Chapter 9

Well Drilling Supervisor and Operations

Topics

To hear audio, click on the box.

Overview

During the 20th century, the military has conducted many major operations in areas without enough surface water to meet operational requirements. The military was used in World War I to locate and develop groundwater resources by deep drilling. More recently, locating groundwater sources in the Saudi desert during the Gulf War was made possible by using military well-drilling expertise. In the Balkans, Seabees were deployed to locate and develop groundwater for peacekeeping operation base camps. Groundwater is often ideal for these semi-permanent installations housing thousands of troops because wells require little maintenance and well yields generally remain constant over time. In a comparison of drinking water sources, groundwater has advantages over both surface water, which requires treatment, and bottled water, which is prohibitive in terms of both cost and logistical requirements. Groundwater will continue to be a critical source of water for military operations in the future.

The Naval Facilities Engineering Command (NAVFAC) invests millions of dollars in water well-drilling equipment and the training required to enable the Naval Construction Force (NCF) to meet water well-drilling requirements at various locations and conditions throughout the world.

The COMSECOND/COMTHIRD Naval Construction Brigades require all Naval Mobile Construction Battalions to maintain an allowance of personnel qualified in water well-drilling operations. The Naval Construction Training Centers (NCTC) and Regiments from both Gulfport, Mississippi, and Port Hueneme, California, provide training in water well-drilling operations. The NEC for water well driller is 5707. The means of attaining this NEC is most often through completion of the water well driller course that is offered at NCTC, Port Hueneme, California.

This chapter can provide only the basic terminology and procedures used in well drilling operations. The extensive knowledge and skills required to perform as an effective well drilling supervisor must be gained through formal training and on-job-training experience.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand the responsibilities of the Water Drilling Supervisor.
2. Identify sources of water.
3. Understand the classification of wells.
4. Identify methods and objectives for drilling water.
5. Understand the use of the Driller's Log.
6. Understand the duties of those on the drilling crew.
7. Identify drilling equipment and operations.
8. Identify causes and prevention of drilling difficulties.
9. Understand how to develop and complete wells.
10. Understand well drilling safety.

Prerequisites

None

This course map shows all of the chapters in Equipment Operator (EO) Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Well Drilling Supervisor and Operations	↑	E O
Asphalt Plant Supervisor and Operations		
Concrete Batch Plant Supervisor and Operations		A
Crusher Supervisor and Operations		D
Quarry Supervisor and Operations		V
Project Supervisor		A
Crane Crew Supervisor		N
Air Detachment Equipment Supervisor		C E
Transportation Supervisor		D

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 WELL DRILLING SUPERVISOR RESPONSIBILITIES

Successful well drilling operations are a direct result of the efficiency of the supervisor and crew. The drilling rig and its controls are not complicated and can be mastered in a short time; however, knowledge of the mechanical operations is only the start; experience is the vital element.

Drilling water wells is an art for which there are no hard-and-fast rules; it is an art that requires a good deal of common sense and improvisation. The well drilling supervisor must have a general knowledge of the physical structure of the earth's crust and the groundwater resources within. Problems often arise in well drilling, and the well drilling supervisor must be able to visualize what is occurring at the bottom of the hole. An awareness of the conditions under which groundwater occurs and of geologic conditions is a shortcut to the solution of some drilling problems that would otherwise take much time and experience to attain through the trial-and-error method.

1.1.0 Resources/Instructions

Department of Defense Directive Number 4705.1, Management of Land-Based Water Resources in Support of Contingency Operations, July 9, 1992

Updates policy, responsibilities, and procedures for management of land-based water resources in support of contingency operations to ensure inter-Service compatibility and interoperability of water support equipment.

Water Supply in Theaters of Operations FM 10-52, Headquarters, Department of the Army, Washington, DC July 1990

This manual is a guide for commanders, staff officers, and other persons concerned with planning, organizing, and operating an Army water supply system in a TO. Concepts and doctrine are presented to enable the planner to design a water purification, storage, and distribution system that will ensure units can provide necessary water support to U.S. forces.

Water Supply Point Equipment and Operations FM 10-52-1, Headquarters, Department of the Army, Washington, DC June 1991

This manual describes water purification, storage, and distribution equipment and its use by TOE units in their GS and DS roles. It also deals with water supply point operations. It includes information on quality control; ground and air reconnaissance; development of a water supply point; NBC and extreme environment operations; and purification, storage, and distribution operations.

Multiservice Procedures for Well-Drilling Operations FM 5-484, , Headquarters, Department of the Army, Navy and Air Force, Washington, DC March 1994

This manual is a guide for engineer personnel responsible for planning, designing, and drilling wells. This manual focuses on techniques and procedures for installing wells and includes expedient methods for digging shallow water wells, such as hand-dug wells.

Operational Guidelines for Humanitarian Civic Assistance Water Well Drilling, United States Army Engineer District, Mobile Engineering Division, Geotechnical and Environmental Branch, Geotechnical and Dam Safety Section, Alexandria, VA 2009

This manual sets a format for everyone involved in well completion starting from site selection and ending with testing the performance of the finished well.

Operating, Safety and Maintenance Manual, T2W Navy, Atlas Copco Drilling Solutions Garland, TX 2006

This Operating, Safety, and Maintenance Manual has been developed to present the operations, safety, and preventive maintenance requirements for safe, effective operation and maintenance of the Atlas Copco Drilling Solutions T2W Waterwell Drill. The purpose of this manual is to provide the operator and site maintenance personnel with the knowledge of the fundamental rules and criteria to be followed for on-site use and for the maintenance of the T2W Waterwell Drill.

2.0.0 WATER SOURCES

Lakes, streams, precipitation, and underground water are sources of fresh water. Part of the precipitation that falls on land areas soaks into the ground and gravity pulls it downward until it becomes part of the ***saturated zone*** (*Figure 9-1*). Water in the saturated zone is referred to as groundwater, and it is within this zone that wells are developed.

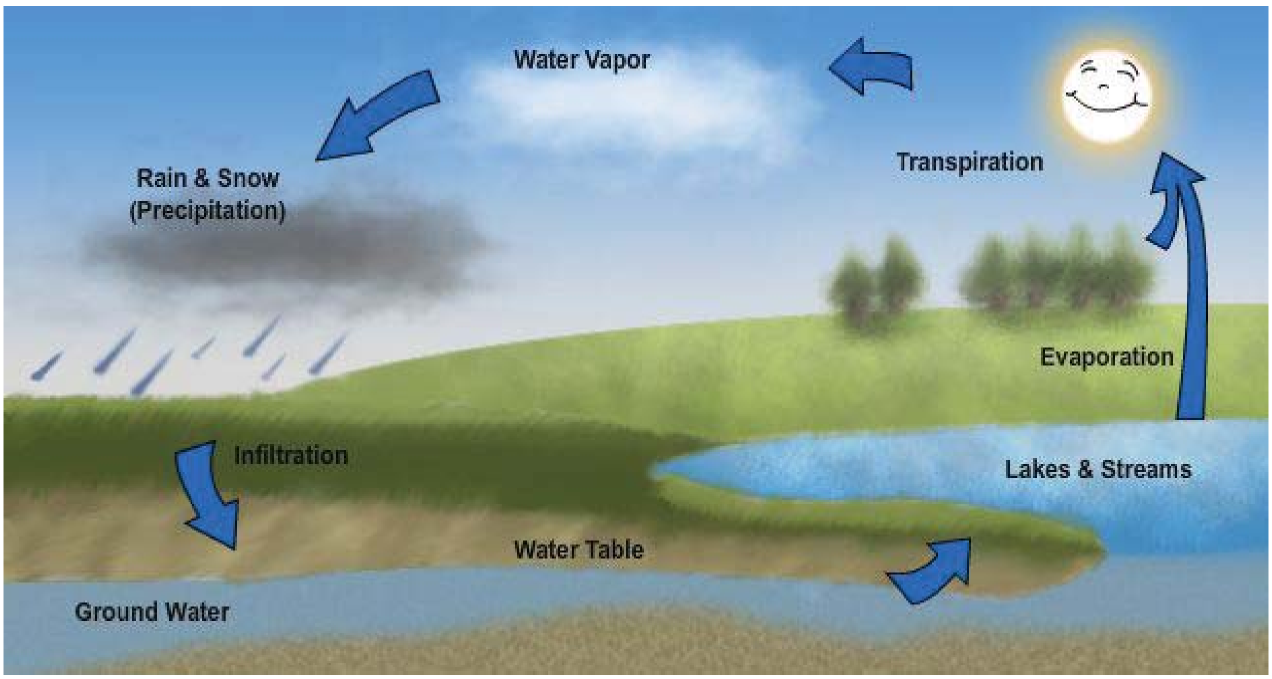

Figure 9-1 — Water cycle.

