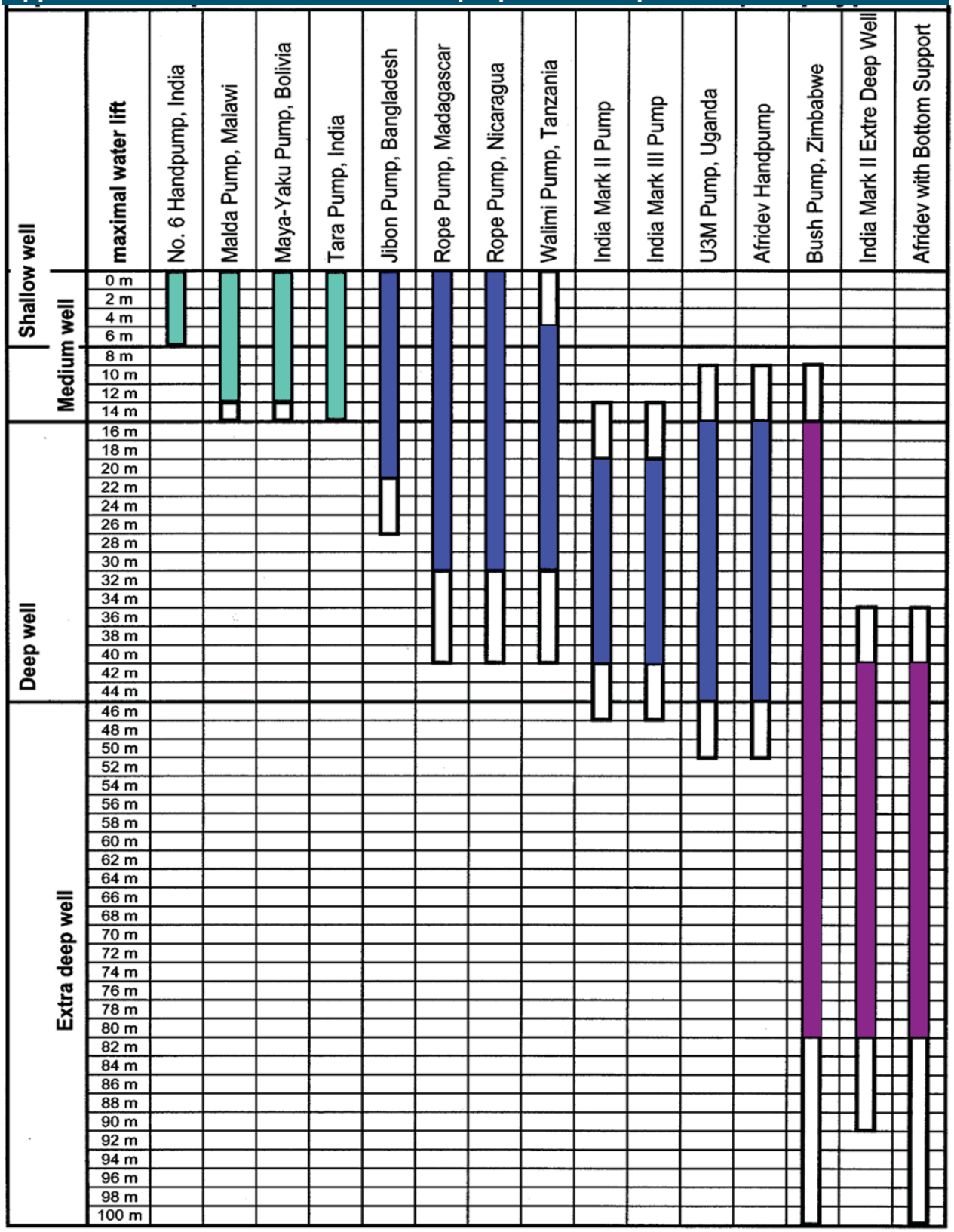
Step 7. There are two ways to make an attachment point for the rope. The easiest is to drill two holes on opposite sides of the bailer about 20 mm below the top. Run a stiff wire through the holes to form a loop and wrap the ends of the wire around the loop, as shown. Heavy-wall PVC pipe is shown in these illustrations. If thin PVC pipe is used, then the top of the bailer must be reinforced with a PVC ring similar to those used in the bailer bottom.



Another way to make the rope attachment is to cut a PVC ring and drill two holes through it into which a steel rod is inserted. When this assembly is glued into the top of the bailer it provides a secure attachment point that will not damage the well screen.



Appendix 7 Hand Pump Operation Depths



Adapted from "Buyer's - and technology selection Guide for Public Domain Handpumps for Drinking Water" Erpf, Karl 2004. SKAT Foundation, Switzerland

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Appendix 8 Well Disinfection Formulas

The math involved in calculating chlorine concentrations is valuable to know for situations that do not fit the "Table Method" described in the Well Disinfection lesson. The Formula Method involves measurements of the well and two calculations:

1. The volume of water in the casing and the gravel pack.
2. The amount of chlorine needed depending on the concentration of the chlorine source.

The following paragraphs describe these calculations in detail.

1. Calculating Well Volume

The volume of water in the casing and gravel pack is found by the formula, $V=\pi R^2H$; where V is volume in liters, π represents pi (3.14), R is the radius of the well casing in millimeters (radius is the diameter divided by 2), and H is the depth of water in the well in meters (distance from the bottom of the well to the top of the water). Divide the result by 1,000 to convert cubic milliliters to liters. To calculate the water in the "annular space" between the well casing and the borehole wall, use the same volume formula. For radius, use ½ of the borehole diameter and for height use the same water column height as for the casing volume. [The borehole should normally be about 50 mm (2") greater in diameter than the well casing; otherwise the gravel pack will not be very effective.] Then subtract the well casing volume from the total borehole volume to get the volume of the gravel pack in the annular space. Multiply the result by 30% to account for the porosity of the gravel pack. Finally, add the casing volume to the adjusted annular space volume. This is the total volume of water in the well that needs to be disinfected.

The following table gives well volumes in liters per meter for different casing diameters. A 50mm thick gravel pack is assumed.

Casing Diameter	75mm (3")	100mm (4")	125mm (5")	150mm (6")
Well volume: liters per meter	6.8	10.8	15.8	21.8

A sample volume calculation: A 100 mm diameter casing (Dc) is in a 150 mm borehole (Db) with a good gravel pack. The well is 30 meters deep (Hd) and the distance from the surface to the water level is 15 meters (Hw). (All results are rounded off.)

The well casing volume is: $Vc= \pi*(Dc/2)^2 *(Hd-Hw) /1000$

$Vc = 3.14*50^2 *(30-15)/1000 = 122$ liters

The total borehole volume (including the casing) is: $Vb=\pi(Db/2)^2 (Hd-Hw) /1000$

$Vb = 3.14*75^2 *(30-15)/1000 = 265$ liters.

The annular space volume (Va) is Vb-Vc or 265 liters minus 122 liters = 143 liters. Only 30% annular space is filled with the water; the rest is gravel. So the water volume in the annular space is Va x 0.3 = 143 x 0.3 = 43 liters.

The total volume of water in the well (Vw) is the casing (Vc) plus the adjusted annular space (Va); Vw=Vc+Va = 122+43 = 165 liters.

2. Calculating Chlorine Amount

The amount of chlorine to add depends on the concentration of the chlorine source. Chlorine is commonly available as dilute laundry bleach (3.5% to 5% chlorine) or as calcium hypochlorite powder used for drinking water treatment (typically 70% chlorine). Chlorine is unstable (and dangerous in high concentrations) so what might have come from the factory as a 5% solution could degrade to 3.5% after a year or so.

A sample concentration calculation: We calculated the volume of water to disinfect; now we need to add the right amount of chlorine to get a chlorine concentration of 250 mg/l in the well. The source of chlorine we have is laundry bleach in a bottle that looks like it has been on the store shelf for a long time. So we will assume that it is only 3.5% chlorine.

The formula for working with concentrations is V*C=Vw*Cw. The volume of bleach to add (V) is what we want to find out and we know the concentration (C) of that bleach (3.5%), the volume of water in the well (Vw) and the concentration in the well (Cw) that we want to reach.
Rearranging the formula gives V=Vw*(Cw/C) or
V = 165 liters * 0.00025/0.035 = 165*.007 = 1.2 liters.
[250 mg/liter is the same as 250 parts per million, then 250/1,000,000 = 0.00025 and 3.5%, or 3.5 parts per hundred, is 35/100=0.035].

The final result from this example of the “high precision” method is 1.2 liters of 3.5% bleach added to 165 liters of water in the well.

Another sample concentration calculation: This example uses the same well as before, but the source of chlorine is calcium hypochlorite powder. The desired chlorine concentration in the well (Cw) is still 250 mg/liter, or 0.25 grams per liter. At a source concentration (C) of 70%, the calcium hypochlorite powder has 0.7 grams of chlorine per gram of powder (70/100=0.7). Using the concentration formula, V=Vw*(Cw/C) the calculation is V = 165 liters * 0.25/0.7 = 165*0.36 = 59 grams. A tablespoon (15 cc) of calcium hypochlorite powder weighs about 12 grams. So in this example, we would dissolve 5 tablespoons (59/12=4.9) of calcium hypochlorite powder in a bucket of water and pour that water into the well before installing the pump.

Casing Diameter / **Disinfection Rate**	75mm (3")	100 mm (4")	125 mm (5")	150 mm (6")
Grams of 70% powdered Chlorine per meter	2.4	3.9	5.6	7.8

Appendix 9 Well Cleanout Tool Fabrication Instructions

Overview

When a hand pump has been removed from a borehole, and the borehole is left open, it is common for children to drop rocks into the hole. This makes a very intriguing sound but renders the well unusable. A tool is needed to remove these rocks without having to re-drill the well.

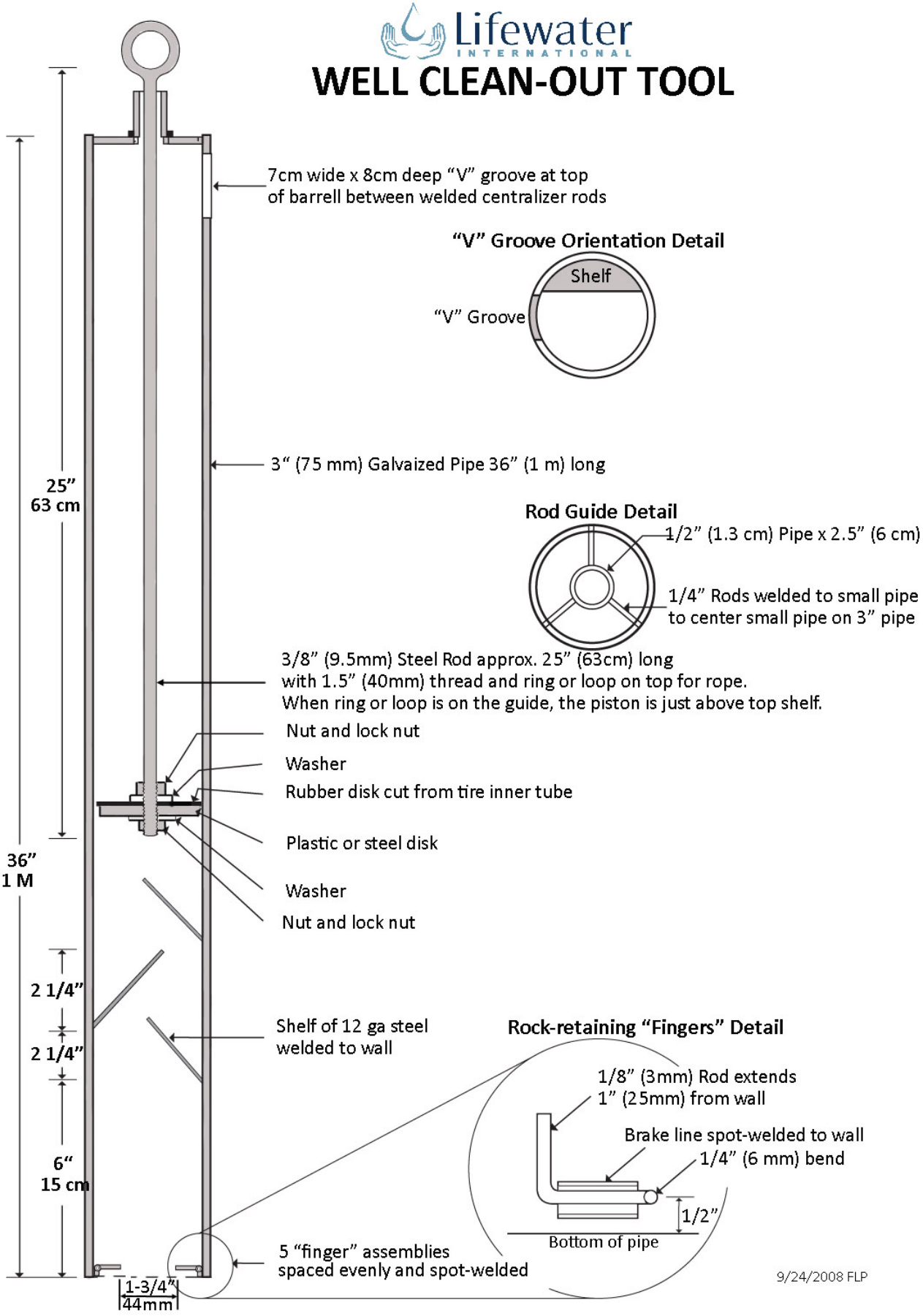
The Lifewater Well Cleanout Tool consists of a meter length of steel pipe in which there is a plunger and a series of overlapping shelves. The pipe is heavy enough to rest on the rocks at the bottom of the well when the plunger is pulled up by a rope. Rocks and sand are lifted up by the sucking action caused by the plunger and when they fall back they rest on the shelves. In addition, there are a series of small "fingers" around the bottom of the pipe that trap larger rocks. If the rocks extend above the water table, as is often the case, then pouring a bucket of water into the well while the cleanout tool is in place is enough to allow several strokes of the plunger before the water filters through the rocks.



1. Complete well Cleanout tool. **2.** Detail of the bottom showing shelves and "fingers."
3. Rocks trapped by the "fingers." **4.** Components of the plunger.
5. Detail of the top showing plunger assembly and the notch for emptying rocks.

