Technical Area: 6 Casing Program / Installation

Item: 6-1 PVC casing, screen pipe

1: Objectives
To be able to explain and advise for specifications of PVC casing, screen pipe.

2. Contents
- Specification of PVC casing, screen pipe

3. Teaching Methods
(1) Explain specifications of PVC casing and PVC screen using specification list.

4. Materials
6-1M1 Specification List of PVC Casing and Screen of PLASCO

PLASCO BOREHOLE CASES.

NOW PROVIDED WITH RUBBER RING SEALS FOR ENVIRONMENTAL HEALTH PURPOSES.

PRODUCT DESCRIPTION	PLASCO PRODUCT CODE	CASE OUTSIDE DIAMETER (mm)	NOM.L CASE WALL THICKNESS (mm)	THREAD DEPTH (mm)	3M EFFECT. LENGTH CASE MASS (KG)	STANDARD SLOT WIDTH (mm)	APPROX. % OPEN AREA OF SCREEN.	DIAMETER OVER BELL (mm)
BELLED END DIN 4925 CASE	06/011/113/003/55/01	113	5.0	2.0	8.1	-	-	121
BELLED END DIN 4925 SCREEN	06/012/113/003/55/01	113	5.0	2.0	8.1	1.0	7.5	121
FLUSH FITTING DIN 4925 CASE	06/006/113/003/40/01	113	7.0	2.0	11.8	-	-	
FLUSH FITTING DIN 4925 SCREEN	06/009/113/003/40/01	113	7.0	2.0	11.8	1.0	7.5	
BELLED END DIN 4925 CASE	06/011/125/003/56/01	125	5.0	2.0	8.8	-	-	132
BELLED END DIN 4925 SCREEN	06/012/125/003/56/01	125	5.0	2.0	8.8	1.0	8.0	132
FLUSH FITTING DIN 4925 CASE	06/006/125/003/42/01	125	7.5	2.0	12.9	-		
FLUSH FITTING DIN 4925 SCREEN	06/009/125/003/42/01	125	7.5	2.0	12.9	1.0	8.0	
BELLED END DIN 4925 CASE	06/011/140/003/56/01	140	6.5	2.6	13.0	-	-	149
BELLED END DIN 4925 SCREEN	06/012/140/003/56/01	140	6.5	2.6	13.0	1.0	8.0	149
FLUSH FITTING DIN 4925 CASE	06/006/140/003/42/01	140	8.0	2.6	15.7	-	-	
FLUSH FITTING DIN 4925 SCREEN	06/009/140/003/42/01	140	8.0	2.6	15.7	1.0	8.0	
BELLED END DIN 4925 CASE	06/011/165/003/41/01	165	7.5	2.6	17.6	-	-	176
BELLED END DIN 4925 SCREEN	06/012/165/003/41/01	165	7.5	2.6	17.6	1.0	8.0	176
FLUSH FITTING DIN 4925 CASE	06/006/165/003/45/01	165	9.5	2.6	22.0	-	-	
FLUSH FITTING DIN 4925 SCREEN	06/009/165/003/45/01	165	9.5	2.6	22.0	1.0	8.0	
FLUSH FITTING PLASCO CASE	06/006/165/003/41/01	165	7.5	2.6	17.6	-	-	
FLUSH FITTING PLASCO SCREEN	06/009/165/003/41/01	165	7.5	2.6	17.6	1.0	8.0	
BELLED END CASE IN ACCORDANCE WITH DIN 4925	06/011/200/003/43/01	200	9.0	2.6	25.7	-	-	212
BELLED END SCREEN IN ACCORDANCE WITH DIN 4925	06/012/200/003/43/01	200	9.0	2.6	25.7	1.0	8.0	212
FLUSH FITTING CASE IN ACCORDANCE WITH DIN 4925	06/006/200/003/58/01	200	11.5	2.6	32.4	-	-	
FLUSH FITTING SCREEN IN ACCORDANCE WITH DIN 4925	06/009/200/003/58/01	200	11.5	2.6	32.4	1.0	8.0	
FLUSH FITTING PLASCO CASE	06/006/200/003/43/01	200	9.0	2.6	25.7	-	-	
FLUSH FITTING PLASCO SCREEN	06/009/200/003/43/01	200	9.0	2.6	25.7	1.0	8.0	
BELLED END DIN 4925 CASE	06/011/225/003/57/01	225	10.0	2.6	32.1	-	-	241
BELLED END DIN 4925 SCREEN	06/012/225/003/57/01	225	10.0	2.6	32.1	1.0	8.0	241
FLUSH FITTING DIN 4925 CASE	06/006/225/003/71/01	225	13.0	2.6	41.1	-	-	
FLUSH FITTING DIN 4925 SCREEN	06/009/225/003/71/01	225	13.0	2.6	41.1	1.0	8.0	
FLUSH FITTING PLASCO CASE	06/006/225/003/57/01	225	10.0	2.6	32.1	-	-	
FLUSH FITTING PLASCO SCREEN	06/009/225/003/57/01	225	10.0	2.6	32.1	1.0	8.0	
FLUSH FITTING PLASCO CASE	06/006/250/003/59/01	250	12.5	4.5	44.9	-	-	
FLUSH FITTING PLASCO SCREEN	06/009/250/003/59/01	250	12.5	4.5	44.9	1.0	7.5	
BELLED END DIN 4925 CASE	06/011/280/003/59/01	280	12.5	4.5	50.6	-	-	297
BELLED END DIN 4925 SCREEN	06/012/280/003/59/01	280	12.5	4.5	50.6	1.0	7.5	297
FLUSH FITTING DIN 4925 CASE	06/006/280/003/73/01	280	16.0	4.5	63.9	-	-	
FLUSH FITTING DIN 4925 SCREEN	06/009/280/003/73/01	280	16.0	4.5	63.9	1.0	7.5	
FLUSH FITTING PLASCO CASE	06/006/280/003/59/01	280	12.5	4.5	50.6	-	-	
FLUSH FITTING PLASCO SCREEN	06/009/280/003/59/01	280	12.5	4.5	50.6	1.0	7.5	
FLUSH FITTING PLASCO CASE	06/006/315/003/50/01	315	14.8	4.5	67.2	-	-	
FLUSH FITTING PLASCO SCREEN	06/009/315/003/50/01	315	14.8	4.5	67.2	1.0	7.5	