Groundwater, pumped from beneath the earth's surface, is often cheaper, more convenient, and less vulnerable to pollution than surface water. Therefore, it is commonly used for public water supplies. Groundwater provides the largest sources of usable fresh water in the United States. Underground reservoirs contain far more water than the capacity of all surface reservoirs and lakes, including the Great Lakes. In some areas, groundwater may be the only option (*Figure 9-2*).

When precipitation soaks into the earth, it first travels through the unsaturated zone or zone of aeration, which is the area above the water table. This area has small open areas between the individual grains of sand and rock that draw the water in like a sponge. Once the water reaches an area of full saturation it must start to move horizontally. It will keep moving horizontally until it encounters either rock or clay, which results in the water being contained and pressure starting to build, conditions that create an aquifer. If the water does not encounter any resistance, it will eventually find its way up to the surface via a spring, which is a channel from the saturated area to the earth's surface.

The volume of water contained in the saturated zone is the total volume of the openings in rocks or between the individual grains of sand or gravel. These openings are referred to as the porosity of the particular material.

The physical characteristics of the zone of saturation can vary widely, depending upon the geologic formations of the earth layers, that is, sand, gravel, clay, rock, or a combination of these. This zone may also vary in depth from a few feet to many hundreds of feet.

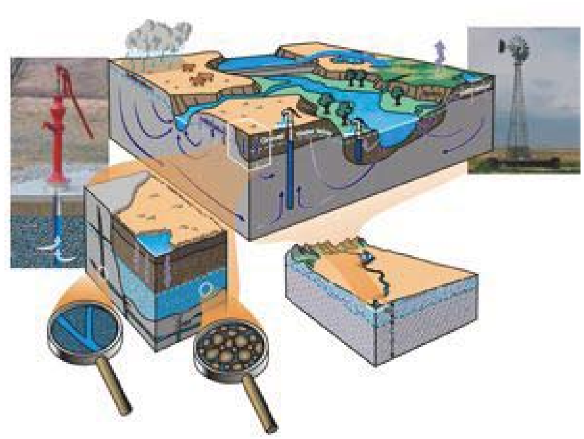

Figure 9-2 –Groundwater.

Water may be found within the saturation zone in one continuous body or in alternating layers of clay and sand. This all depends on the impermeability or the permeability of the formations within the saturation zone; for example, while clay may hold a relatively high volume of water, the openings between the individual particles are so small that they prevent the flow of water. Clay is then said to be impermeable. Confined between two layers of clay may be a layer of sand, which is both porous (holds water) and is permeable (allows the water to flow) (*Figure 9-3*).

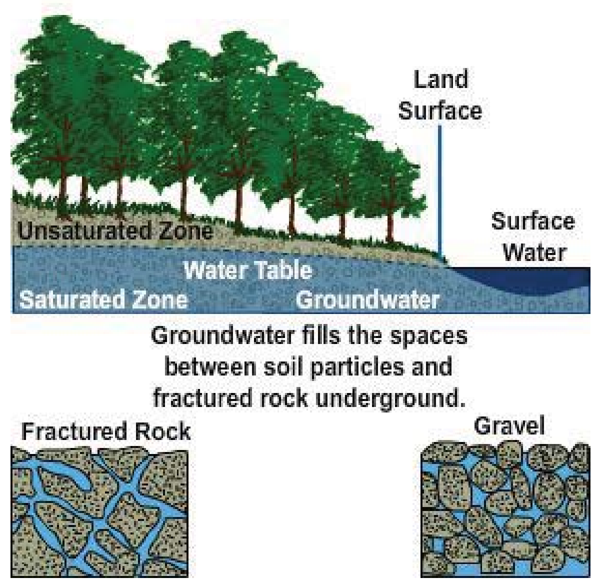

Figure 9-3 — Saturation zone.

A porous and permeable formation that can yield water in usable quantities is called an aquifer. If an aquifer is not confined by an impermeable layer above it, the aquifer is said to be under water table conditions and is subjected to atmospheric pressure. If an aquifer is confined both above and below and the recharge area or source of water is higher than the point where a well is to be located, the water will be under greater than atmospheric pressure and will rise to some point above the water table. When the pressure is sufficient, the well may be free flowing. An aquifer under this condition is called an artesian.

Sedimentary rocks are the most common types of rocks in aquifers. They are formed by the accumulation of sediments that have been deposited by water, wind, or ice. Limestone is a sedimentary rock formed from the accumulation of chemical compounds and minerals that settle together out of water. Throughout thick, nearly horizontal layers of limestone, as well as shale and sandstone, are huge reservoirs of groundwater. Sedimentary rock formations are among the most common and productive of all aquifers, and when found in sandy or gravel formations are easy to drill.

Both ***igneous*** and ***metamorphic*** formations are viewed as a group of hard, dense rocks. Unless highly fractured and occurring close to the earth's surface, they contain far less water than sedimentary rocks. The recovery of water from solid rock depends on the existence of many cracks, fissures, or crevices in the rock. Extremely fine deposits of sedimentary materials usually produce little water. Although highly porous, they are relatively impermeable; clay is a good example of a fine particle material.

Topographical features created by water action offer an excellent chance for the recovery of groundwater at relatively shallow depths. Alluviums are the most productive formations for groundwater. Alluvium is mixture of sand, gravel, and rocks that have been deposited by moving water. Types of alluvium deposits include the following: alluvial valleys that are rather extensive in area and are the sites of ancient rivers or the flood plains of active rivers; alluvial fans that are an accumulation of sediments at the base of mountains, deposited where drainage streams fan out; and alluvial basins that are essentially structural troughs created by a rim of mountains and glacial outwash.

2.1.0 Groundwater Exploration

The detection of groundwater sources is critical for successful well-drilling operations. Without proper analysis, the potential for finding an adequate source is less likely. Determining the most suitable sites to drill for groundwater falls primarily on ***geospatial teams*** and the water detection response team (WDRT). Geospatial teams use data from terrain and other geospatial products to recommend the best sites to conduct well-drilling operations. These teams use the results of field reconnaissance and geophysical surveys to provide recommendations. They also have the capability of reachback to experts at the Topographic Engineering Center to obtain data and analysis from historic records and further SME analysis to identify areas with a high potential for developing water supply sources. Geospatial teams are not equipped or trained for actual detection, only predictive analysis (*Figure 9-4*).