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WELL CLEAN-OUT TOOL

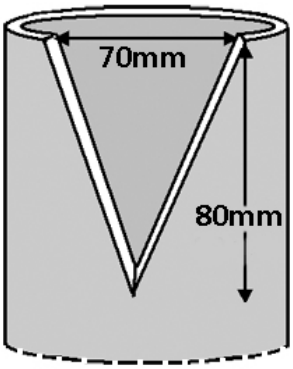


Materials

3” (75 mm) dia. Galvanized water pipe	3 feet (1 M)
3/8” (10 mm) rod	28 inches (710 mm)
½” (12 mm) galvanized water pipe	3 inches (75mm)
Approx ¼” (6 mm) rod	5 (130 mm)
¼” (6 mm) brake line	3 inches (75 mm)
12-16 gauge galvanized wire	12 inches (305 mm)
10-12 gauge (2-3 mm) steel plate, 3”x3”	4 pieces
Nuts for 3/8” (10 mm) rod	2 pieces
Washers for 3/8” (10 mm) rod	2 pieces
Truck tube cut 3” (75 mm) dia. round	1 piece

Tools

Arc welder	Tubing cutter
3/32 inch (thin) welding rod	Bench Vise
Hacksaw	Hammer
Wrenches for nuts	Drill motor with drill bit equal to rod diameter
Threader for rod	Drawing compass for circle
Angle grinder	File (half-round is best)
Wire cutter	



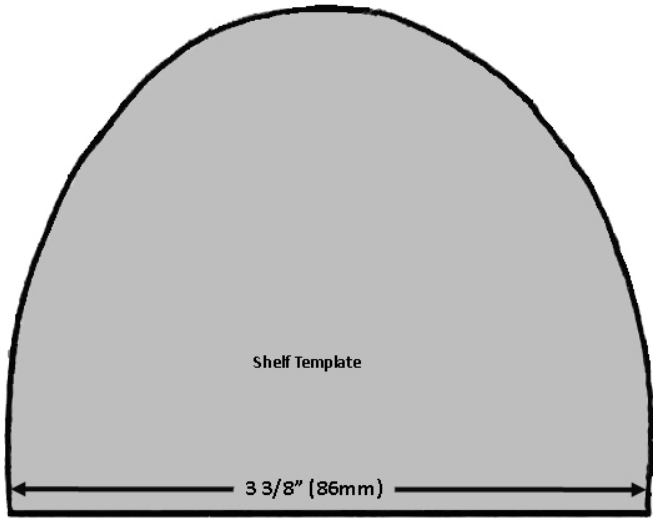
Fabrication Details

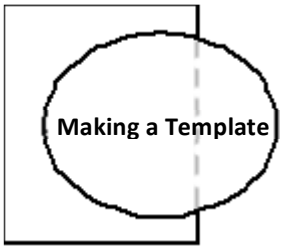
Barrel: Cut the 1-meter length of pipe with a hacksaw or pipe cutter, filing off any inside sharp edges. Using a hacksaw, cut a “V” notch at one end of the pipe that is 70 mm between the top of the “V” to where the cuts join at the bottom of the “V” and 80 mm in from the end of the pipe as shown in the illustration. Smooth the inside and outside edges of the cuts with a file.

The best pipe to use is heavy gauge galvanized water pipe. This typically has a wall thickness of approximately 1/4-inch (6 mm). Thinner-walled pipe can be used, but it has to be made longer so that it will be heavy enough. If the barrel is too light, then it will be lifted off of the rocks when the plunger is pulled. If a longer barrel is used, then the plunger rod also needs to be lengthened (taking care that it does not hit the upper shelf).

Shelves: Use the template to the right to cut the three shelves out of 10- or 12-gauge steel plate. Grind or file as necessary to create a fairly snug fit at 45 degrees inside the pipe. This template is for 3-inch galvanized pipe.

If working with a different pipe diameter, make a new shelf template by cutting a spare piece of the pipe at a 45 degree angle and filing the inside edges smooth. Lay the 45 degree side on a piece of the 10- or 12-gauge steel plate as shown in the sketch and draw or scribe around the inside onto the plate.





To weld the shelves, place the pipe in a bench vise with the "V" cut facing to the side and tack-weld the upper shelf inside the lower end of the tube, facing up about 10.5 inches (267 mm) from the bottom. Weld the next shelf on the opposite side about 8.25 inches (210 mm) from the bottom. The third shelf should be welded about 6 inches (150 mm) from the bottom. Each shelf has three weld spots, one at each top corner and one centered on the base. To facilitate welding of the shelves, the lower 12" (30 cm) of pipe may be cut off to give easier access. When the barrel pipe is welded together again, the outer weld bead must be ground flush with the pipe to prevent damage to the well screen.

Rod Guide: Cut 1/4-inch (6 mm) rod into approx 1.5 inch (38 mm) lengths with a hacksaw. Cut a piece of 1/2-inch (12 mm) water pipe about 3 inches (75mm) long. Ensure that the water pipe is cut squarely and the inside edges are filed smooth. On a flat surface, stand the water pipe on end then weld the three rod ends to the bottom, spaced evenly around the pipe. Finish welding on the bottom of the pipe to strengthen the weld. Place the guide on top of the upper end of the barrel (with the "V" cut), centered with two of the three legs at the edges of the "V." Weld the rods thoroughly to the pipe then grind any protruding rods smooth with the edge of the barrel.

Plunger Rod: Thread one end of the rod about 1.5 inches (40 mm). Bend the other end around a 3/4-inch (18 mm) rod to create a loop at the end for the rope, centered on the rod with no gap between the end of the loop and the rod.

Piston and Rubber Flap: Cut the remaining steel plate into a circle 1/4-inch (6 mm) smaller than the inside of the 3-inch barrel, drilling a hole the size of the rod in the center. (A PVC disc at least ¼" thick would also work in place of the steel disc). File the edges smooth. Cut the truck inner tube the exact diameter of the pipe with a hole in the center the same size as the rod. Notches or holes can be cut along the rim of the plunger so that it will drop easier.

Rock-Retaining Fingers: Cut 1/4-inch (6 mm) brake line into 5/8-inch (16 mm) lengths, reaming flashing or roughness from the cut ends with a reaming tool until smooth. Cut galvanized wire into 2 inch (50 mm) lengths. Clamp each wire in a vise with ¼" protruding and bend 90 degrees from the shaft. Slide a piece of the ¼" brake line to the bend, placing the remaining end into a vise. Using a pair of fence pliers or narrow pliers, bend the piece with the brake line on it so the resulting bend is 90 degrees from each of the other runs. Each of the fingers should be bent in the same way so they fit in sequence inside the pipe (see photo on previous page). After ensuring the fingers rotate smoothly in their sleeves, draw or scribe a line ½" inside the bottom of the barrel. Divide the inside circumference by 5 and mark the inside at that interval, making 5 equal spaces. One-at-a-time, place the sleeve on the line parallel to the bottom and at the 1/5th mark. Using a thin welding rod or wire, start a puddle just under the tube and move just to the tube, quitting the weld as it contacts the tube. Be careful not to burn through the thin-walled tube. Repeat welding the remaining 4 tubes then check for free movement of the wire.

Install the Rod and Piston: Insert the rod just through the top guide, thread a nut all of the way onto the threaded portion of the rod, and tighten to the unthreaded surface. Place a washer, the inner tube, the round plate, another washer and then a second nut on the rod and tighten until just snug. Do not over-tighten as this will deform the rubber. Peen the thread or add a jam nut on the bottom to prevent loosening. Check smooth functioning of the piston assembly and adjust if necessary.

Operation: With a 3/8" (9 mm) braided rope securely tied to the loop in the piston rod, the cleanout tool is ready to use. It is most easily operated using a tripod and single pulley assembly when significant rock removal is necessary. Each well takes some experimentation to achieve optimum performance. Pull the plunger up quickly to get maximum suction. Don't pull the plunger more than three or four times before bringing the tool to the surface. Otherwise, the tool can settle into the rocks and become stuck.

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Appendix 10 Daily Work Report

This form must be completed at the end of each work day and signed by the Crew Chief.

Date:	Project Name:	Borehole Number:
Borehole Location:		

How long did you work today?

Crew Members Working:

Start Time: Finish: Break Length: hours Hours Worked Today:

Distance Driven: Purpose:

What work did you do today?

☐ Mobilized ☐ Set up drill site ☐ Drilled pilot hole ☐ Reamed ☐ Installed casing & gravel pack
☐ Developed well ☐ Installed pump ☐ Built pump pad ☐ Closed dry borehole ☐ De-mobilized
Other Work:

Problems Encountered:

How far did you drill today?

Start Depth: meters Finish Depth: meters Total Drilled Today: meters

From (m)	To (m)	Sediment Type	Drilling Difficulty

What supplies did you use today?

Fuel for: ☐ Vehicle ☐ Drill Rig ☐ Mud Pump ☐ Other: Total Fuel Cost:
Oil for: ☐ Vehicle ☐ Drill Rig ☐ Mud Pump ☐ Other: Total Oil Cost:

4" PVC Blank:	meters	Bentonite:	bags	Rebar:	meters
4" PVC Pre-Slotted:	meters	Gravel Pack:	liters	Bleach:	liters
1-1/4" Galvanized:	meters	Cement:	bags	Hand Pump type:	
Other Pipe:	meters	Gravel (Concrete):	bags	Pump Cylinder type:	
PVC Caps:		Sand (Concrete):	bags	Pump Rod:	meters

Other supplies used today:

☐ Receipts for all purchases are attached

This work report is correct and complete:_____

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Appendix 11 Well Completion Report

Well Location	
Well Number or Name:	Project Name:
Country:	Location Sketch N↑
Province/State:	
County/Township:	
Town/Village:	
GPS Coordinates:	
Owner's Name:	
Site Description:	Scale:

Method: ☐ Hand-Dug ☐ Mud Rotary ☐ Air Rotary ☐ Cable Tool ☐ Other:			
Total Depth of Borehole (or shaft):	meters	Borehole (or shaft) Diameter:	cm
Depth water was first encountered:	meters	Depth to Water Table:	meters

Well Construction Organization:		Well Completion Date:
Crew Chief's name:	Signature:	Date:
Inspection Organization:	Inspector's Name:	Date:

Borehole Log

From (m)	To (m)	Sediment Type	Drilling Notes

Well Construction Details

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Blank Well Casing: ☐ 4" (100mm) PVC, schedule 40		Installed: meters
Other casing type:		Installed: meters
Slotted Well Screen: ☐ 4" (100mm) PVC, schedule 40		Other screen type:
Screened Intervals: From to meters and From to meters and From to meters		
Screen is: ☐ Pre-Slotted ☐ Hand Slotted		Length of screen sump: meters
Well screen end: ☐ Open bottom ☐ PVC Cap ☐ Wood Plug ☐ Cement Plug ☐ Hand-made point		
Describe placement of centralizers:		
Gravel pack grain size:		Gravel pack volume: litres
☐  2-4mm ☐  4-6mm ☐  6-8mm		Top of gravel pack: meters
Backfill material: ☐ Cuttings from mud pit ☐ Clean sand ☐ Other: Backfill placed from: meters To: meters		
Sanitary Seal: ☐ Equal parts cement &sand ☐ Bentonite		From: meters To: meters

Well Development and Yield

Development method: ☐ Hand bailing ☐ Surge block ☐ Hand pump ☐ Electric pump ☐ Other		
Developed by:		Development Time: hours
Yield test method: ☐ Hand bailing ☐ Hand pump ☐ Electric pump Other method:		Test time: minutes
Starting Water level: meters	Final Water level: meters	Yield: litres/min

Pump Installation

Pump type:	Cylinder diameter mm	Cylinder depth meters
Riser main: ☐ 1.25" Galvanized ☐ 2" PVC ☐ 2.5" PVC ☐ Other:		
Pump rod: ☐ Galvanized ☐ Stainless ☐ 10mm ☐ 12mm ☐ Threaded ☐ Hook & Eye		
Hand Pump Tests: ☐ Foot valve not leaking ☐ 20-Stroke test = litres In minutes		
Other pump details:		
☐ Square Pad: meter X meter		☐ Round Pad: meter radius
Pad Thickness: cm	Curb Height: cm	Drain Length: meters
Protected by fencing? ☐ Yes ☐ No		Waste water drains to:

Well Disinfection

Type of chlorine used: ☐ 3% Liquid ☐ 5% Liquid ☐ Dry Powder ☐ Other:		
Volume used: litres		Time left in well: hours
Was pump locked? ☐ Yes ☐ No	Who pumped out the chlorine?	

Water Quality Test Results

Colour:	Odour:	Taste:	pH:
Nitrates: mg/l	Chlorides: : mg/l	Iron: mg/l	TDS: mg/l
Bacteria test type:		Test Performed by:	
Bacteria Test Results: ☐ Pass ☐ Fail		☐ Quantitative Coliform:	MPN per 100ml
Other water quality test results:			

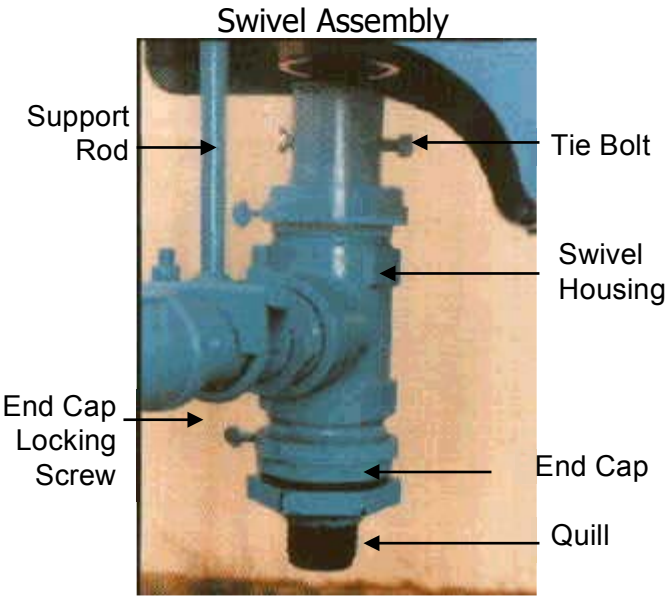
Appendix 12 LS100/200 Rig Maintenance Guides

by Harry Westmoreland, Lone Star Bits

1. Servicing Swivel Seals

One of the most common routine servicing tasks required on the LS100/200 is to stop drilling fluid (mud) leaking past the swivel seals during drilling. It is critical to stop the leakage as soon as it is detected to prevent permanent damage resulting from the abrasive particles in the drilling fluid scoring and eroding the sealing area on the quill (under the seals). If routine tightening of the end caps and greasing (with the grease gun) fails to stop the leakage it is time to replace the swivel seals as follows.