NOTE 1. ALL THREAD FORMS ARE IN ACCORDANCE WITH DIN 4925.

NOTE 2. CASES MAY INCLUDE A RUBBER SEAL IN THE JOINT, IF SO REQUIRED".

Technical Area: 6 Casing Program / Installation

Item: 6-2 Casing Program

1: Objectives

To be able to explain and advise for how to determine casing size, borehole size and how to prepare casing program.

2. Contents

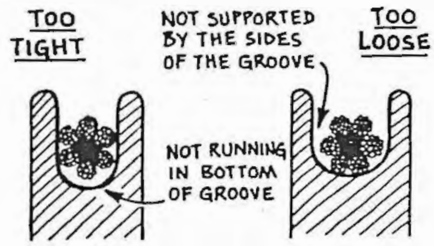
- Determination of casing size
- Determination of borehole size
- Determination of screen position
- Preparation of casing program

3. Teaching Methods

(1) Explain purpose of casing program and typical casing program drawings.
(2) Explain how to determine borehole size accrodring to casing diameter using typical casing program drawings.
(3) Explain how to determine screen position using manual.
(4) Explain how to prepare casing program using casing program calculation form

4. Materials

6-2M1 Drilling Chap. 7 P311-P314
6-2M2 Drillers Training and Reference Manual Chap.5 P147-P156
6-2M3 Typical Casing Program (Sedimentary Formation)
6-2M4 Typical Casing Program (Hard Rock Formation)



The pipe/rods: When pulling the pipe and racking it, check it for:

- scratches, grooves and wear,
- bends,
- damaged shoulders or threads.