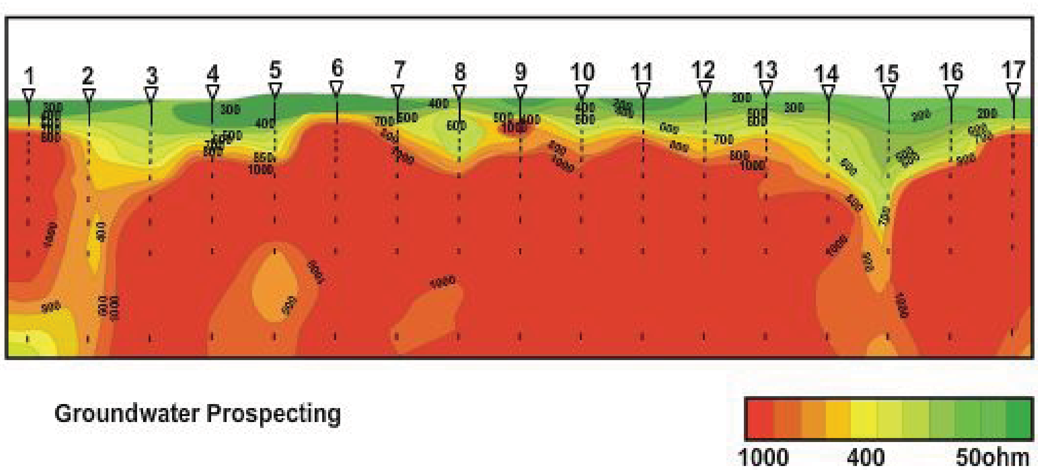

Figure 9-4 — Groundwater prospecting.

The mission of the WDRT is to assist the military planner, terrain team, and all DOD well-drilling teams in locating adequate groundwater supplies before drilling to improve military well-drilling success. In unfamiliar terrain, drilling by trial and error can be costly and time-consuming.

Well-drilling teams may drill exploratory or test holes to detect groundwater, but this method is time-consuming. It is only recommended if other water detection methods are not available or have been proven to be unsuccessful.

Test your Knowledge (Select the Correct Response)

1. What term is used to refer to water in the saturated zone?

   A. Aquifer
   B. Groundwater
   C. Artesian
   D. Well

2. What type of features created by water action offer an excellent chance for the recovery of groundwater?

   A. Geological
   B. Plains
   C. Topographical
   D. Mountains

3.0.0 WELLS

3.1.0 Classifications, Advantages, and Limitations

Well construction methods are many and varied, and range from simple digging with hand tools to high-speed sophisticated drilling equipment. The most common construction methods are listed below:

Digging Method:

In this method the hole is constructed by digging to the desired diameter and depth with hand or power tools. The dug out materials are removed by lifting them from the hole in some type of container. The hole is shored, staved, or cased as the depth is increased. When casing is used, a common practice is to add casing at the surface, allowing it to sink by its own weight as the hole is excavated below the bottom of the casing (*Figure 9-5*).

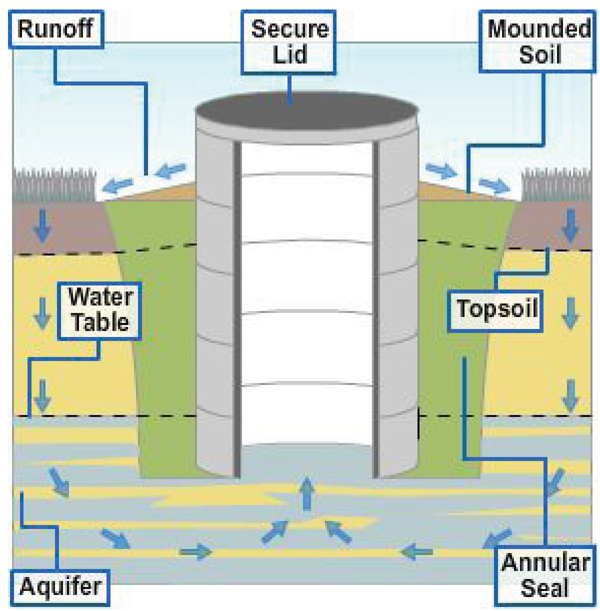

Figure 9-5 — Dug well.

Boring Method:

In this method the hole is constructed by the use of a selected diameter hand or power auger which is turned to bore the hole to the desired depth. Cuttings are removed by pulling and emptying the auger or bucket or by the screw action of the auger flite itself.

Driving Method:

In this method the hole is constructed by forcing a casing equipped with a drive point into the ground by a series of blows, either manually or machine-delivered, on the top of the casing. Driven wells (or "well points") should be installed only in soft formations that are relatively free of cobbles or boulders. They are feasible only where lifts are shallow and the quantity of water desired is small. Well points can be installed by hand or machine.

Jetting and Hydraulicing Method:

The jet drill is basically a combination percussion unit and pressure pump. The pressure pump is mounted on the machine together with pipe and hose connections leading from the pump to the drill pipe, with a return hose from the well casing to a pit or other suitable container. A suction hose returns the water from the pit or container to the pump. The drill pipe consists of a small diameter standard pipe with a bit or chisel attached to the bottom section. Water is forced down through the drill pipe by means of the pressure pump and out through the holes in the bit. This water, being under pressure, carries the cuttings to the surface through the space between the casing and the drill pipe. The lifting and dropping action of the drill pipe chops up the material in the hole and loosens it so that it may be washed to the surface. This method uses a short, fast stroke and is very effective in soft ground, sand and gravel, or other loose unconsolidated formations. This method is best suited for smaller holes of from 2- to 4-inch diameter. A percussion machine is also used for drilling holes by the hydraulicing method. The difference between this and the jetting method is that with the hydraulicing method no pressure pump is needed. The hydraulicing unit utilizes a bit with an opening at the top and a valve seat and ball check valve above it. Water is directed into the hole by gravity in the space between the drill pipe and the casing; the up-and-down motion of the drill pipe acts as a displacement pump. The ball-check valve opens on the down stroke and draws material and fluid into the drill pipe. The valve closes on the up stroke, holding the slurry within the pipe. Eventually the pipe fills up, and the mixture of fluid and cuttings is discharged at the surface. Like jetting, the hydraulicing method is fast and efficient in relatively soft formations such as clay and sand.

Cable Tool Method:

The cable tool method is used to construct wells by alternately lifting and dropping a set of drilling tools suspended on a wire cable so that with each stroke the drill bit strikes the bottom of the hole. The repeated action of the percussion drill permits bit penetration of the underground formations. The loosened material and drill cuttings are mixed with drilling water by action of the bit, and the resulting slurry must be removed from the drill hole by a bailer or sand pump. In drilling a dry hole, water must be added periodically to replace that removed with the drill cuttings. Tools for drilling and bailing are carried on separate lines or cables. Each cable is spooled on a separate drum. In cable tool or percussion drilling there are basically three major operations: first, the drilling of the hole by chiseling or crushing the rock, clay, or other material by the impact of the drill bit, second, removing the cuttings with a bailer as cuttings accumulate in the hole; and third, driving or forcing the well casing down into the hole as the drilling proceeds. Well casing used in most percussion type drilling operations usually ranges from 4 to 24 inches in diameter. This casing is used to keep the well bore from collapsing and to prevent surface or sub-surface leakage of water or contaminants into the well bore.

Conventional Fluid Rotary Drilling Method:

In the conventional mud-rotary method of drilling, drilling is accomplished by rotating a drill pipe and bit by means of a power drive. The drill bit cuts and breaks up the rock material as it penetrates the formation. Drilling fluid is pumped through the rotating drill pipe and holes in the bit. This fluid swirls in the bottom of the hole, picking up material broken by the bit, then flows upward in the well bore, carrying the cuttings to the surface (*Figure 9-6*).

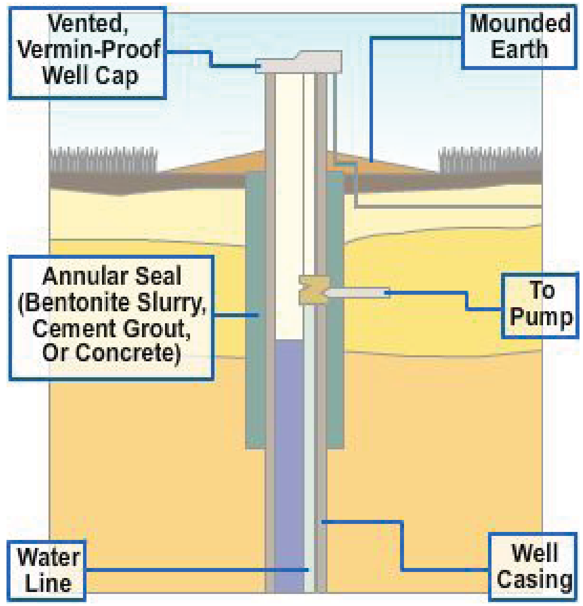

Figure 9-6 — Drilled well.