Parts needed: set of two swivel seals
Consumables: grease filled grease gun, clean rag



Prepare to Remove the Swivel Assembly

Stop drilling, circulate long enough to clear the hole and pull back to position the last connection just above the drill table. Land the connection on the slips and break out the last joint of drill pipe. Stop the drill motor and lower it to a height for easy access to the swivel assembly. Cover the drill pipe connection in the slips and the borehole to prevent anything falling in.

Remove the Swivel Assembly

1. Disconnect the delivery hose from the swivel assembly hose connection.
2. Loosen the securing bolt at the top of the swivel support rod.

Support the weight of the swivel assembly as you remove the tie bolt that attaches the swivel assembly to the hexagonal gearbox drive shaft.

The swivel assembly should now slide off the drive shaft and can be removed when the support rod drops free.

Dismantle the Swivel Assembly

Loosen the two end cap locking screws (with the “T” hex key if they are cap screws) and then slide the swivel housing off the quill.

Remove the end caps from the swivel housing and remove and discard the worn seals.



End cap, locking screw, and grease fitting

Clean and inspect the quill for wear in the seal areas. If severe wear, note if adjacent areas can be used for new seal area when re-assembling.



Minor wear under seals

Re-Assembly

Clean the swivel housing and end caps.

Install new Swivel Seal (as shown in picture).
IMORTANT – check that the small drilled holes in the Swivel Seal are visible above the end of the housing. If not, turn the seal over and they should be. (These holes allow the grease to reach the inside of the seal.)

Screw on the end cap until snug (do not tighten at this stage).

Install the second new Swivel Seal at the other end of the housing in the same way and screw on the end cap.

Slide the Swivel Housing onto the Quill and tighten the end caps until the seals just grip the quill and begin to resist free rotation of the quill. Lock the end caps with their locking screws.

Re-Attach the Swivel Assembly

Attach the Swivel Assembly onto the end of the gearbox drive shaft using the tie bolt, taking care to locate the swivel support rod in the right place

Adjust the position of the swivel housing on the quill using the swivel support rod and secure it in position with the locking bolt.
IMPORTANT - The swivel housing should NOT be resting on the hex nut at the bottom of the quill. There should be a clearance of at least 1/8 inch between the bottom end cap and the hex nut.

Grease the new swivel seals using the grease gun through the grease fittings on each of the two end caps. Grease should “leak” out of the end cap when the seals have been completely packed with grease.

Resume Drilling
Install new drill pipe and resume drilling.

IMPORTANT – if any mud leakage is seen at the swivel, immediately add more grease and/or tighten the end caps as required to stop the leakage (loosen lock screws before tightening end caps, re-tighten lock screws afterwards).



New swivel seal installed with drilled holes visible

2. LS100/200 Drill Motor Clutch Replacement



Parts Required
New clutch assembly (old drum may be re-useable)
New transmission housing (gearbox) gasket

Preparation
Lower the drill motor to a convenient working height on the mast. Cover the bore hole to prevent any parts or tools being dropped into it.

Procedure
Remove the bolts holding the gearbox assembly together and separate the gearbox assembly by lifting off the drill motor assembly. Take care not to damage the gasket (if possible).

Assistant should visually check that all the gears remain in the lower section of the gearbox housing as it is quite common for one of the gear shafts to "stick" in the upper housing as the motor assembly is lifted. (If a gear shaft "sticks", another crew member should be ready to hold a clean rag under the motor assembly, to stop the gear from dropping out, until the assembly has been laid down. Remove any gear that stuck in the upper housing, wipe it clean and re-install it into the lower section of the gearbox.)



Disconnect the spark plug wire from the spark plug as a safety precaution.

Remove the fixing bolt (and flat washer) that secures the clutch assembly onto the motor drive shaft using a wrench. A sharp tap with a hammer on the free end of the wrench, while holding the other end on the bolt (as shown), will loosen the bolt and make removal easy.

Once bolt and washer removed, pull the clutch assembly off the end of the drive shaft - and look for the small, half moon shaped key that may fall out of the slot in the shaft. The slot in the shaft is only visible when the clutch has been removed.



Find the small, half-moon shaped, woodruff key.

Rotate the shaft until the slot is on the top of the shaft by gently pulling on the motor starter cord.

Clean both the key and the slot with a clean rag. Add some clean oil to the slot and place the key into the slot (flat side up) with the front end tilted down slightly. (This will help slide the new clutch assembly over the key without dislodging it.)

Discard the old clutch rotor and shoe assembly from inside the clutch drum and pinion assembly. Be careful to save the fiber spacer shim washer that separates these assemblies. Examine the inside of the clutch drum for excessive wear and the pinion gear for damage (discard if severe wear or damage).

Identify the spring side of the new rotor and shoe assembly; this side must face the drum. Visually locate the slot in the bore of the new rotor and shoe assembly; rotate this slot into the 12 o'clock position. Gently push the new rotor and shoe assembly onto the shaft with the slot aligned to fit over the woodruff key.



IMPORTANT - The rotor and shoe assembly must engage the woodruff key for the clutch to function. After pushing the assembly onto the shaft it will not turn freely by hand if the woodruff key has been properly engaged.

Replace the fiber spacer washer and the drum and pinion assembly onto the shaft and then, secure with bolt and flat washer to complete the clutch re-assembly. Tighten bolt with wrench and then finish tightening with a tap on the free end of the wrench with a hammer. The drum and pinion assembly should turn freely on the shaft.

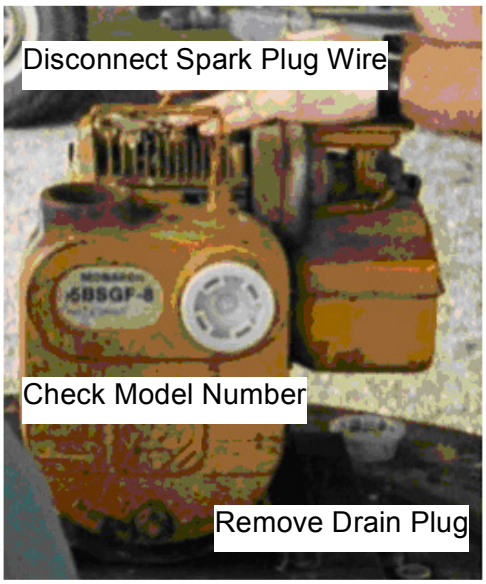
Before re-assembling the motor onto the transmission, check gasket on transmission housing and replace if necessary (hold in place with smear of clean oil). Install bolts, washers, lock washers and tighten nuts to complete the assembly. Re-attach spark plug wire on motor to complete the job.

Before resuming drilling, ensure the oil level in the gearbox is topped up to the drain hole level.

3. Mud Pump Shaft Seal Replacement

One of the most common maintenance tasks required on the LS100/200 mud pump is to replace a leaking shaft seal. A leaking seal is evident when drilling fluid (mud) is seen dripping out of the adapter between the pump housing and the engine and collecting on the base plate below.

Parts needed: shaft seal, pump housing gasket **Consumables:** cleaning cloth, lubricating oil



Before dismantling the pump to replace the pump shaft seal:

1. Disconnect the spark plug wire to prevent accidental starting of the engine

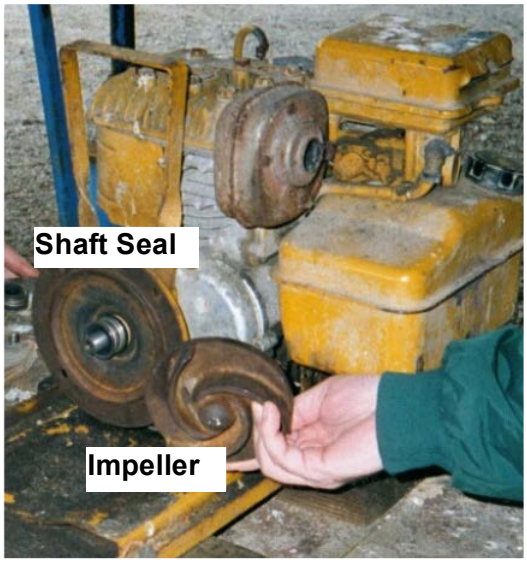
2. Check you have the correct replacement seal. The pump model number can be found on the housing next to the inlet. With the model number, check the repair parts list and identify the code number for the "Mechanical Seal"

3. Disconnect the hoses from the pump and drain all the fluid out of the pump by removing the drain plug.

Remove 4 bolts securing the pump housing and separate it from the adapter plate, taking care to keep the gasket intact.

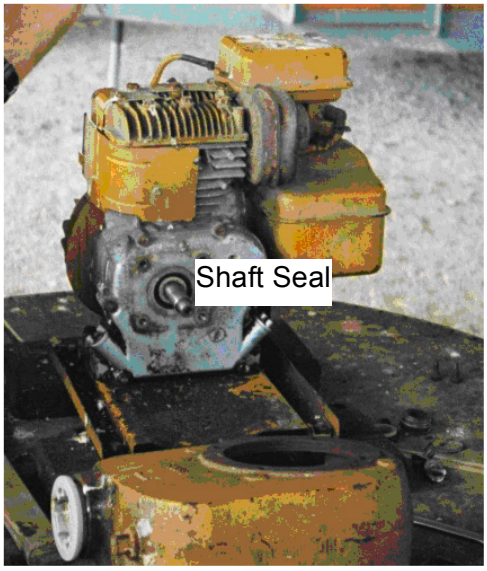
Remove the impeller by unscrewing it in a counter clockwise direction. No need to jam the engine to do this, instead, use a rubber mallet (or a piece of wood and a hammer) to tap it loose first.

CAUTION:
The outer edges of the impeller are VERY sharp, so handle with care (use gloves). The impeller is a brittle casting that can be easily damaged, so do NOT hit it with the hammer.



Remove the leaking shaft seal by simply pulling it off the shaft. The shaft sleeve may slide off with the seal.

Remove the 4 bolts that secure the adapter, and attached handle, to the engine. Separate the now loose adapter from the engine.



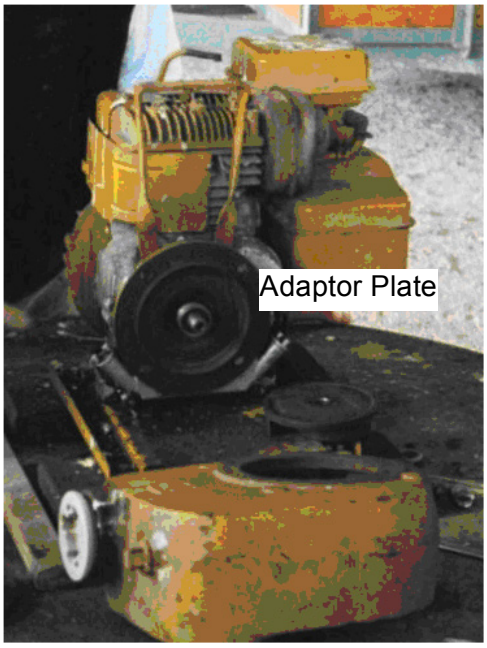
After removing the adapter, do not remove the flinger (looks like a large washer) from the shaft. Wipe the shaft clean and smear with light oil. If the sleeve came off with the seal, wipe it clean, oil it and replace it on the shaft.

Press (or tap) out the old ceramic seat and rubber mounting from the backside of the adapter plate. Clean the adapter plate area around the shaft hole and lubricate with light oil. Using hand pressure only, press-in the new ceramic seal with the protective paper supplied (smooth side of the ceramic facing out towards the pump). Paper keeps dirt out.
Re-assemble the adapter and handle onto the engine. Correct position is with the slot in the adapter facing down. This ensures that any drilling fluid (mud) leaking past the shaft seal drops down onto the base plate for easy detection.

After the four adapter bolts have been tightened evenly (hand tight with ring spanner) it is time to install the other half of the new seal onto the shaft.

Add a few drops of light oil to the graphite end of the seal and slide that end first onto the shaft. Check that all the protective paper has been removed so that the two matching polished surfaces of the new seal come together.

Caution - any dirt particles on the polished surfaces will shorten the life of the new seal.



Replace the impeller. Using gloves, screw it on clockwise until hand tight. Add a shim washer behind the impeller if warranted (same thickness as the wear depth in the pump housing).

Replace the pump housing gasket onto the adapter (smear with oil to hold in place) and assemble the housing onto the adapter with four bolts.

After tightening the four bolts evenly, check that the impeller rotates freely by gently pulling the engine starter cord. (If impeller is rubbing against the pump housing, disassemble and use a thinner shim washer behind the impeller. Make adjustments until impeller rotates freely after assembly.)

Replace drain plug, re-fill the pump housing with water, connect the hoses and re-attach the spark plug wire to complete the repair.