When pulling long stands, **break** the stands at a **different joint** each time you pull so that all joints get inspected, greased and retightened.

The handling tools:

- The hoist plug (like the rotary head and the kelly) gets screwed into every joint. Make sure that these threads are in extra good shape or they will damage all the joints.
- The slips or slotted plate must fit accurately and grip securely to avoid damaging the string.
- The wrenches or tongs (and the chuck jaws) must bite cleanly and without slipping.
- If not mounted on the machine, the clamps or slips holding the pipe at the collar must be carefully lined up to avoid bending the pipe when the weight comes on the clamp.

Section 13 Casing – hole design

- Use of casing
- Casing threads and connections
- Casing – sizes and capacities
- Casing handling tools
- Running casing
- The casing program
- Casing and drill string failures
- Hole design

Use of casing

The main reason for using casing is to keep the hole open. Keeping the hole open may be important because we plan to use it for something. Or, it may be necessary just so that we can go on drilling in the hole.

For some years now a range of alternatives to steel casing have been available. Steel casing is still seen as the most suitable for running in a hole where drilling is to continue.

For permanent installation in a corrosive environment (and for other reasons as well) other casing materials are preferred. Smaller diameter and relatively shallow wells or piezometers are efficiently completed using PVC casing. Larger shallow wells (for example dug by bucket auger) might use precast cement casing.

Larger and deeper wells designed for long life and consistent performance may be finished with **fibreglass** casing. This casing is now manufactured in most water-well sizes. It can be run to depths exceeding 600m (2,000 ft).

Casing must withstand the crushing force caused by lowering the water level inside the casing during developing or pumping. The worst situation occurs when a driller pumps or bails rapidly before he has cleared the screen.

Steel makes the strongest casing. Steel water well casing up to 219 mm ($8^5/_8$ in) diameter has a collapse strength greater than 8000 kPa (1,200 psi).

Greater care must be taken with fibreglass casing. The 200 mm (8 in) casing has a collapse strength of 770 kPa (110 psi); the 150 mm (6 in) diameter casing, 1700 kPa (250 psi). PVC collapse strength is less, but of no real concern for wells up to 200 mm (8 in) if properly installed. Further discussion of well casings is provided in sections of Chapter 6.

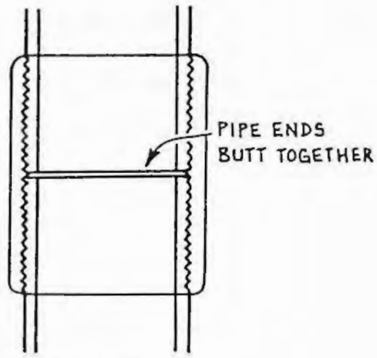
Casing threads and connections

Diamond drill casing (previous section) is manufactured with a rectangular thread. The W series flush jointed casing has a pitch of 4 threads per inch. The older 'X' series casing has an 8 threads per inch pitch .

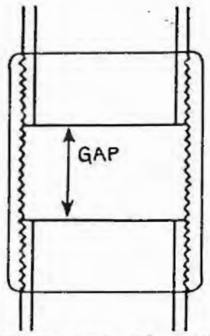
Taper sealing threads (previous section) with a 1 taper and a round thread profile are used for oilfield and waterwell collar casing (including "Slimline"). The thread pitch is 8 threads per inch.

The finer threaded Australian Swelled (not cressed) joint casing has a flat taper of 1 in 64. Like the collar casing, the joint seals on the threads. Some drillers prefer the swelled casing for holes where the casing must be driven and pulled.

Drive pipe is used for some work where heavy driving is involved, especially sampling. The ends of the drive pipe tubing butt up inside the collar to transfer the driving impact.