The drill pipe and bit move progressively downward, deepening the hole as the operation proceeds. At the land surface, the drilling fluid flows into a settling pit where the cuttings settle to the bottom. From the settling (mud) pit the fluid overflows into a second pit from which it is picked up through the suction hose of the mud pump and recirculated through the drill pipe. In the rotary drilling method the well casing is not introduced into the hole until drilling operations are completed, the walls of the hole being supported by the pressure (weight) of the drilling fluid.

Air Rotary Drilling Method:

In the air rotary method of drilling, air serves as the fluid, and excavation is accomplished exactly as is done in the conventional rotary method. The bit cuts and breaks up the formation.

Air is forced down through the drilling pipe and out through holes at the bottom of the rotary bit. A stream of water is often introduced into the air system to help cool the drill bit and control dust. The air serves both to cool the drill bit and force cuttings up and out of the hole. The cuttings move up in the annular space between the drill pipe and the wall of the hole, and are collected at the top. Air is used principally in hard clay or rock formations because once the air pressure is turned off, loose formations tend to cave in against the drill pipe. This method is not generally recommended for drilling in unconsolidated materials because the quality of the samples is usually poor. Foaming additives are occasionally used to increase the uphole-carrying capacity of the return air.

Down-the-Hole (Down-Hole Hammer, Hammer Drilling) Method:

The down-the-hole method involves a pneumatically operated bottom-hole drill that efficiently combines the percussion action of cable tool drilling with the turning action of rotary drilling. The pneumatic drill can be used on a standard rotary rig with an air compressor of sufficient capacity. It is used for fast and economical drilling of medium to extremely hard formations. Fast penetration results from the blows transmitted directly to the bit by the air piston. Continuous drill hole cleaning exposes new formation to the bit, and practically no energy is wasted in re-drilling old cuttings. Down-the-hole drilling is generally the fastest method of penetration in hard rock. The bit is turned slowly (5 to 15 rpm) by the same method by which the drill bit in the fluid or air drilling operation is rotated. Foaming additives are occasionally used to increase the uphole-carrying capacity of the return air.

Top Drive Air Rotary with Casing Hammer Method:

This is a relatively new and popular method designed for fast penetration rates. Sand, gravel, boulders, and glacial till are drilled and cased simultaneously. Screened wells can be drilled, cased, and developed at high speed. The drill pipe is inserted inside the casing and picked up simultaneously with a special adapter when adding drill pipe and casing. After making up the tool joints with the hydraulically powered breakout tongs, the casing is welded and drilling continues. The air-operated hammer of one manufacturer develops up to 7,200 foot pounds of driving force at 70 blows per minute with a 24-inch stroke. The hammer can be cleared from over the hole for pulling pipe and for conventional rotary drilling.

Test your Knowledge (Select the Correct Response)

3. What action removes the cuttings from a well being dug using the boring method?

   A. Flushing
   B. Screwing
   C. Pulling
   D. Injecting

4. What is generally the fastest method of penetrating hard rock?

   A. Top drive air rotary
   B. Fluid rotary
   C. Down-the-hole
   D. Cable tool

4.0.0 ROTARY DRILLING

When using a hand drill to bore a hole, you press the cutting tool or bit into the material to be bored. The material is cut as you turn the bit by means of the drill handle. During the drilling process, chips of the cut material are carried to the top of the hole by the flutes of the bit. A rotary drilling rig operates on the same principle, except for the method of raising the cut material. This material is washed to the surface by a fluid substance instead of being carried by the bit itself. The bit of a rotary drilling rig is attached to the lower end of the drill pipe.

The methods of drilling for water are referred to as rotary mud or rotary air drilling. Rotary mud drilling is currently the most common method used to drill wells and is used where ground formations are loose and unconsolidated. Mud drilling is also used in consolidated formations but is not very efficient. The rotary air drilling method is preferred when ground formations are consolidated. A limitation of the air drilling method is the cfm output of the air compressor.

When you are conducting rotary mud or rotary air drilling operations and you encounter a formation that is hard to penetrate, the down-hole-drilling hammer attachment can be used. The down-hole drilling hammer attaches to the lower end of the drill pipe and rotates as well as hammers (short rapid blows) against the hard formation. To use the down-hole-drilling hammer, you must “trip-out” all the drilled steel and flush all the mud and foreign material before connecting the hammer. Air from an air compressor passes through the string of drill steel and exits out the down-hole-drilling hammer bit. This air cleans the cuttings from the bit and carries the cuttings to the surface.

Regardless of the drilling method performed, the objectives of drilling are are follows:

1. To identify and locate the site of each test hole.
2. To maintain a log of formations penetrated and representative samples obtained.
3. To determine the depth to each water level and obtain samples of water from aquifers.

5.0.0 DRILLER’S LOG

A driller's log, or well log, is used to record an accurate record of the depth and changes in formation along with a description of the samples taken every 5 feet or at every formation change. Also recorded is a description of the drilling action that is a valuable clue to a change in formation; for example, with the rotary method, drilling action in clay or shale is smooth. ***Chattering*** of the bit is an indication of sand or gravel. Smooth drilling, but rapid penetration, indicates fine sand. Additionally, the log includes information of the time it took to drill each foot. As drilling speed is largely determined by the composition of the formations, information from the well log may be used in graph form to reveal the top, bottom, and thickness of each formation. Clues to the composition of each formation are provided by this log and verified by the samples obtained.

6.0.0 ROTARY DRILLING CREW and DUTIES

The water well rig is normally operated by a tool pusher, a driller, a derrick hand, and a floor hand. For expediency, water well drilling as performed in the NCF is a continuous operation; therefore, you are required to have more than one shift. The hours of each shift depend upon the crew size available, the experience level of the members of the crew, and the condition of the equipment, for example, two 12-hour shifts or three 8-hour shifts.

6.1.0 Tool Pusher

The tool pusher acts as the "team commander," responsible for team members and drilling operations. The tool pusher is responsible for safety, site selection, setup, drilling operations, well completion, well development, pump operations and site close out--as well as outlining the overall drilling program and seeing that it is carried out, training and care of team members, transportation and maintenance of equipment, and coordination for support equipment. The tool pusher may or may not be the resident expert in well drilling. If not, he or she relies heavily on the driller’s experience.

6.2.0 Driller

The driller is responsible for personnel assigned to the tower, carries out the drilling orders, operates the rig, and must know the depth, viscosity, density, sand content, type of cuttings, number of steel, and the psi of the mud pump. The driller also ensures that all drilling-related activities are properly recorded in the driller’s log.

6.3.0 Derrick Hand

The derrick hand is the assistant driller. The derrick hand works in the mast and performs tasks such as racking the steel pipe, screwing the hoisting plug, and handling the drill pipe or casing. The derrick hand also monitors the mud pit fluid level and ensures that all mud properties are maintained, and also maintains the driller's log and gathers and analyzes borehole cuttings.

6.4.0 Floor Hand

The floor hand, also known as the WORMM (worker, oiler, racker, mud, and maintenance man), makes fuel and water runs, maintains a safe and clean site, and ensures that all tools and equipment are properly cleaned and lubricated. The floor hand also assists in connecting and disconnecting drill steel, racks the steel on the trailer, maintains the drilling fluid properties, and performs various tasks required for maintaining the rig and equipment.

All crew members must wear protective clothing or equipment such as hardhats, gloves, safety shoes, and safety belts. When wearing hard hats, the derrick hand and any other crew member working overhead should wear chin straps to keep the hard hat from dropping on personnel below. Also, while working in the mast, crew members should attach their tools securely to the safety belt by means of line. Before ascending, they should clean their shoes of all mud and inspect footholds for grease. No crew member should wear loose or flapping clothes. Gloves should be worn for protection when handling wire rope. Safety shoes with reinforced tops will protect toes from being crushed.