Appendix 13 Well Drilling Training Helps

The following is a compilation of "Materials" from each lesson in this manual:

Lesson	Materials
All	Course manual for each student (translated if needed)
All	Name Tags & Holders (color code by team)
All	Blank "Flipchart" approx 2'x3' (newsprint works, but may bleed through)
All	Masking tape, pins, or binder clips to hold up Flipchart & posters
All	Markers for Flipcharts and dry-erase for white boards
All	Pens or pencils for students (encourage writing in their manuals)
1.1	Paper & pens for expectations hand
1.4	Bible
2.1	Poster of Water Cycle
2.3	Poster of groundwater diagram with wells
2.4	Geology map or topography map of the training area
2.5	Posters: Latrine and High-Low Water table
2.5	Copies of Figure 10, Case Studies for Well Location
3.2	Poster of LS200 Parts
3.2	Drill rig and tools
3.2	Shipping packing list
3.2	Fuel and oil if the rig will be started up during this lesson
3.3	Poster of Drill Site Setup
3.3	Sets of drill site components, cut out for each team (Appendix 13).
3.3	Tape to mark mud pits (classroom setting)
3.3	Drill rig and tools.
3.4	Poster of Drill Site Setup
3.5	Drill rig and tools.
3.5	Poster of Well Construction Stages
3.6	Posters of viscosity examples, mud thickness chart
3.6	Samples of bentonite, soda ash and polymer

3.7	pH test strips
3.7	Marsh Funnel and watch with second hand
3.7	Soda ash
3.7	Bentonite
3.7	Polymer
3.7	55-gallon drum
3.7	Mud pump and hoses
3.7	Water
3.8	Same as previous mud mixing lesson
3.8	Shovels
3.8	5-gallon buckets
3.8	Drill rig ready to operate
3.9	Several liters each of clay, silt, fine sand, coarse sand, and gravel
3.9	Several dozen gallon sized plastic zip-lock bags
3.9	Labels and permanent marking pens
3.9	About 2-3 liters of hydrated bentonite
3.9	Paper for drawing a boring log
3.10	Poster of “Casing Off” Contamination
4.1	Poster of Well Design Exercise
4.1	PVC casing
4.1	Tools: measuring tape, marking pen, hack saw
4.2	Well components posters, labeled & unlabeled
4.2	Borehole, PVC casing, glue, rope
4.3	Gravel and coarse sand , set of sifting screens, buckets
4.3	Alt: Samples of sifted and washed gravel pack
4.4	Borehole with casing and gravel pack installed
4.4	Option: Bailer construction supplies and tools (see Appendix 8)
4.6	Poster of stages of well development
4.6	Bailer
4.6	Surge block (optional)
4.7	Posters of damaged and repaired pump pads
4.8	Wood or brick for demo pad form (optional)

4.9	Boards and stakes to form small concrete pads(optional demo)
4.9	Cement, sand, gravel, water (optional demo)
4.9	Concrete mixing and finishing tools (optional demo)
5.1	Buckets of Water
5.1	Clear plastic Mark II cylinder for demo (if available)
5.1	One functional Mark II cylinder for each team
5.1	Posters: Cylinder Operation and Cylinder Parts
5.2	Poster of deep well pumps
5.3	Posters of Afridev pump head and cylinder
5.4	Poster of Mark II head
5.4	Mark II cylinders for each team
5.5	Poster of Disinfection Table
5.5	Bottle of locally-obtained chlorine bleach
6.1	Bell & socket PVC pipe or straight pipe with couplings
6.1	Tools: hack saw, fine sandpaper, PVC cement
6.2	Riser main pipe
6.2	Tools: Pipe vise, pipe cutter, 1.25” pipe threader, reamer or round file.
6.2	Electrical tape
6.3	Pump rod for each group
6.3	Tools for each team: hack saw, die and handle, file, pump rod clamp
6.4	Sample fishing tools.
6.4	Tools, pump rod, and riser main as “fish”
6.4	Mock well for each team
7.3	Copies of Daily Work Report and Well Completion Report (Appen. 10 & 11)
7.4	Quill, wrenches, rags, and grease
7.5	Poster of drill site
8.2	Poster of Good Pump Pad

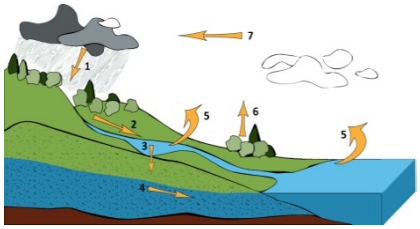
ADDITIONAL TRAINING MATERIALS

Lifewater has developed facilitator aids that are continually being revised and updated. Following is a partial list of materials that are available upon request from the Lifewater office, Info@Lifewater.org:

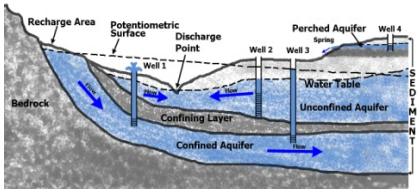
- Poster-sized (24" x 36") illustrations from the manual in PDF format (see index below)
- Sample Daily class schedule
- Suggested lesson sequence
- "Oral Exam" questions for final course review

"Posters" for Shallow Well Drilling Training (2'x3' PDF format)

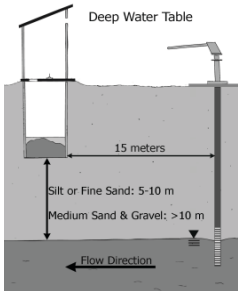
The following posters are available from the Lifewater office, Info@Lifewater.org
Note: Poster numbers 22, 58, 85, 90, 91, and 93 are without parts labels. These labels will be written in during the relevant lesson. If the posters are laminated, then the labels can be erased and the posters reused for the oral exam. Otherwise, two copies of these posters will be needed.



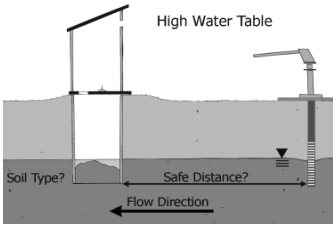
3. Water Cycle



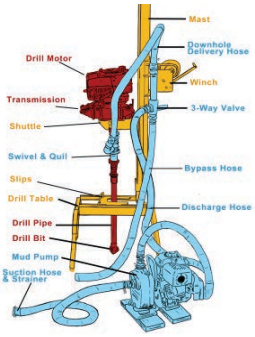
7. Groundwater Diagram with Wells



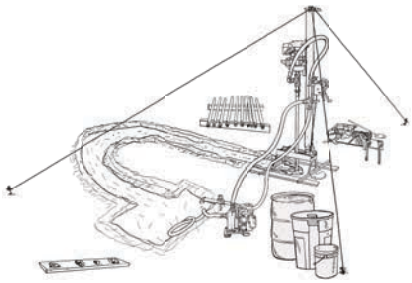
8. Latrine with Deep Water Table



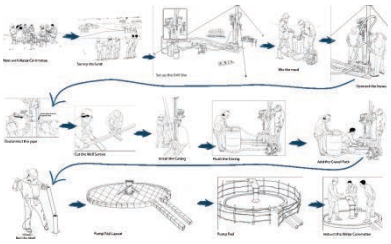
9. Latrine with High Water Table



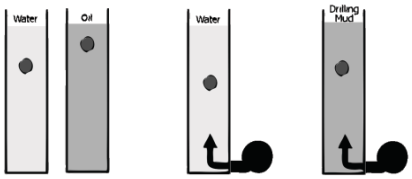
22. Parts of the LS200



29. Drill Site Setup



Well Construction Stages

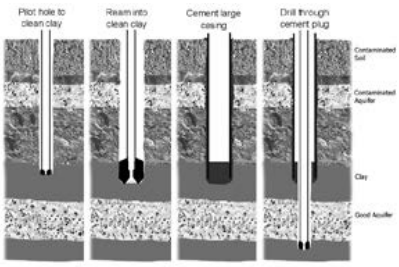


41. Viscosity Examples

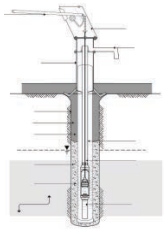
Material Being Drilled	Sediment Grain Size	Marsh Funnel Viscosity (seconds/quart)
Natural swelling clays*	<0.08mm	32 to 37
Non-swelling clays and fine sand	0.08-0.43mm	40 to 45
Medium sand	0.43-2.0mm	45 to 55
Coarse sand	2.0-4.8mm	55 to 65
Gravel	4.8-19.0mm	65 to 75
Coarse gravel	>19.0mm	75 to 85

*Note: When drilling in clay the cuttings tend to form clumps which may be as difficult to lift as gravel so a thicker mud than is indicated here may be needed.

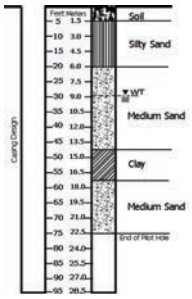
T1. Drilling Mud Thickness



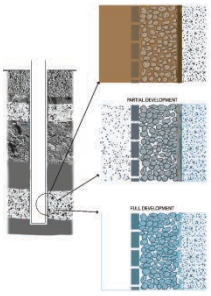
57. Stages of Casing-Off



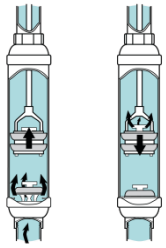
58. Well Components



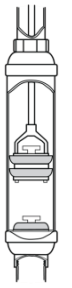
59. Well Design Exercise



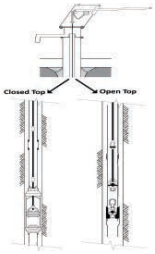
70. Stages of Well Development



84. Cylinder Operation



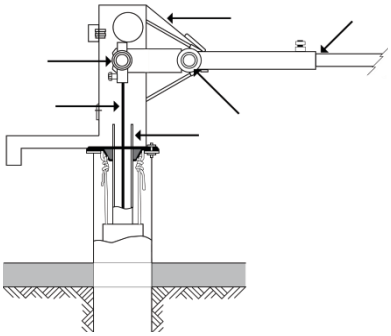
85. Mark II Cylinder



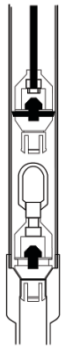
89. Deep-Well Pumps

	Casing Diameter / Disinfection Rate	75mm (3")	100mm (4")	125mm (5")	150mm (6")
1	Liters of 3.5% liquid bleach per meter of water	0.05	0.08	0.11	0.16
2	Liters of 5% liquid bleach per meter of water	0.03	0.05	0.08	0.11
3	Teaspoons of 70% Powdered Chlorine per meter	0.21	0.33	0.48	0.66
4	Grams of 70% powdered Chlorine per meter	2.4	3.9	5.6	7.8
5	Well volume: liters per meter	6.8	10.8	15.8	21.8

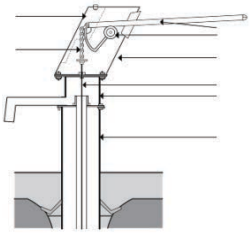
T4. Well Disinfection Table



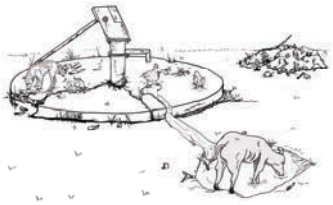
90. Afridev Head



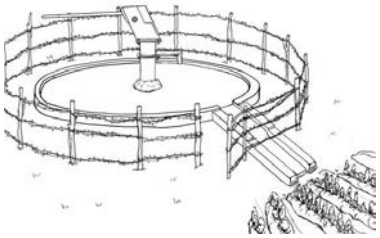
91. Afridev Cylinder



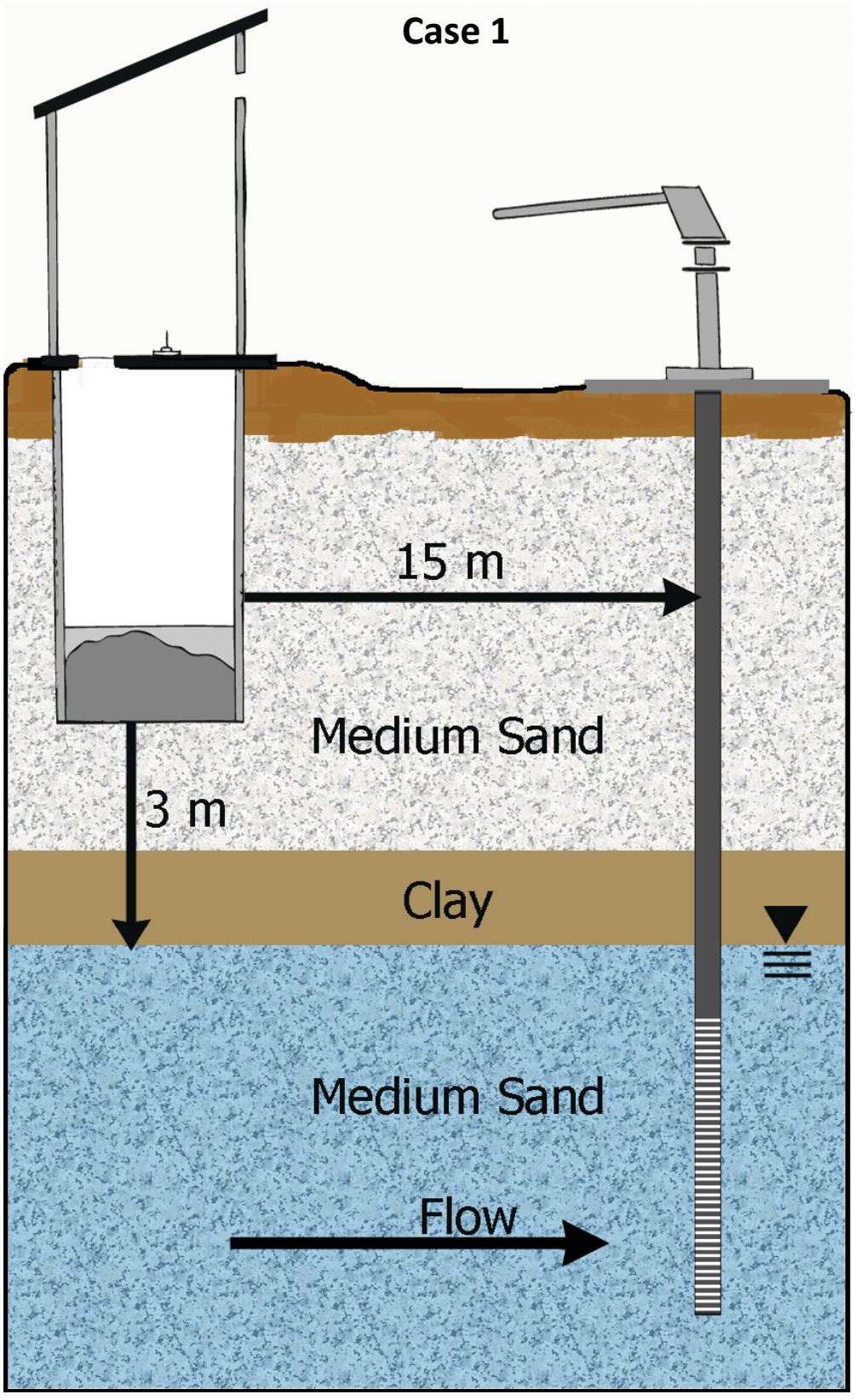
93. Mark II/III Head

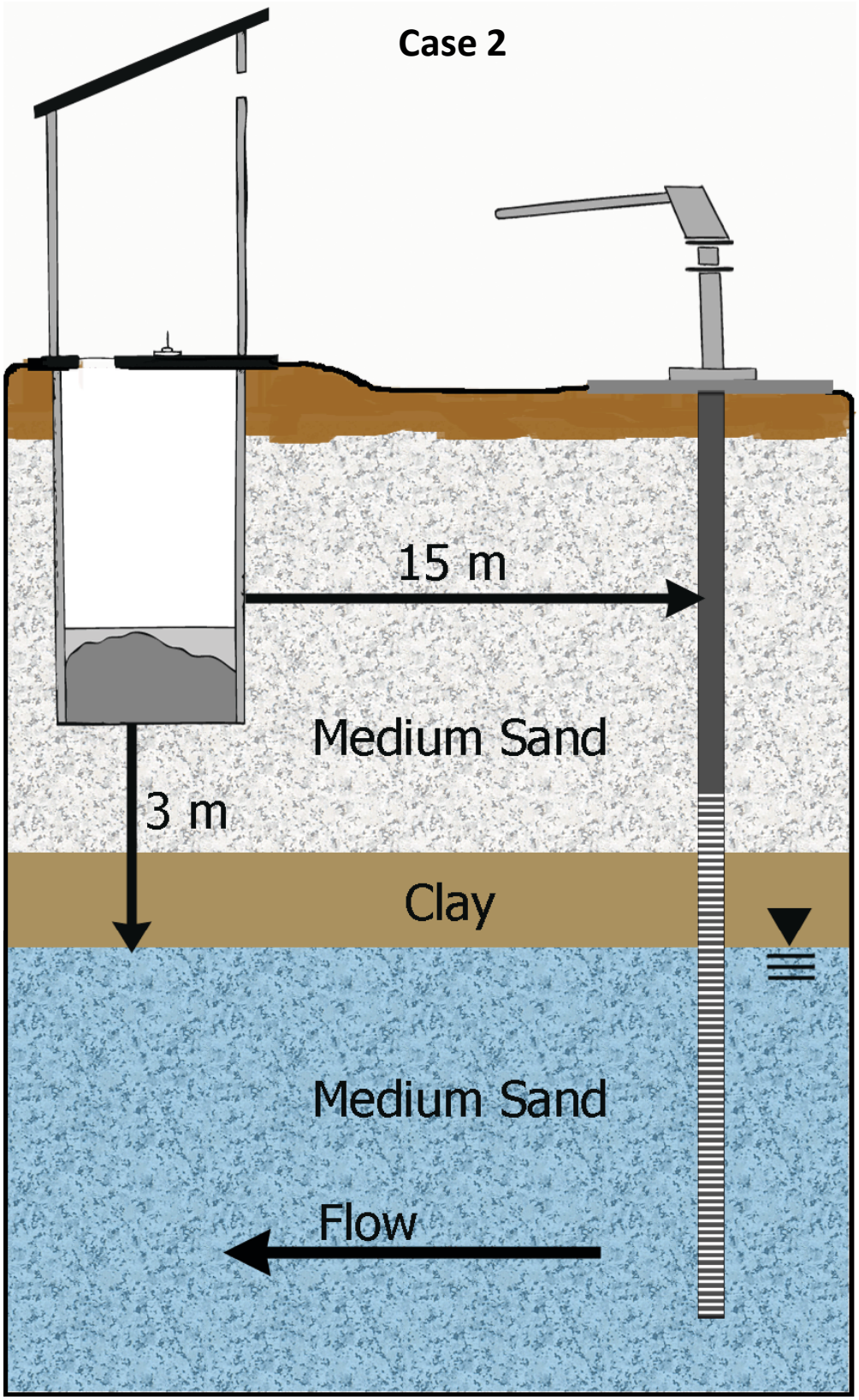


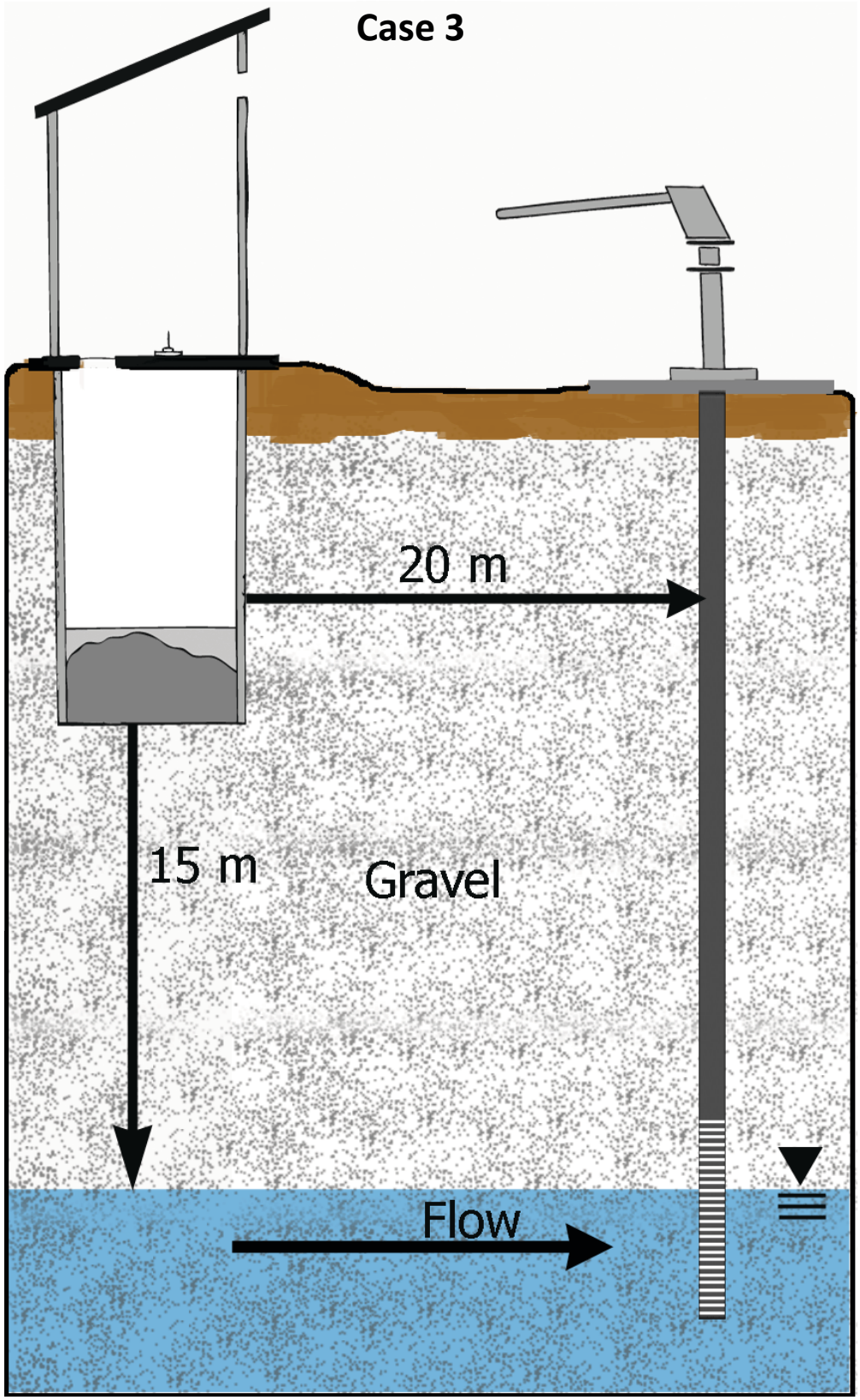
71a. Bad Pump Pad

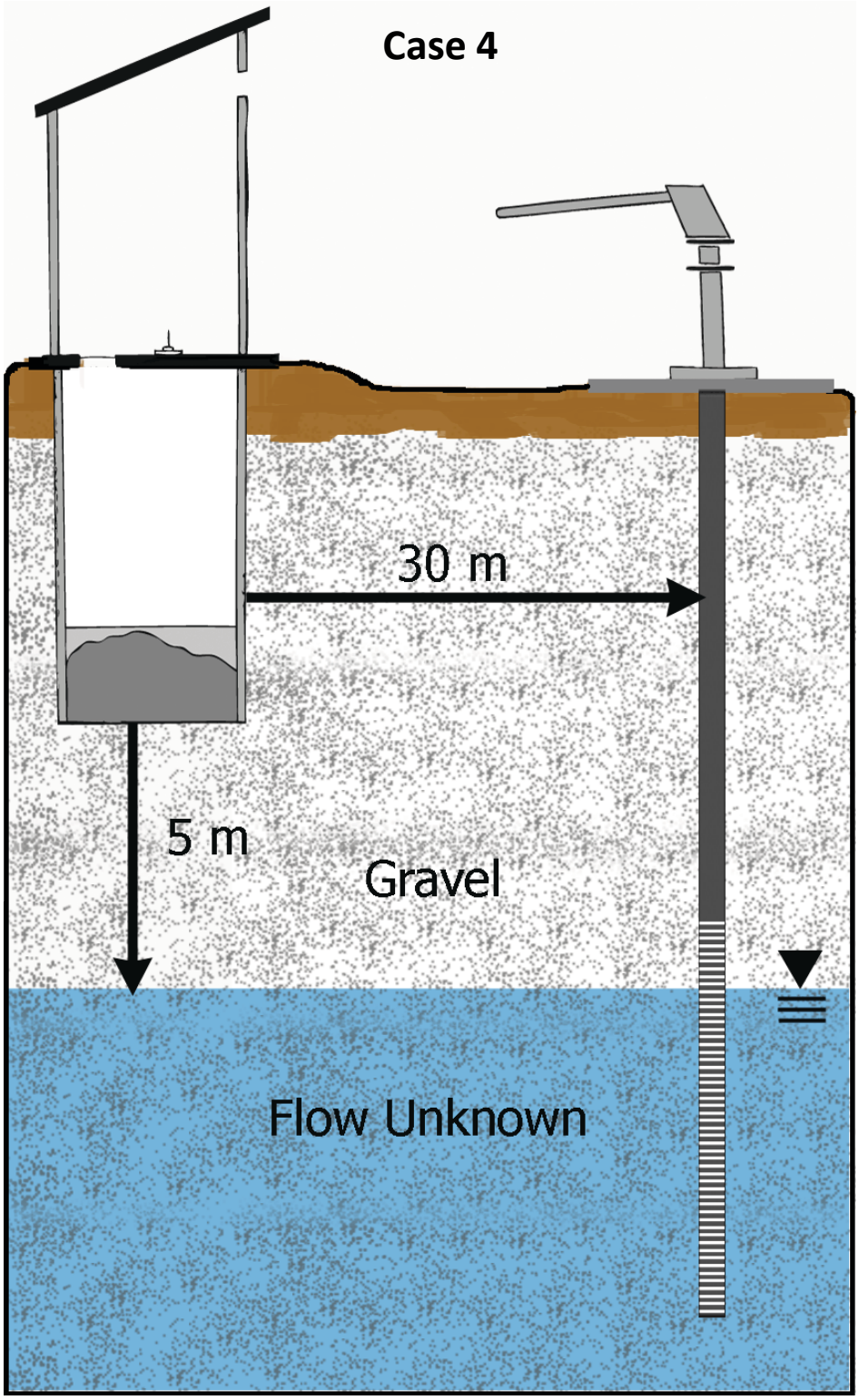


71b. Good Pump Pad

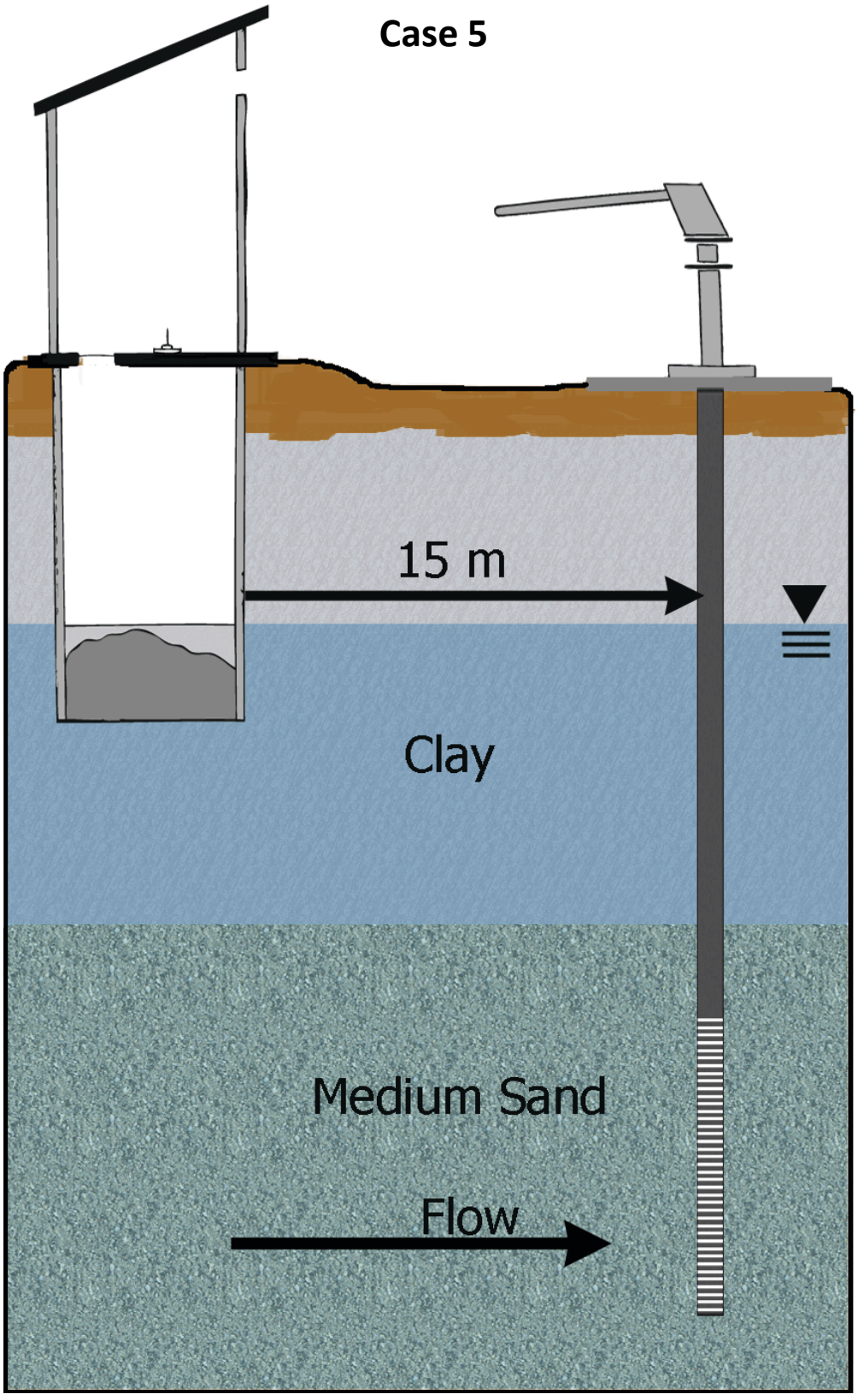

Case 1
15 m
Medium Sand
3 m
Clay
Medium Sand
Flow

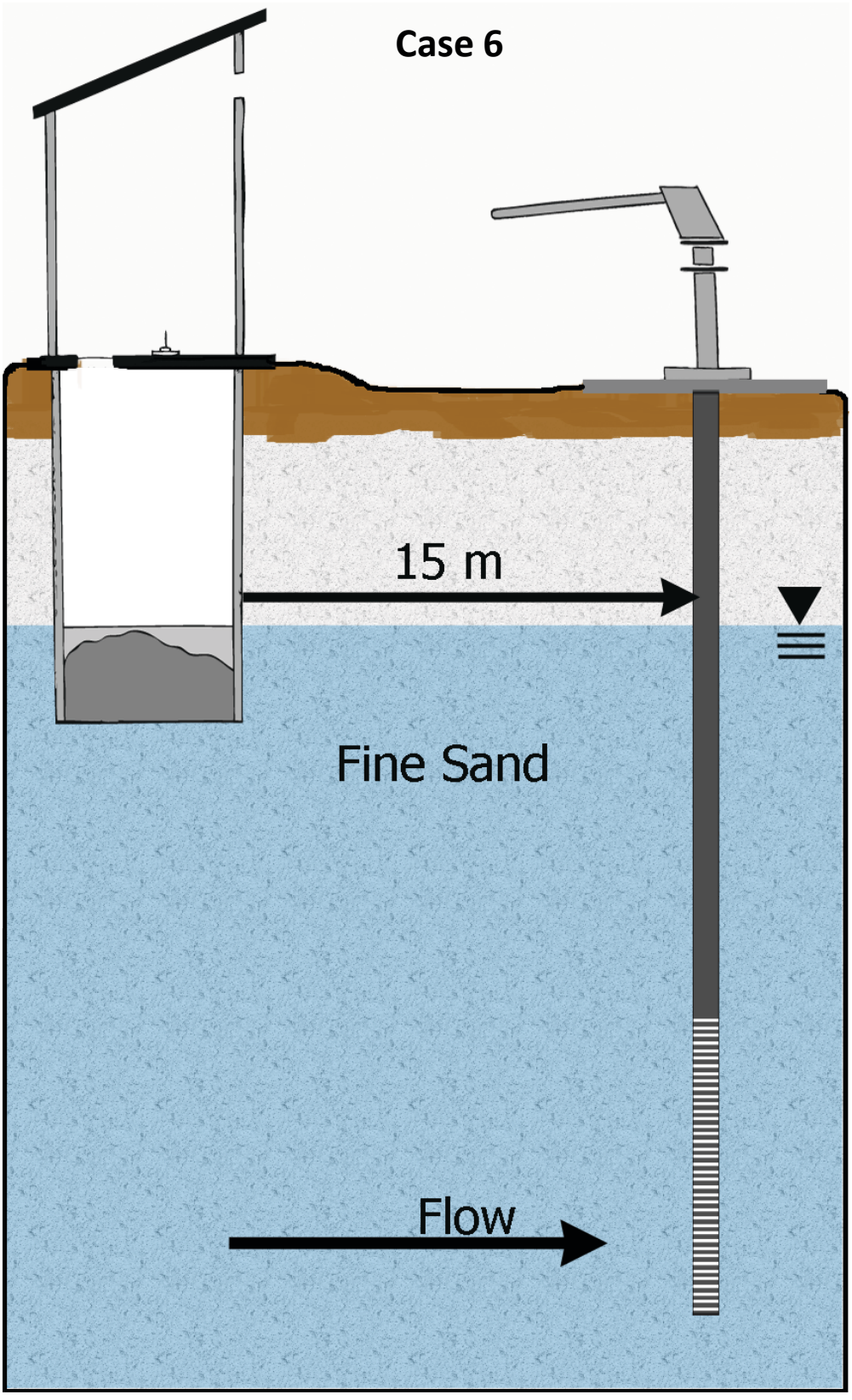

Case 2
15 m
Medium Sand
3 m
Clay
Medium Sand
Flow


Case 3
20 m
15 m
Gravel
Flow

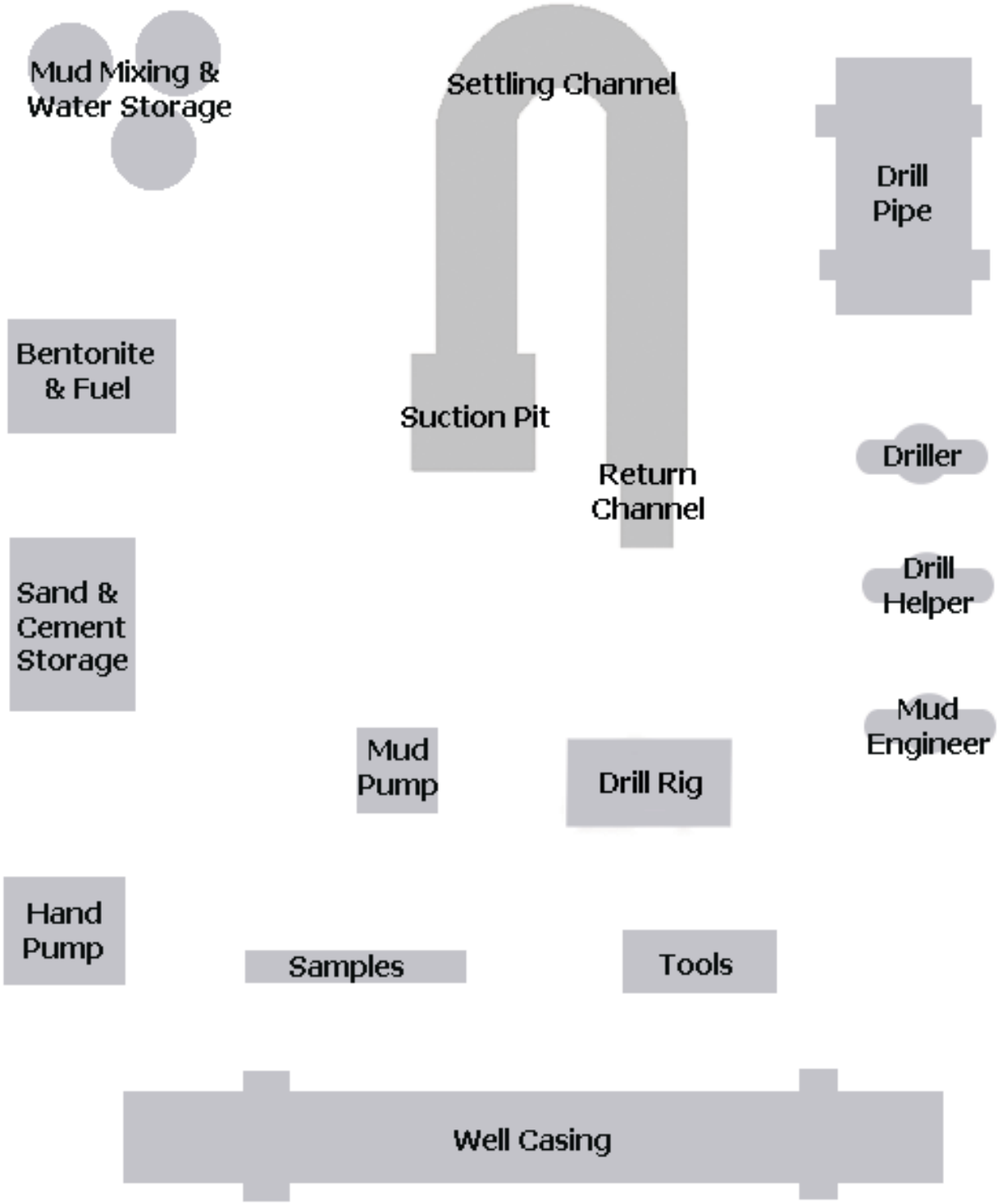

Case 4
30 m
5 m
Gravel
Flow Unknown

Case 5




Case 6
15 m
Fine Sand
Flow

Lesson 3.3 Setting Up a Drilling Site. Reproduce this page on heavy paper then cut out a set of these drill site components (Figures 24 and 25) for each team. Ask the students to try different arrangements. In a windy setting, provide blank paper and tape to hold the pieces down.



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Lifewater INTERNATIONAL

Appendix 14 Field Tests for Water Quality

1. Introduction

Anyone, with a little practice, can obtain useful information about the quality of a drinking water supply using simple field tests. This booklet was written to guide an inexperienced user through the procedures for identifying six water quality parameters. The bacteriological results in particular are very instructive and can help people understand that there is "something" in the water that may harm them. After reading this booklet, and a little practice, anyone will be able determine whether or not a source of water is acceptable for drinking. If a source is tested periodically, a water quality problem can be identified before it becomes a major issue.

Lifewater International gratefully acknowledges the contributions of Mike Turvey, a water quality expert and long-time Lifewater volunteer, who developed the water testing kit and wrote most of this course material. Mike spent many years researching and evaluating different water test methods in some very remote places under extreme circumstances.

2. Where Do You Start?

Commercial laboratories can analyze a water sample for hundreds of minerals from aluminum to zinc. Add to those the thousands of organic compounds that may be in water and the number of possible compounds that can be analyzed becomes overwhelming. This complexity can cloud the most simple and basic question – "What is in this water and will it harm me?"

The question of whether or not a water source is safe to drink can, in the right circumstances, have a simple answer. The key lies in determining what parameter (chemical test subject) is really important in a particular situation and finding an inexpensive test to determine if the water passes or fails for that subject. If you are examining a water source near an industrial plant, then there may be many chemicals to be concerned about, some of which may be very difficult to identify in the water. However, in a rural area where no industrial or agricultural chemicals are used, then just a few tests may be sufficient.

In addition to deciding what to test for in a water sample, it is necessary to know what is an acceptable level or concentration of that parameter. In other words, what is "safe water?" The World Health Organization (WHO), the US Environmental Protection Agency, and others have established acceptable levels for many water quality parameters. The ones discussed in this course are summarized in Table 1. Most of these levels are based on the health effects of drinking a given chemical in water over an entire lifetime. The

term, “Level of Concern” is used for the purpose of this course. It is always a good idea to determine what regulations pertaining to water quality have been established in the country where you are working.

Table 1. Comparison of Chemical Drinking Water Standards
(mg/l, except for pH)*

Parameter	WHO	US EPA	CANADA	EEC	JAPAN
Nitrates	12	10	10	12	10
pH	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5	6.5 – 9.5	5.8 – 8.6
Chlorides	250	250	250	250	200
Hardness	na	na	na	50	300
Iron	0.3	0.3	0.3	0.2	0.3
TDS	1000	500	500	na	500

*These parameters are only the ones that are tested by the Lifewater kit. The World Health Organization, US Environmental Protection Agency, Health Canada, European Economic Community Ministry of Health and Welfare and Japanese Health Ministry have adopted standards for many additional parameters.

3. The Lifewater International Water Test Kit

Lifewater International’s water test kit is intended for evaluating drinking water sources in places where industrial or agricultural chemicals are not typically used. We have identified six easily tested parameters that are important for establishing the suitability of a drinking water source. These are: coliform bacteria, nitrates, pH, chlorides, hardness, and iron (Table 2). Some of these, like hardness, are not a “contaminant” but may be useful for indicating a water quality problem. The reasons for testing each of these are explained in Section 7, “Parameters of Significance and Test Procedures.”