7.0.0 WELL DRILLING EQUIPMENT

7.1.0 T2W

The T2W drill (*Figure 9-7*) is a mobile water well rig designed for drilling 6-24 inch (152-610mm) hole diameters with drill string weight which will require support and pullback of 30, 000 pounds (13,608 kg) using air rotary, down-the-hole drill (DHD) hammer methods and mud rotary compatible methods on prepared (if necessary) ground that is flat and firm. The T2W Waterwell drill is set up to handle 4.5 inch-diameter x 20-foot long drill pipe (114.3mm x 6.096m), but will accommodate the U.S. Navy's special length of 4.5 inch-diameter x 18 foot, 10 inch-long (114.3mm x 5.74m) drill pipe. The inner half of the drilling table retracts hydraulically while the outer half swings away from either side of the table to accommodate 6-inch (152.4mm) casing. The table opening is 10.75 inches (273mm). The T2W uses the truck diesel engine to drive the hydraulic system.

Figure 9-7 — T2W.

The T2W power train consists of the truck diesel engine connected directly to a heavy duty transfer case which connects to the rear axles and the hydraulic pump drive gearbox.

The T2W Series Waterwell drill utilizes four (4) leveling jacks to keep the drill level and stable while drilling.

Drilling functions are hydraulically powered. If the drilling conditions permit, off-board compressed air is used to operate the DHD (down hole drill) and clean the hole. The hydraulic pumps are driven through a heavy duty transfer case by the truck diesel engine. The systems that support the drilling functions of the drill are controlled by hydraulic and electrical components.

The derrick is a single tube, 12 inch x 16 inch (305 cm x 406 cm) structural steel tubing with a 50,000 lb. (22,680 kg.) rating. The centralizer table on the T2W is designed to handle 6 inch (152.4mm) I.D. (inside diameter) casing, and the outer table section can swing out from either side or be removed for ease of casing and tooling handling. The inner half of the table section retracts with a hydraulic cylinder. A single rod holder is mounted on the left side of the derrick. The derrick is raised and lowered by two hydraulic cylinders.

Drill pipe changing is done by moving drill pipe in and out of the rotary head with rod handling slings and/or the single rod loader. The rotary head can be used to move all drill pipes in and out of the hole. The main hydraulic winch can be used to add and remove drill pipe to the drill string below drill string weights of 12,000 pounds (5443 kg.). All drilling functions, with the exception of the dual hoist and jib controls located on the helper's side, are controlled from the operator's console adjacent to the drill table. The operating controls and gauges are positioned within easy reach of the operator.

The carrier-mounted, truck engine powered drill is designed for shallow waterwell drilling, providing a pullback force of up to 30,000 lb. (13,608 kg).

The rotary head moves up and down the derrick at a 3:1 ratio to the double-ended rod, double-acting cylinder. The feed sheaves and guide rollers are constructed for long life and minimal wear. Premium feed cables operate at a 3:1 reaving ratio, resulting in overall short cable length and less stretch. The cable, which is detachable at the wedge-type cable anchor, is adjustable at the cable anchor external to the derrick.

The T2W is highly mobile and can travel at highway speeds as compared to the previous well rig model which must be transported to the drill site by a tractor trailer.

7.1.1 Operations

Figure 9-8 shows T2W rotary drilling operations.

Rotary drilling methods use the combination of raw weight and rotation to chip and carve rock from a hole. The rotary method works fine in soft formations where adequate weight and stress can be applied to the rock to initiate fracture and chipping. Rotary drilling is done by rotating a tricone bit against the rock while applying sufficient down pressure onto the bit to crush the rock.

Figure 9-8 — T2W operations.

A stabilizer is normally used to keep the hole straight and to prevent the bit from becoming stuck. After the drill has been set up for drilling, there are a number of operations which involve handling heavy drill rods, drill bits, and other components used for various drill rod and drill bit changing procedures.

CAUTION

Heavy components must be handled with care using appropriate lifting aids provided to facilitate heavy component lifting operations.

Safety should be the main concern for anyone working on or around the drill. Do not perform any function that could put someone in danger. Always wear correct safety gear while working on or around the drill. This includes an approved hard hat, safety glasses, steel toe shoes, respirator and ear protection. Do not wear loose-fitting clothing that can become caught in rotating components.

Rotary Drill String

Rotary drilling with a tricone bit consists of several processes. There is an order that should be followed to maximize performance. To rotary drill, an operator must use the following procedure: install a stabilizer or starter pipe on the rotary head, install a tricone bit on the stabilizer or starter pipe, start a hole with the rotary bit, add drill pipe to the drill string, follow rotary drilling procedures, remove the drill pipe, remove the stabilizer or starter pipe from the drill string, remove the tricone bit from the stabilizer or starter pipe, and continue the process till the proper depth is reached.

7.2.0 Top-Head Drive Rotary Well Drilling Rig

The top-head drive rotary well drilling rig is a special top-head drive ISO/air transportable water well-drilling rig (ITWD) (*Figure 9-9*) whose development and production effort were conducted or controlled by NAVFAC towards providing the NCF with the capability for rapid water well drilling in a variety of environments.

The self-propelled ITWD design has a lightweight derrick, a telescoping mast, and a top-head rotary drive actuated by hydraulic cylinders able to accommodate 20-foot-long sections of drill pipe and well casings. When the derrick is lowered for transport, the entire rig weighs 23,000 pounds; it is capable of fitting inside a standard cargo container without disassembly and is air transportable on board a C-130 aircraft. The ITWD is capable of rotary drilling 12 1/4-inch holes to 1,250-foot depths and down-hole-drilling (DHD) hammer (percussion) drilling, 6-inch holes to 1,500-foot depths. The ITWD will travel at a top speed of 10

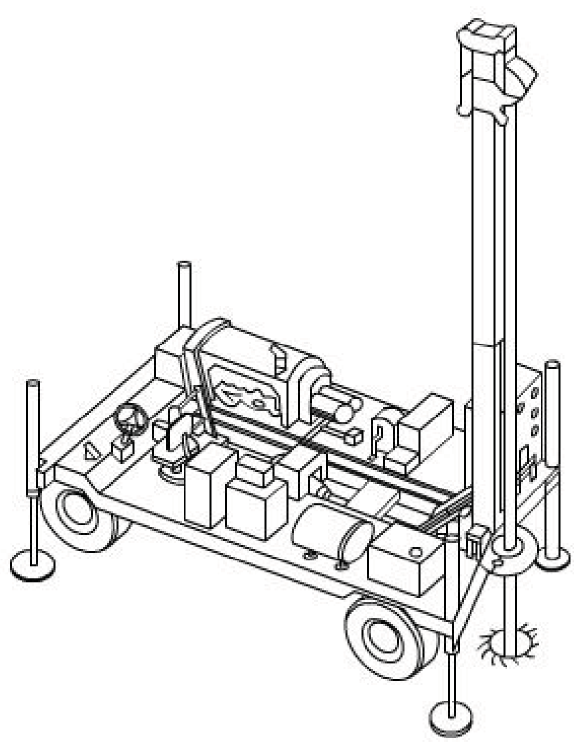

Figure 9-9 — ITWD.

mph over unpaved roads and has a cross-country rough terrain capability.

ITWD Components

The ITWD derrick consists of the telescoping mast structure, the pulldown/pullback mechanism, the top-head assembly, and the hoist assembly. Other components are a stabilization system, main frame, handling equipment, hydraulics, control console, and so forth.

The drill derrick system is capable of generating 15,000 pounds pulldown and 30,000 pounds pullback force through the top-head during the drilling operation. The top-head drive is a variable speed drive that imparts rotation and torque to the drill pipe for drilling and has an rpm range from 0 to 200 rpm. The tophead drive is mounted to a carriage that is free to move up and down over the length of the moving mast section. The tophead drive also has a hollow spindle for injection of air or mud, giving the ITWD capabilities for rotary air or rotary mud drilling.