The test methods employed in Lifewater’s kit give reliable results, but those results do not have a high level of precision. For most parameters, results are expressed within a range of values and are determined by comparing the color change of a test strip with a standard color chart. These methods were chosen to keep the cost per test as low as possible and to avoid the need to employ harsh chemicals in the performance of the test. Many commercially available test kits may be more precise but they cannot be legally transported on an airplane due to the chemicals they use. Lifewater’s test kit is small, lightweight, and can be mailed or carried on an airplane without special permission or packing methods.

To collect and precisely analyze water for disease-causing bacteria can be even more complicated than testing for chemical contamination. It requires well-trained technicians with a fully equipped laboratory. Fortunately, the simple coliform bacteria field test included in Lifewater’s test kit gives “presence/absence” results without complicated

procedures or equipment. The actual quantity of bacteria present in the sample is not revealed. However, the goal is to have no disease-causing bacteria in the water, so quantification and identification of the exact bacteria present is not always necessary.

The Lifewater water test kit will do ten tests each for bacteria, nitrates and pH, and five tests each for hardness, chlorides and iron. The number of tests in the kit is a function of the relative importance of the parameter, the cost of the test strip, and the degree to which the parameter normally varies over a region. Information on ordering replacement test materials is provided in Table 5 of this Appendix (page).

Table 2. Lifewater Test Kit Contents

Test Media	Sampling Supplies
Bacterial growth media pillows (10)	Plastic sample bags (10)
Nitrate/Nitrite test strips (10)	Packaged alcohol wipes (10)
pH test strips (10)	Bottle hand sanitizer (1)
Chloride test strips (5)	Sample cups (5)
Hardness test strips (5)	Permanent marker (1)
Iron test strips (5)	Note pad (1)
	Pencil (1)

4. Hidden Water Quality Problems

The six parameters covered by Lifewater's test kit do not constitute everything that might cause a rural water source to be unsafe for drinking. The tragic experience in Bangladesh is a case in point. Development agencies, trying to give rural villagers a source of drinking water that was free from disease-causing bacteria, unwittingly tapped into underground aquifers that had high levels of arsenic. After years of drinking water containing this naturally occurring, poisonous mineral, many people have become ill and some have died. In other locations, past wars or industrial activities may have left behind harmful chemicals in the groundwater.

These types of water quality problems require considerable research to identify. That research may already have been conducted, so one should always consult with the government agencies that are tasked with water quality concerns to learn what is already know about the area where you are working. If there has been no research on naturally occurring water contaminants or past activities that might have polluted the groundwater, then it is not possible, using Lifewater's simple testing kit, to make a sweeping statement regarding the safety of a drinking water source. All that can be said with confidence is that the six parameters for which the kit is designed to test are either above or below a level of concern.

5. Why Test the Water?

There are different reasons for testing a drinking water source. The purpose for testing a water source will determine the best test method to use. For example:

- You want to know if the water presents a current health risk for the community.
- You want know if the quality of their drinking water shows a trend that reveals a future health risk.
- You are required by the government to submit water quality data before a new well can be used for drinking water.
- You need to design a treatment system to make water safe to drink.

The field test methods described here are suitable for the first two purposes. However, complying with government rules typically requires the water to be collected and analyzed by a certified laboratory. And most field tests cannot provide enough detail about the contaminants in the water to properly design a water treatment system.

To know if there is a current problem, compare your water test results with the "Levels of Concern" in Table 1, particularly the World Health Organization water quality standards. If the level for a given parameter exceeds the recognized standard, there is a health risk. Steps should be taken to both discover the cause and formulate a plan to correct it.