The hoist system is attached to the side of the derrick, operates independently of the derrick operation, and is rated for a 3,000-pound hook loading. This capacity is sufficient to add and remove 18.5-foot drill pipes and to set typical 20-foot casing and surface pipe. The hoist is capable of lifting up to 180 feet of 4 1/2-inch drill pipe when “tripping out” the drill hole. When increased hoisting is required for lifting longer drill strings, the top-head drive that has a capacity equivalent to its 30,000 pullback rating can be used as an additional hoist.

A split centralizer and pipe-handling system located on the ITWD worktable is used to break and make drill pipe connections, to support the drill string during pipe handling, to provide a centralizer bushing for the drill string, and to aid in setting casing and making casing joint. The centralizer is a split design consisting of a rear section welded to the main frame and a removable forward section. The forward section is held in place by two pins and can be manually swung out or detached to facilitate setting large diameter casing or surface pipe. The forward section is removed during transport and stored on top of the worktable. The centralizer accommodates various sizes of split bushings to adapt to a number of drill pipe, casing, and down-hole-drilling hammer diameters.

A hydraulically powered breakout wrench is also mounted on the worktable. This wrench is used with a manual holding wrench (used to support the drill string and stop rotation) to make and break pipe and casing joints.

Test your Knowledge (Select the Correct Response)

5. The T2W uses what component to drive the hydraulic system?

   A. Generator
   B. Truck diesel engine
   C. Pump cart
   D. Air compressor

6. What is a major disadvantage of the ITDW over the T2W drill rig?

   A. Well depth
   B. Portability
   C. Over-the-road speed
   D. Transportability

8.0.0 DRILLING DIFFICULTIES

Lost circulation is one difficulty you may encounter when drilling. Sometimes it occurs in zones of high porosity that usually contain large supplies of water. Whenever circulation is lost you should make a test of the well. Formations that draw off or absorb all or part of the circulating fluid offer problems ranging from minor inconveniences and loss of time to extreme conditions that render rotary drilling impossible.

Formations that contain joints and fissures, such as quartzite, sandstone, limestone, and dolomite, present problems arising from caving, abrasion, and complete loss of circulation.

Shale that is jointed and fissured seldom draws off an excessive amount of circulating mud; however, drilling fluid that is absorbed causes the shale to swell and heave, filling up the drill hole. This has been overcome by the use of special drilling fluids. This condition is rare, and satisfactory drilling progress can usually be made by using a drilling fluid of high viscosity and weight.

Sands and gravel often absorb enough drilling fluid to hinder drilling progress. Fluid loss, which in most cases will be continuous, should be replaced with mud, not water. Water, when used to maintain sufficient volume for circulation, soon lowers the viscosity and weight of the mud-water mixture, and caving results.

Two methods are used to regain lost circulation. The preferred method is to drill through the zone of lost circulation and to set a string of conductor casings below the porous zone. The chief requirement for this procedure is a plentiful supply of water to circulate the cuttings away from the bit and into the formation. Mud is desirable but the quantity needed usually precludes its use. When using water to carry off the drill cuttings, always remember to continue to operate the pump for a few minutes after drilling has stopped. This flushes the cuttings out of the hole and prevents the drill pipe from sticking when it is stopped to make a connection. In extreme cases where it is necessary to drill as much as 100 feet or more through a formation in which circulation is lost, a small quantity of mud is spotted around and above the bit while an additional joint of pipe is installed in the drilling string. This prevents excessive settling of the drill cuttings and consequent sticking while the drill pipe is standing. When the bottom of the zone has been reached, drilling is continued into the underlying formation for about 50 feet to give room for cementing the casing. When the casing has been run and cemented, the ordinary rotary drilling procedure is resumed.

In the second method, circulation can usually be regained by mixing a clay-type material with the drilling fluid that can be bought commercially. The water well drilling school located at NCTC, Port Hueneme uses the second method when circulation is lost during drilling operations; however, to regain circulation the school recommends dropping approximately a yard of 3/4-inch to 1-inch clean aggregate to regain circulation. The amount of clean aggregate used depends on the size of the area in which circulation is lost. If circulation is lost in cavernous limestone, the fluid level in the hole is checked and tested for fresh water.

A cheap, abundant supply of water is often the determining factor between a straight well hole and a loss of time, labor, and equipment.

Much depends on the experience and ability of the driller when drilling through difficult formations. The driller will have to use the capabilities of the machine and experience to keep the hole straight. The harder formations, especially those which are dipped and those that are broken and creviced, present many difficulties. Use only a roller and three- or four-wing drag bits for this type of drilling. Fishtail and some of the single-cone roller bits are not suitable for any except the softest formations.

8.1.0 Crooked Holes

One way to detect crooked holes during drilling is to watch for wear on the drill pipe. If wear occurs at a set distance from the top of the ground, it indicates the hole was deflected at this point. In drilling, detection of deflections of the bit and drill pipe is not easy because the hole can be quite crooked without noticeably affecting the operation of the rig. The driller must be alert to any indication that the hole is going crooked.

To avoid crooked holes, make sure that the bits are of a form and size that prevent undue eccentricity during rotation. They must be sharp and dressed to proper gauge. The drill collar that holds the bit to the lower end of the drill pipe must be large enough in diameter to hold the pipe centrally in the hole and to prevent the bit from working off to one side. Avoid excessive bit pressures.

Another difficulty sometimes encountered is the sticking or freezing of the drill pipe. An inexperienced drill operator can cause the drill pipe to stick by not circulating mud in the hole. The drill pipe is kept free in the hole by simultaneously rotating the pipe and circulating a mud-laden fluid. If either operation stops, only a short time should elapse, depending upon the formation being penetrated, before pulling the bit into the casing (or out of the hole altogether, if no casing has been installed). Failure to do this often causes the drill pipe to become stuck due to sand and cuttings settling around it.

The drill pipe may also stick in some formations if lost mud is replaced with water and not mud. Formations are often encountered that drain off or absorb a certain amount of the drilling mud. If this mud is replaced with clear water to keep up the fluid level in the hole, the water thins the mud to a point where the mud exerts a cutting action on the walls of the hole and causes extensive caving around the drill pipe, fastening it securely in the hole.

Inadequate equipment may cause the drill pipe to stick; for example, a mud pump with insufficient capacity would not keep circulation moving fast enough to prevent drill cuttings from settling out and jamming the drill pipe.

Balling up could cause the drill pipe to stick. Balling up is the accumulation of soft, sticky shale or clay around the drill collar and bit. Occasionally, mud collars are formed that are forced up the hole by the pump action. This balling, if allowed to continue, forms a coating around the drill collar that sticks to the drill pipe securely when it is raised off the bottom. The usual cause of balling up is a high rate of penetration, combined with a speed of rotation insufficient to mix the drill cuttings thoroughly. To overcome these conditions, the drill operator should raise the pipe frequently by raising it off the bottom 4 or 5 feet and then drop the pipe while it is rotating rapidly. If this is done and if the rate of penetration is held to a speed that gives the circulating fluid time to mix the drill cuttings thoroughly, this source of trouble can be held to a minimum.

As mentioned before, loss of circulation may result in a stuck drill pipe. Loss of circulation is especially troublesome in porous limestone that contains much water. When one of these porous zones is penetrated by the drill, the pressure of the drilling mud causes it to drain off rapidly into the formation. The sudden reversal of circulation in the hole deposits the suspended drill cuttings around the drill pipe. This often happens so suddenly that there is no time to remove the drill pipe.

8.2.0 Recovery of Stuck Drill Pipe

Every precaution should be observed to prevent the drill pipe from sticking as only extreme scarcity of drill pipe justifies extensive recovery operations in drilling shallow wells; however, there are a few things that can be done successfully with the equipment at hand, depending upon how tightly and in what manner the drill pipe is stuck.

When the drill pipe becomes stuck by balling up while drilling in soft shale or clay, it can often be loosened by circulating clear water. An upward strain should be kept on the pipe while circulating the water.

When the pipe is stuck by sand or drill cuttings that have accumulated in the hole, circulation should be maintained with the heaviest mud obtainable. When possible, the pipe should be worked. Any movement transmitted through the pipe, however slight, helps dislodge the sand particles into the mud stream that carries them to the surface.

When a drill pipe is stuck through lack of circulation, there is not much that can be done to recover the entire string of pipe; however, an attempt should be made to pull the pipe with jacks. Sometimes the pipe can be recovered by mixing the proper circulating fluid and circulating it while working the pipe with both the rotating and hoisting mechanisms. In some instances, the pipe can also be recovered by cutting it with a blasting charge in the bottom of the hole or about where the pipe is stuck.

8.3.0 Fishing

One of the major problems encountered when well drilling is the recovery of tools lost in the well. Lost tools are recovered by fishing. The most frequent cause of tool loss results from the drill pipe twisting off. Such “twist offs” usually occur near the lower end of the pipe. They may consist of a simple shearing off from the pipe or of a fracture at a coupling. The accidental dropping of a drill pipe into a hole also calls for fishing. Among less common accidents requiring fishing is the dropping of tools, such as slips or wrenches, into the hole. When a break occurs, remember the exact depth of the break. This helps in locating the tops of the tools and coupling to them with a fishing tool. Recovery of lost drill pipes depends upon whether the driller can set the tool down on top of the pipes and connect to them.

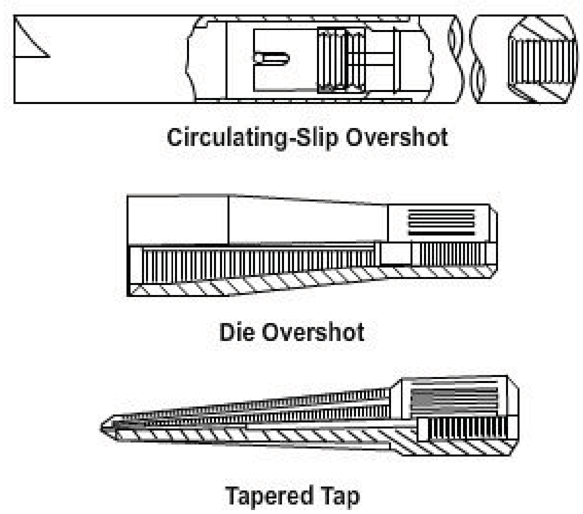

Figure 9-10 — Fishing tools.

Some of the more common fishing tools are the circulating-slip overshot, the die overshot, and the tapered fishing tap (*Figure 9-10*).

The circulating-slip overshot, as implied by its name, provides circulation through the lost pipe to assist removal when fishing. This tool is similar to the die overshot in its action but provides a watertight coupling between the drill pipes.

The die overshot is a long, tapered die of heat-treated steel. When fitted over the lost drill pipe and rotated, the die overshot, like the fishing tap, also cuts its own threads. The tapered thread is fluted to permit the escape of metal cut by the threads. The upper end of the die has a thread to fit the drill pipe. The die is hollow but, as is also true of the tap die, circulation cannot be completed to the bottom of the hole through the lost pipes because the flutes allow the fluid to escape.

The tapered fishing tap, as its name implies, is a fluted, tapered tap made of heat-treated steel. Its action is similar to that of a machine tap, as it cuts its own threads when rotated, and thus grips the lost drill pipe.

Remember: In many shallow wells, it is more economical to abandon the hole than it is to fish for the lost tools.

Test your Knowledge (Select the Correct Response)

7. How can an inexperienced drill operator cause the drill pipe to stick in the drill hole?

   A. Leveling the derrick improperly
   B. Circulating an insufficient amount of mud down the hole
   C. Using excessive rotary head speed
   D. Leaving the rig unattended

8. What is one way to detect crooked holes during drilling?

   A. The bit will free float.
   B. The pipe string will vibrate.
   C. The drill pipe will shown signs of wear.
   D. The derrick will tilt.

9.0.0 WELL DEVELOPMENT and COMPLETION

Once an aquifer has been tapped by the drilled hole, the important and essential phase of completion and development must be accomplished in order to assure maximum yield under sanitary conditions. Development and completion of a well includes the following operations:

1. Setting the casing and screens.
2. Removing the drilling fluid.
3. Stabilizing the aquifer by removal of a predetermined percentage of the fines, grouting, and sterilizing the well.

The first operation after drilling the hole is to set the screens and casing. The casing prevents collapse of the walls in unconsolidated formations. The screens prevent collapse of the drilled hole wall in the aquifer while allowing water to enter the casing freely. After the casing is set, the well is gravel packed (*Figure 9-11*). Gravel packing is placing graded aggregate on the outside of the casing to allow for more production and prevent fines from entering the well pump, tanks, and systems.

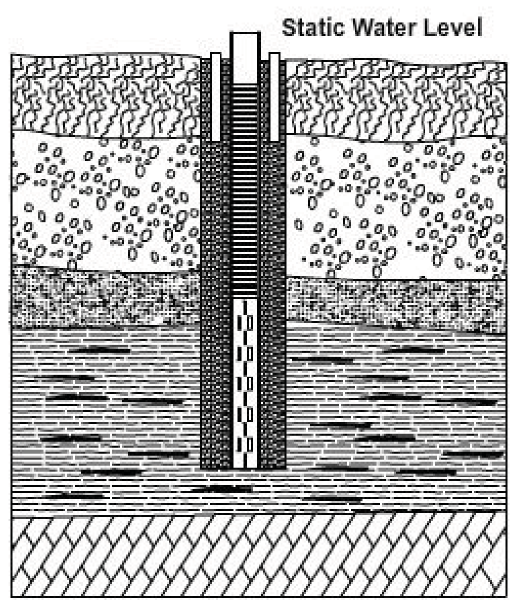

Figure 9-11 — Gravel pack casing.

When the screens, casing, and gravel pack have been completed, the well is ready for development. You accomplish development by removing the drilling fluid from the aquifer and employing any means that induces an alternating flow of water in and out through the screens. This action stirs up the unconsolidated material in the aquifer and allows removal of the finer particles. Gradually, the coarsest particles become stabilized around the screens, and the last vestiges of drilling fluid are removed, permitting the well to yield its maximum capacity.

A variety of methods are used for setting screens, removing drilling fluid, and developing aquifers. The method used for either of these operations is often determined by the tools and equipment available.

When development of a well is complete, you are required to grout as a sanitary protective measure to prevent seepage of surface water or contaminated water from water-bearing formations above into the aquifer. You accomplish grouting by cementing from the top of the gravel pack to the annular space between the well wall and casing.

10.0.0 SAFETY

Safety is paramount in all construction operations. You must always be safety conscious and on the alert for potential dangers to personnel and equipment. Safety considerations cannot be overemphasized.

1. Always wear hard hats.
2. Wear gloves to protect hands when handling wire rope.
3. When working in the mast, personnel should wear safety belts, and attach their tools securely to the belts by lines.
4. Before ascending, personnel should clean safety shoes of all mud and inspect footholds for grease. Wearing of safety shoes with reinforced tops will protect toes from being crushed when working with drilling tools.
5. Sheave guards should remain over all moving gears and chain drives.
6. Personnel should not wear loose or flapping clothes.
7. Keep the drilling table or platform free of loose tools, both to prevent accidents to personnel and loss of tools down the drilled hole. Keep the platform as clean and dry as possible.
8. Do not attempt to lube or adjust moving gears.
9. When hoisting loads, do not get in between any moving part and stationary object.
10. Stay clear of suspended loads.
11. Repair or replace all parts that need repair as needed.

Test your Knowledge (Select the Correct Response)

9. What is the first operation after drilling the hole?

A. Remove the drilling fluid.
B. Set the screens and casing.
C. Move the well drilling rig to a safe location.
D. Install the pump.