To identify possible future health risks, record the results of water samples over a period of time to identify any trends. For example, if the level of nitrate is 2 mg/l now, and it rises to 5 mg/l one year later, something is causing the nitrate level to increase. You can then take steps to identify and eliminate the source of nitrate before it rises to the "problem" level of 10 mg/l. It is always easier to prevent a water source from becoming polluted than it is to clean it up once it becomes polluted.

To identify a trend in the quality of a water source, it is necessary to:

- Test at approximately six-month intervals;
- Conduct the test in the same manner each time; and
- Maintain records of the test results where they can be compared with each other.

6. Proper Water Sampling Procedures

The first principle for obtaining a water sample is that it should be representative of the water source. For example, if people obtain water from a well by dropping a bucket into the well, then the water sample should be collected from that bucket. Furthermore, care should be taken to not introduce any foreign element to the sample, such as dirt from the sampler's fingers. So always wash your hands before collecting a water sample. Sterilize your hands and tools before collecting a sample that will be tested for bacteria.

The water sample should be tested within a few minutes of being collected. Several of the parameters tested by the Lifewater kit can change when exposed to air or to increased temperature. If a sample was collected, stored in a bottle, transported, and then analyzed at

the end of the day, there is no guarantee that the test results would represent the true character of the water source. In addition to changes that might occur in the sample parameters, contaminants can be introduced during transport. [In the case of the test for bacteria, once the sample bag has been sealed, it can be transported as long as care is taken to avoid puncturing or otherwise contaminating the sample bag.]

For the "dip stick" type tests, collect the sample in the small cup provided in the Lifewater test kit. If sampling from a faucet, let the cold water tap run in a small stream for about 30 seconds. If sampling from a bucket, spring, stream or pond, just dip the cup into the water. Rinse out the cup three times and then fill it to about the halfway point. Perform the individual tests as directed in Section 7. You do not need to collect a new sample or use a new cup for each test. However, enough cups are provided so that a new one should be used at each water source to be tested.

For the bacteria test, dip water directly into the sample bag without touching the inside of the bag. If you are sampling for a bacteria test from a faucet, it is good procedure to first sterilize the end of the faucet using one of the alcohol wipes included in the kit. That way, the sample will accurately represent what is in the water source and not what was in the mouth or on the hands of the last person to drink from the faucet.

Specific testing procedures are described in Section 7. In general, for the "dip stick" type tests, dip one of the test strips for a brief time (each test is different) in the sample being tested, allow the color to develop, and compare the color against a color chart. If you have a mid-color that seems to be more than one level and less than the next level, estimate it at the mid number. For example, if the color is between 5 mg/l and 10 mg/l, record the result as 7.5 mg/l.

7. Parameters of Significance and Test Procedures

Apart from "hidden" water quality problems (see Section 4), which are not very common, it is the normal activities of life - human and animal waste disposal and agriculture practices – that commonly result in water being polluted. The primary water quality parameters that can identify a health risk from these activities are coliform bacteria and nitrates. Secondary parameters that are easy to measure and further contribute to understanding a water source include: pH, chlorides, hardness, and iron. An additional water quality parameter that is not measured with this test kit due to cost, but is discussed in this course, is Total Dissolved Solids (TDS). It can also be considered a secondary parameter.

Each of these parameters are discussed in the following paragraphs and summarized in Table 3. A summary of immersion and color development times for the chemical test strips is provided in Table 4.

Table 3. Concern Levels, Contaminant Sources and Corrective Actions

Parameter	Level of Concern	Contaminant Sources	Corrective Actions
PathoScreen™ Bacteria test	ANY black color change	Human sewage, animal manure	Find and eliminate or move source; disinfect well
Nitrates	10 mg/l as N	Animal manure, latrines, septic tanks	Stop drainage, move contaminate source
pH	Less than 6.5, more than 8.5	Natural condition or industrial wastes, chemical storage.	Isolate contaminant source from water
Chlorides	250 mg/l	Septic drainage, ocean intrusion	Stop drainage, new well?
Hardness	none	na	Different soaps
Iron	0.3 mg/l	Natural geology	None
TDS (total dissolved solids)	500 mg/l	Natural geology, chemical storage, septic tanks, ocean intrusion	Isolate contaminant source from water, possible new well.

A. Coliform Bacteria

Significance. There are many kinds of bacteria that can cause disease in humans. These bacteria will be present in the intestines of an infected person, so the bacteria will also be present in that person's feces. If those feces contaminate a water source, then the disease-causing (pathogenic) bacteria will be transmitted to other people who drink the water. It is extremely important to make certain that a source of drinking water is free from disease-causing bacteria.

It requires a well-equipped laboratory and trained technicians to identify each kind of disease-causing bacteria that might be present in a water source. Therefore, it is convenient to look for one kind of "indicator" bacteria that are easy to identify. Coliforms are a family of bacteria that live in the intestines of humans (and livestock) and their presence in a water sample is relatively easy to identify. One characteristic that disease-causing bacteria and coliform bacteria have in common is that they produce hydrogen sulfide when they grow. Not all strains of hydrogen sulfide-producing bacteria cause disease, but if they are found in drinking water then it is a certain sign that the water has been contaminated with feces. If any that hydrogen sulfide-producing bacteria – such as coliforms - are found in a water source then, to be safe, it should be assumed that other disease-causing bacteria are also present.

A number of tests for hydrogen sulfide-producing bacteria in water have been developed. Lifewater's kit uses the PathoScreen™ test by HACH Chemical Company. This procedure can be carried out at tropical "room temperature" (75°–90°F / 24°-32°C) so it does not require incubation and results can usually be obtained within 24 hours. There is a simple color reaction in the sample of water being tested that is easy to see (black=bad; yellow=OK). A black color

change indicates the presence of bacteria that produce hydrogen sulfide. Since these bacteria are associated with the human intestine, a black (positive) test result indicates that disease-causing (pathogenic) bacteria may also be present in the water. Therefore, the water's bacterial safety is highly suspect. Hydrogen sulfide-producing bacteria detected by the PathoScreen™ test include: *Salmonella, Citrobacter, Proteus, Edwardsiella,* and some species of *Klebsiella*. However, the test does not specifically identify which of these bacteria, if any, may be present in the sample.

The numerical standards for bacteria in drinking water that have been established by the World Health Organization (WHO), US Environmental Protection Agency (EPA), and other similar organizations are based on laboratory-based analytical methods. The presence/absence results obtained by the PathoScreen™ test cannot be directly compared to these standards.

Test Procedure. Properly performing the PathoScreen™ test requires good technique and a close attention to detail. The most common source of error in performing this test is introducing bacteria from the sampler's hands or equipment into the water sample being tested.

There are six steps to preparing a bacteria test. The steps should be carried out in this order: 1) Cut open the media pillow, 2) Collect the water sample, 3) Add the media, 4) Seal the sample bag, 5) Interpret the results and 6) Dispose of the sample. These steps are described in detail in the following paragraphs.

1) Open the media pillow. Hach suggests a large toenail clipper for this operation, but you can also use a sharp pocketknife. Take an alcohol swab out of its foil pouch and spread open the foil pouch on a stable surface. This will give you a sterile spot to use later. Wipe the knife blade or clipper with the swab. Cut off the end of the media pillow and lay the opened media pillow on the opened alcohol swab foil. Do not let the powdered media spill out. Leave the opened media pillow on top of the alcohol swab pouch while you are collecting the water sample.

2) Collect the sample. The primary concern here is to open the Whirl-Pak sample bag without contaminating the inside. Before collecting the sample, write the date, time, and place of the sample on the white part of the bag (use the "Sharpie" permanent marker included in the kit). Then tear off the top of the bag off along the perforated mark. Collect the sample by first holding the top white strips (ones without the wire) and pull open the bag. If you are sampling from a faucet, wipe the end with the alcohol swab, let the water run for about ½ minute, then carefully fill the opened bag to the 100 ml level line. When sampling from a container of water or a surface water source, use the small cup (wiped with the alcohol swab then rinsed) to dip the water and pour it into the bag to the 100 ml level line. If you collect too much, carefully pour out the excess. The sample bag contains a small tablet of sodium thiosulfate that removes any chlorine that might be in the sample water. This will allow whatever bacteria that are present to grow, so the tablet should not be removed especially when sampling a city water source that might be chlorinated.

3) Add the media. With the sample of water in the bag filled to the 100ml line, stand the sample bag upright and pour in the contents of the media pillow. The media powder is a nutrient that stimulates the growth of bacteria so they can be detected. It is important to get all of powder into the sample bag.

4) Seal the sample bag. Pull the white wire strips taut so the bag is somewhat sealed. While firmly holding the wire strips, carefully but quickly whirl the bag three times. Then fold the wire strips over to keep the bag sealed. The diagram that is packed with the bag illustrates how this should be done. If the growth media does not fully dissolve during the sealing process the bag can be slightly agitated but be careful not to squeeze it or otherwise cause the sample to leak out. The sample will be yellow in color.

To transport the sample bag set it in a plastic bottle – such as a drinking water bottle – with the top cut off. Several sample bags can be held in one liter bottle. Then place it in a secure spot (NOT inside your backpack) where it won't tip over or get kicked around. Set the bag aside at tropical room temperatures (75°F/24°C or higher).

5) Interpret the results. Observe the sample bag after 24 hours have elapsed. Record the color change, if any. If after 24 hours the sample has turned black, then it may be concluded that the water is contaminated by fecal material and that disease-causing bacteria are probably present in the water. If the sample turns black in less than 24 hours, then either there may have been a large number of bacteria in the sample or they are fast-growing bacteria. In either case, the sample should be carefully disposed of as soon as it definitely turns black; there is no need to wait the full 24 hours when the result is obviously positive. (Letting such a sample sit around your room can produce enough hydrogen sulfide to cause the bag to swell and emit an awful stench.)

After 24 hours, if the sample still looks yellowish or perhaps cloudy, make a note of its appearance, let it sit for an additional 24 hours then recheck the sample. If the color changes from yellow to black or any black precipitate (small specks or dots) forms, record the test as positive. Any sample that turns black within 48 hours is considered positive, regardless of its appearance at 24 hours.

Any amount of black precipitate - seen as small dots - is considered to be a positive result for hydrogen sulfide-producing bacteria. If the sample bag has black dots or an accumulation of black dots, the test is positive. You can carefully waft the odor from a sample bag containing black dots. A negative test does not smell very good, but a positive test smells absolutely terrible (like sewage).

After 48 hours of incubation, if the sample still appears yellow, record the test as negative for hydrogen sulfide-producing bacteria.

6) Dispose of the sample. If the test results were positive for hydrogen sulfide-producing bacteria (the sample turned black), then it should be assumed that disease-causing bacteria are present in large quantities in the sample bag. At best, exposure to the contents of the sample bag could cause diarrhea and at worst a serious life-threatening illness. Therefore, great care must be exercised in disposing of such a sample. The exact procedure will depend on what is available. If your hands have any cuts or scrapes, ask someone else to dispose of the sample. Ideally, the bag should be punctured while submerged in a basin of chlorinated water; like a toilet bowl to which a heavy dose of liquid bleach has been added. That way, the contents will not spray out if the bag is under pressure and the sample (not the plastic bag) can then be flushed away. The bag should be rinsed out with bleach to kill all bacteria then burned or disposed of in such a manner that it can't be recovered. Finally, use bleach to disinfect your hands and any surfaces that might have come in contact with the sample. These precautions are not required for a negative sample, but it is wise to get into the habit of handling all bacteria test samples as if they were infectious.

B. Nitrates

Significance. Nitrates and nitrites are nitrogen-based compounds that dissolve in water and can cause adverse health effects, especially in infants. These compounds are present in certain types of rocks so elevated levels of nitrates may occur naturally in some groundwater aquifers. Nitrates from these natural sources normally do not occur at levels much above 1 mg/l, so a level greater than that is likely due to human or animal waste or from the use of nitrogen-based fertilizers. Chicken manure is especially rich in nitrates.

The level of nitrates that are thought to have an adverse human health effect is 10 mg/l. Above this level, the possibility increases for infants less than six months of age to develop a condition known as "blue baby syndrome" or methemoglobinemia, where their blood can't carry sufficient oxygen. Therefore, infants should not drink water with nitrates above 10 mg/l. Adults or older children are not normally affected by drinking water having 10 mg/l nitrates. The World Health Organization (WHO) has set 12 mg/l as the standard for nitrates.

Once groundwater has been contaminated with nitrates, there is no simple method for removing them from the water. If the source of nitrates is eliminated, then (depending on the characteristics of the aquifer) the nitrate concentration in a well may decrease to a safe level over time. Therefore, attention must focus on keeping potential sources of nitrate from contaminating the well.

Common sources of high nitrate levels include latrines or pit toilets, leaking sewer lines, livestock pens, chicken coops, and heavy application of nitrogen-based fertilizers (including "night soil"). Any of these things, if located too close to a well, can cause high nitrate levels in that well.

Test Procedure. Using one of the small sample cups provided in the test kit, dip one test strip in the water sample for two seconds, remove, wait 1 minute and match the Nitrate+Nitrite (end pad) and the Nitrite (middle pad) colors. Record the results. To determine Nitrate nitrogen level subtract the Nitrite level from the Nitrate+Nitrite level. Complete the color match within one minute.

C. pH

Significance. The pH level of water is a measurement of the degree to which it is acidic (pH lower than 7) or alkaline (pH higher than 7). Under natural conditions, the pH of groundwater is mainly influenced by the soil formations through which it moves. Most waters have a natural pH between 6 and 9. If the pH is less than 6.4, the water may be corrosive to metal pipes and may leach metals from the pipe into the water. Waters with a pH above 8.5 tend to leave salt deposits on fixtures, especially where the hardness of the water is high. The WHO standard for ph is between 6.5 and 8.5. Anything outside of that range, or if there is a significant change over time, should be investigated.

Test Procedure. Dip one test strip into the water sample for 10 seconds with constant, gentle back-and-forth motion. Remove strip and shake once briskly to remove excess water. Wait 20 seconds and match color with closest color on color chart. Match the test pad at the end of the strip with the colors in column A of the color chart and match the pad in the middle of the strip with column B. Complete the readings within 10 seconds.

D. Chlorides

Significance. Chlorides are an indication that salt water has entered into the drinking water supply. In a coastal region, the source is usually seawater, but other areas can have high levels of chloride from certain types of rocks or from an ancient seawater aquifer. Chlorides are not a direct health hazard, but water with a level of chlorides above the WHO standard of 250 mg/l will have a salty taste (if the chlorides came from sodium chloride). So if a well has safe water but tastes salty, people will tend to drink from a better tasting source even though that source might have bacterial contamination. Chloride levels tend to be stable within an aquifer. Therefore, increasing levels of chlorides over time can indicate a developing problem, such as over-pumping the aquifer.

The Lifewater kit does not include a test for sodium and the WHO has not set a health-based standard for sodium. However, a high concentration of sodium in drinking water is linked to high blood pressure, hypertension, renal diseases, cirrhosis of the liver, metabolic disorders and cardiovascular diseases.

Test Procedure. Dip one test strip into the water sample for 10 seconds with constant, gentle back-and-forth motion. Remove strip and shake once briskly to remove excess water. Wait 30 seconds and match color with closest color on color chart.

E. Hardness

Significance. Many minerals may dissolve in water as it moves through the ground. Of these, calcium and magnesium are the ones that commonly make water "hard." Hard water (20 – 180 mg/l) uses more soap in cleaning, causes formation of a soapy film on fixtures, and can cause clothes to wear out prematurely. Very hard water (more than 200 mg/l) can cause scale to form in pipes and appliances.

Hardness in water does not have any adverse health effect and WHO has not established a recommended maximum level. One reason it is included in the test kit is that in some circumstances water hardness can be a convenient way to distinguish between two different aquifers.

Test Procedure. Dip one test strip into the water sample for 3 seconds, remove strip and immediately match color with closest color on color chart. Color is stable for 1 minute.

F. Iron

Significance. As with other minerals that may be found in water, iron can be picked up from the soil formations through which groundwater flows. The presence of iron in water may impart an unpleasant metallic taste. When iron combines with tea, coffee, and alcoholic beverages, it produces an inky, black appearance and a harsh, offensive taste. Vegetables cooked in iron-contaminated water turn dark and look unappetizing. If the iron level is above the WHO standard of 0.3 mg/l, the water can cause staining of laundry or discoloration of the faucets and basins. However, even high concentrations of iron are not considered a health problem. Nevertheless, if it tastes bad, people may turn to other water sources, even if those sources pose a real health hazard.

Test Procedure. Dip one test strip into the water sample for 30 seconds with constant, gentle back-and-forth motion. Make sure all of the pads on the strip are in contact with the sample water. Remove the strip, wait 2 minutes, then view through the aperture on the strip to match with the closest color on the color chart.

G. Total Dissolved Solids (TDS)

Significance. Total dissolved solids are not a measurement of any one parameter but rather an aggregate total of all dissolved material in the water. A TDS measurement includes metals, salts, and anything else that is soluble when a water source contacts it in its underground or above ground flow. TDS levels less than 500 mg/l are generally acceptable, levels between 500 mg/l and 1000 mg/l are questionable, and with levels above 1000 mg/l there is a very high probability that the water has taste problems and/or laxative effects. Even at levels greater than the WHO standard of 1000 mg/l, people can accept the taste of the water especially if it is their only supply.

Test Procedure. Since there are no "dip strip" tests for TDS, this parameter is not included in the Lifewater test kit. The easiest way to test for TDS is to purchase a small pocket meter from one of the suppliers listed in Appendix A. Follow the manufacturers directions for taking a TDS measurement.

Table 4. Immersion and Color Development Times for Test Strips

Parameter	Dip in Water Sample for:	Let Color Develop for:	Level of Concern
Nitrates	2 seconds	60 seconds	10 mg/l
pH	10 seconds	20 seconds	<6.5 or >8.5
Chloride*	10 seconds	30 seconds	250 mg/l
Hardness	1 second	20 seconds	none
Iron	1 second	15 seconds	0.3 mg/l

* See additional details in instructions provided with the test strips

8. Sample Variability and Test Precision

Some variability commonly occurs in test results. This may be due to differences in the way the sample was collected and tested, seasonal fluctuations in the parameter, or a change caused by a source of contamination. In most cases, the more samples that are tested, the better one can understand the variations that occur.

The simple test methods used in this course will record significant changes of a parameter. For example, these tests will identify real changes in nitrates in the range of milligrams per liter, whereas commercial laboratory results may show changes on the order of tenths of a milligram per liter. If the test strips indicate a water sample having 5 mg/l of nitrate and a subsequent sample having more than 10 mg/l, a commercial laboratory might show the same samples at 4.93 mg/l and 12.4 mg/l. (In other words, the test strips are accurate, but not as precise as a laboratory.) A potential health risk has been documented by both methods, but the test strips revealed it for a much lower cost using a simpler methodology.

9. Reporting Test Results

Record all test results on the Test Data Record provided on Table 6 of this Appendix (page). It is important to record detailed observations about the water source being tested, especially if sources of contamination are evident.

These tests will usually be conducted in the presence of a crowd of people pushing in on you, carefully watching your every move, and wondering what you are doing. If a translator is available, simply explain that you are testing the water to make sure that it is safe to drink.

Specific water test results should only be discussed in private conference with the village leaders. DO NOT make any statements to a crowd along the lines of, "This water is bad for you." Conversely, unless you have completed a bacterial test that shows no disease-causing bacteria are present do not state that the water is safe to drink. Whatever you say in a crowd can easily be misunderstood or not fully heard. Your words will be further distorted when they are reported to other people, and so on.

If a village leader is present in the crowd and asks about the results, explain that you need to evaluate the tests and will discuss the results with him or her at a later time. Then do so, even if it means going out of your way. We do not want to cause anxiety from unanswered questions. In your private meeting with the village leaders, take time to explain the significance of the tests – particularly bacteria and nitrates – and be prepared to respond to the question, "What can we do about it?"

Some developing nations have water quality monitoring programs, even if they lack the money to do any actual testing. It is wise to be informed of these programs before you begin testing. If a country has such a program, make an effort to report your findings to the responsible authorities.

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Table 5. Lifewater International Water Test Kit Supplies

Lifewater is not presently selling water test kits.[8] The following information is provided for those who wish to obtain their own test kit components from the vendors that Lifewater uses. The quantities indicated are the smallest units that may be purchased. The test strips should not be used past their shelf life. An order may be received with nearly half of the test strip's shelf life already past.

Item	Vendor	Part No.	Quantity	Shelf Life
PathoScreen™ Media P/A	Hach	26106-96	50	36 mo
Whirl-Pak Sterile Sample bags	Hach	2075333	100	
Chloride test strips	ITS	480127	30	12 mo
Chloride Test Cards Only	ITS	480127 (Cards)	1	
Nitrate test strips	ITS	481109	30	12 mo
Nitrate Test Cards Only	ITS	481109 (Cards)	1	
Hardness test strips	ITS	481108	30	24 mo
Hardness Test Cards Only	ITS	481108 (Cards)	1	
pH test strips	ITS	480104	30	20 mo
pH Test Cards Only	ITS	480104 (Cards)	1	
Iron test strip	ITS	480125	30	18 mo
Iron Test Cards Only	ITS	480125 (Cards)	1	
Note pad (3x5)	Staples	199984-53	5	
Permanent marker-fine point	Staples	125328-53	12	
Small Pencil	Staples	116012-74	144	
Zip lock bags (4x6)	Staples	427301-53	1000	
Corrugated box (7x3x4)	Consol. Plastics	114564KW	100	
Sample Cups (3oz)	Albertson's		80	
Sanitizing Fluid (.5 oz)	Rite-Aid		6	
Alcohol Wipes	Rite-Aid		100	

Vendor Phone Numbers

Hach: 800-227-4224 or www.Hach.com
ITS (Industrial Test Systems): 800-861-9712 or www.sensafe.com
Consolidated Plastics Co.: 800-362-1000

Sources of Low-Cost Pocket TDS meters (partial list)

Automated Aquarium Systems www.automatedaquariums.com/mw_t74.htm
MG Scientific 800-343-8338 www.mgscientific.com/store/group.asp?GROUP_ID=192
Marine Depot 714-385-0080 www.marinedepot.com/a_ro_tester.asp
Omega,com 888-826-6342 www.omega.com/ppt/pptsc.asp?ref=TDSH&Nav=greee02

[8] As of October 2013.

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Table 6

Water Test Data Record Form

Source Name _____

Location _____

Latitude _____ Longitude _____

Source Type Well: Drilled or Hand-Dug?
Pump: Hand or Power or None?

Surface Water: Spring or Stream or Pond?

Other (describe)_____

Sampled by _____

Date _____ Time _____

Results

PathoScreen Bacteria POS NEG No Test

Nitrate+Nitrite _____ Nitrite _____

pH _____ Chlorides _____

Hardness _____ Iron _____

TDS _____

Observations

Water Turbidity: High Medium Low Clear

Color _____ Odor _____

Sources of contamination? (describe)

_____

_____

_____

_____

Water Test Data Record Form

Source Name _____

Location _____

Latitude _____ Longitude _____

Source Type Well: Drilled or Hand-Dug?
Pump: Hand or Power or None?

Surface Water: Spring or Stream or Pond?

Other (describe)_____

Sampled by _____

Date _____ Time _____

Results

PathoScreen Bacteria POS NEG No Test

Nitrate+Nitrite _____ Nitrite _____

pH _____ Chlorides _____

Hardness _____ Iron _____

TDS _____

Observations

Water Turbidity: High Medium Low Clear

Color _____ Odor _____

Sources of contamination? (describe)

_____

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Appendix 15 References

General Well Drilling

Drilled Wells. Ball, Peter. SKAT, Swiss Centre for Development Cooperation in Technology and Management 2001. Online at: http://www.pat-drill.com/pdf/Drilled_Wells.pdf.

Multiservice Procedures for Well-Drilling Operations. US Army Field Manual FM 5-484, 2007. Available for purchase from: http://www.amazon.com.

"PAT Book of Borehole Designs." Ball, Peter and Yamchinda, Porphol. PAT-Drill, Bangkok, no date. Online at: http://www.pat-drill.com/pdf/Bore_hole_design.pdf.

"Water Well Drilling Agreement and Instructions for Use." National Groundwater Association Press, 2004. Available for purchase from: http://www.ngwa.org/publication/index.aspx.

Wells Construction: Hand Dug and Hand Drilled. Peace Corps Information Collection and Exchange Manual M-9, September 1982. Online at: Http://ces.iisc.ernet.in/energy/water/paper/drinkingwater/wellsconstruction/dnctechniques.html.

Rural Water Supply Network publications on "Cost Effective Boreholes" http://www.rural-water-supply.net/en/resources/sort/year-desc/filter/2_32

Hydrogeology

Basic Ground-Water Hydrology. Heath, Ralph. Water Supply Paper 2220 US Geological Survey, 1983 (2004 revised). Online at: http://pubs.er.usgs.gov/djvu/WSP/wsp_2220.pdf

Water Quality

"Interpreting Drinking Water Quality Analysis" www.walrus.com/~gatherer/interpret.html

"Water Quality Parameters" www.state.ky.us/nrepc/water/ramp/rmtests.htm

"Water Quality Parameters" www.agen.ufl.edu/~wq/resources/params.html

"Water Quality Parameters" http://imc.lisd.k12.mi.us/tests.html

WHO information on Chlorides: http://www.who.int/water_sanitation_health/GDWQ/Chemicals/chloridefull.htm

Hand Pumps

Mark II Installation and Maintenance Manual. Dempster Industries, Inc., Beatrice, NB

Mark II manuals may also be obtained from pump manufacturers, most of which are located in India. Free online versions have not been found, but the Rural Water Supply Network publishes excellent hand pump manuals at: http://www.rural-water-supply.net/en/resources/sort/year-desc/filter/2_33.

Installation and Maintenance Manual for the Afridev Handpump. 2007, Skat Foundation, Switzerland. http://www.rural-water-supply.net/en/resources/details/286

"Technology Selection – and Buyer's Guide for Public Domain Handpumps for Drinking Water" Erpf, Karl 2009. Rural Water Supply Network. http://www.rural-water-supply.net/en/resources/details/26

Community Development

When Helping Hurts: How to Alleviate Poverty Without Hurting the Poor . . . and Yourself. Steve Corbett and Brian Fikkert, 2012. Moody Publishers, Chicago, IL.

Walking With the Poor. Bryant L. Myers, 2011. Orbis Books, Maryknoll, NY.

African Friends and Money Matters: Observations from Africa (Publications in Ethnography, Vol. 37). David E. Maranz, 2001. SIL International, Dallas, TX.

"Rethinking Hydro-Philanthropy: Smart Money for Transformative Impact." Edward D. Breslin, Water For People 2010. http://www.waterforpeople.org/assets/pdfs/rethinking-hydrophilantropy.pdf

Maintaining Hydraulic Systems

"Basic Information for Performing Hydraulic System Maintenance" http://www.hwhcorp.com/ml40628-3.pdf

"Hydraulic Hints & Trouble Shooting Guide" http://www.eaton.com/ecm/groups/public/@pub/@eaton/@hyd/documents/content/ct_233701.pdf

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Appendix 16 English-Metric-English Conversions

Multiply	By	To Obtain	Multiply By	To Obtain
Length				
Inch (in)	2.54	Centimeter (cm)	0.394	Inch
foot (ft)	0.305	Meter (m)	3.28	Foot
Yard (yd)	0.914	Meter (m)	1.09	Yard
Mile (mi)	1.609	Kilometer (km)	0.621	Mile
Area				
Square inch	6.452	Sq centimeters	0.155	Square inch
Square foot	0.093	Square meters	10.764	Square foot
Acre (ac)	0.405	Hectares (ha)	2.471	Acre
Volume				
Gallon (gal)	3.785	Liter (L)	0.264	Gallon
Gallon (gal)	0.00378	Cubic meter	264.17	Gallon
Cubic inch (cu in)	16.39	Cubic centimeter	0.061	Cubic inch
Cubic foot (cu ft)	0.0283	Cubic meter	35.315	Cubic foot
Cubic foot (cu ft)	28.32	Liter (L)	0.035	Cubic foot
Acre foot (ac ft)	325,853	Gallon		
Acre foot (ac ft)	1,233.5	Cubic meter		
Cubic meter	1,000	Liters		
Flow Rate				
Gallon/min (gpm)	0.063	Liter/second	15.85	Gallon/min
Cu Ft/min (cfm)	0.028	Cubic meter/min	28.32	Cu Ft/min
Cu Ft /sec (cfs)	1.7	Cubic meter/min	0.589	Cu Ft /sec
Million gal/day (mgd)	3.785	Cubic meter/day	0.264	Million gal/day
Weight				
Pound (lb)	0.454	Kilogram (kg)	2.2	Pound
Speed				
Miles/Hour (mph)	1.61	Kilometers/Hr (kph)	0.621	Miles/Hour

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Personal Notes