10. Development of the well is accomplished by performing which action down hole?

   A. Pumping high pressure air
   B. Thrusting the bit
   C. Inducing an alternating flow of water
   D. Stacking the casings

Summary

This chapter discussed the responsibilities of a Well Drilling Supervisor. It gave an overview of water sources and ground exploration. It identified types of wells and their advantages and limitations. This chapter also discussed the types of well drilling equipment, types of drilling available, and a brief job description of each crew member. The chapter went into detail on the T2W mobile drilling system and its characteristics, as well as the ITWD. It then progressed to some problems that you might encounter when drilling a well, for example crooked holes and recovery of stuck pipes. The chapter concluded with information regarding well development and completion, with an emphasis on well safety and some of the recommended precautions that should be taken when working on or around well drilling operations.

This chapter provided general information about all processes needed to supervise a well drilling operation. You should always refer to the manufacturer's manuals and instructions for the most up to date information regarding the equipment you will be operating.

Review Questions (Select the Correct Response)

1. In which underground zone should a water well be developed?

   A. Plant zone
   B. Saturated
   C. Aeration
   D. None

2. What are some of the advantages of using groundwater over surface water?

   A. Easier to access
   B. Cheaper
   C. Lower transportation costs
   D. Less likely to run out

3. Where is the zone of aeration located?

   A. Between aquifers
   B. The earth’s surface
   C. Above the water table
   D. Surface water

4. What formation is porous and permeable and can yield usable quantities of water?

   A. Artesian
   B. Alluvial basin
   C. Aquifer
   D. Capillary fringe

5. (**True or False)** An artesian well is a source of fresh water flowing freely from an aquifer in which the water pressure exceeds atmospheric pressure.

   A. True
   B. False

6. Which rock formation is most likely to produce water in usable quantities?

   A. Igneous
   B. Sedimentary
   C. Alluvial
   D. Metamorphic

7. When nothing is known of the water resources in a particular area, the existence of water-producing formations can be verified by which means?

   A. Exploratory drilling
   B. Inspecting outcrops of rock formations
   C. Studying maps and documents
   D. All of the above

8. What is the mission of the water detection response team?

   A. Dig water wells
   B. Develop topographical maps
   C. Provide predictive analysis of water locations
   D. Conduct field reconnaissance and geophysical surveys

9. What type of drilling method is used in areas where ground formations are loose and unconsolidated?

   A. Mud drilling
   B. Air drilling
   C. Down-hole drilling
   D. Percussion drilling

10. Which well drilling method is suited for 2 to 4 inch bore holes

   A. Digging
   B. Boring
   C. Driving
   D. Jetting

11. Of the crew members operating the rotary well-drilling rig, who has the responsibility for carrying out the overall drilling program?

   A. Project supervisor
   B. Tool pusher
   C. Driller
   D. Derrick hand

12. Personnel engaged in well-drilling operations should observe which safety measure?

   A. Wear tight fitting clothes while working around moving machinery.
   B. Wear gloves when handling wire rope or metal parts.
   C. Wear safety shoes and hard hats.
   D. All of the above

13. Why are foam additives sometimes added during the down-the-hole method of drilling?

   A. To seal the bore hole walls.
   B. To increase the uphole carrying capacity of the return air.
   C. To increase the lubricating properties of the drilling lubricant.
   D. To decrease the tendency of the drill bit from sticking in the bore hole.

14. What is the most common method for drilling a water well?

   A. Bore
   B. Rotary
   C. Jet
   D. Blasting

15. Who is the tool pusher’s right hand man?

    A. Driller
    B. Derrick hand
    C. Worm
    D. Utilitiesman

16. What is the maximum diameter hole a T2W can drill?

    A. 6 inches
    B. 10 inches
    C. 12 inches
    D. 24 inches

17. What is the pullback required on a T2W when using the air rotary drilling method?

    A. 15,000 pounds
    B. 20,000 pounds
    C. 25,000 pounds
    D. 30,000 pounds

18. What is the first step in setting a rotary drill string?

    A. Install a stabilizer on the rotary head
    B. Install a tricone bit on the stabilizer
    C. Start the hole with the bit
    D. Ensure adequate water pressure is available

19. On the ITWD, what is the purpose of the split centralizer?

    A. To break and make drill pipe connections.
    B. To support the drill string during handling.
    C. To aid in setting casings.
    D. All of the above

20. **(True or False)** One method of regaining a loss of circulation that takes place during well drilling is to circulate the cuttings away from the drill bit with plenty of water.

    A. True
    B. False

21. **(True or False)** Undue wear of the drill pipe is an indication of a crooked drill hole.

    A. True
    B. False

22. During a drilling operation, the drill pipe may stick due to which cause?

    A. Capacity of a mud pump is inadequate.
    B. Drill pipe has been allowed to stop and remain stationary in the hole.
    C. Mud has balled up around the drill collar and bit.
    D. All of the above

23. The drill pipe of your rotary well-drilling rig becomes stuck with drill cuttings that have accumulated in the hole. How can you remedy the situation?

    A. Pull upward on the pipe with jacks.
    B. Circulate heavy mud while trying to turn the pipe.
    C. Pour oil along the sides of the pipe.
    D. Pull upward on the pipe and circulate clear water around it.

24. Which is a practical use of a fishing tool?

    A. Recovery of a twisted-off drill pipe
    B. Recovery of a wrench that falls into the drill hole
    C. Recovery of a drill pipe that falls into the drill hole
    D. All of the above

25. **(True or False)** Stabilizing the aquifer by removal of a predetermined percentage of the fines, grouting, and sterilizing the well.

    A. True
    B. False

26. **(True or False)** Gravel packing is placing ungraded aggregate on the outside of the casing to allow for more production and prevent fines from entering the well pump.

    A. True
    B. False

Terms Introduced in This Chapter

Chattering	Produced by the bit as it bounces off the material being drilled, caused by an uneven bottom surface and the flexibility of the drill string.
Geospatial teams	Teams that are made up of experts that are trained in deciphering terrain and groundwater prospecting graphs.
Igneous	Igneous rocks begin as hot, fluid material; the word "igneous" comes from Latin meaning “fire.” This material may have been lava erupted at the Earth's surface, or magma at shallow depths, or magma in deep bodies. Rock formed of lava is called extrusive, rock from shallow magma is called intrusive, and rock from deep magma is called plutonic.
Metamorphic	Sedimentary and igneous rocks become changed by conditions underground. The four main agents that metamorphose rocks are heat, pressure, fluids and strain. These agents can act and interact in an infinite variety of ways. As a result, most of the thousands of rare minerals known to science occur in metamorphic rocks
Saturated zone	A subsurface zone in which all the pores or the material are filled with groundwater under pressure greater than atmospheric pressure.
Sedimentary	Sedimentary rocks consist of the granular materials that occur in sediment: mud, sand, gravel, and clay.
Topographical features	The features of a map that represent the natural features of the earth's surface and their relative positions and elevations. Those features collectively form a "model" of the surface.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Department of Defense Directive Number 4705.1, Management of Land-Based Water Resources in Support of Contingency Operations, July 9, 1992.

Multiservice Procedures for Well-Drilling Operations FM 5-484, , Headquarters, Department of the Army, Navy and Air Force, Washington, DC March 1994.

Operational Guidelines for Humanitarian Civic Assistance Water Well Drilling, United States Army Engineer District, Mobile Engineering Division, Geotechnical and Environmental Branch, Geotechnical and Dam Safety Section, Alexandria, VA 2009.

Operating, Safety and Maintenance Manual, T2W Navy, Atlas Copco Drilling Solutions Garland, TX 2006.

Water Supply in Theaters of Operations FM 10-52, Headquarters, Department of the Army, Washington, DC July 1990.

Water Supply Point Equipment and Operations FM 10-52-1, Headquarters, Department of the Army, Washington, DC June 1991.

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