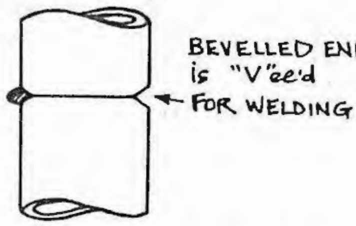


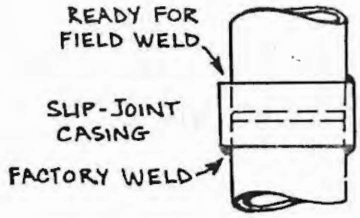
DRIVE PIPE



STANDARD CASING

Most waterwell casing is also available with **plain** or **slip joint** ends ready for welding.





Casing - sizes and capacities

The following tables provide some listing of sizes and capacities for steel casing types in use.

Casing handling tools

Waterwell casing driving equipment for use with cable tool rigs is described on page **in Chapter 3.**

Rotary waterwell rigs normally drill a hole adequate for the casing to run without driving. Rotary drillers sometimes are forced to **wash down** the casing. For this job, a serrated shoe is sometimes used. The "teeth" may be hard-faced to give greater life.

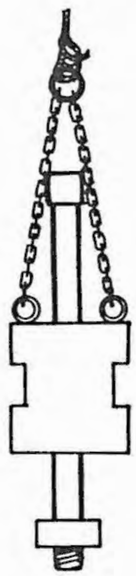
DIAMOND DRILL "FLUSH JOINT" CASING				
Size	O.D. mm	I.D. mm	Mass kg/m	Capacity L/m
AW	57.1	48.4	5.64	1.84
BW	73.0	60.3	10.43	2.86
NW	88.9	76.2	12.80	4.56
HW	114.3	101.6	16.83	8.10

WATER WELL "SWELLED" CASING			
O.D. mm	I.D. mm	SwellO.D. mm	Mass kg/m
101.6	93.9	107	9.67
127.0	117.5	135	14.87
152.4	142.9	160	19.05

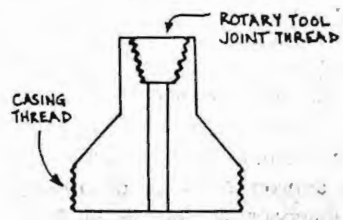
WATER WELL "SLIMLINE" CASING							
	TUBING		COUPLING		MASS Kg/m		CAPACITY
Size	O.D. mm	I.D. mm	O.D. mm	length mm	Bevelled End	Threaded and Coupled	Capacity L/m
4	101.6	90.12	109.2	93	13.6	13.7	6.38
5	127.0	114.3	135.5	96	18.9	19.1	10.26
6 5/8	168.3	155.6	177.7	98	25.4	25.6	19.02
6 5/8	168.3	154.08	177.7	98	28.3	28.5	18.65
8 5/8	219.1	206.4	228.4	107	33.3	33.6	33.46
8 5/8	219.1	205.02	228.4	107	36.8	37.1	33.01
10 3/4	273.0	257.42	-	-	51.0	-	52.04
12 3/4	323.9	307.14	-	-	65.2	-	74.09

WASH DOWN SHOE

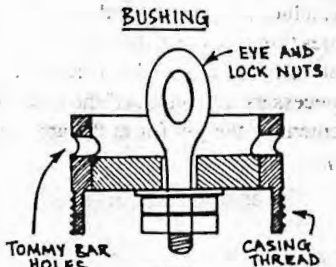
Rigs equipped for air circulation or air hammer operation can use a **pneumatic casing driver.** Some of these tools have the ability to pull casing as well as drive it. Some down hole hammer tools will also operate as casing drivers. Site investigation and diamond drills use a **monkey** casing system. The drive hammer is operated using a quick-drop winch or a cathead.



Casing bushes and hoist caps: To connect casing to the top drive or head or to the hoist, a bushing or a cap is used.



BUSHING



CAP

Running casing

Getting the hole cased can be a real problem. The problem is greatest when the down hole conditions are so bad the casing is the only answer.

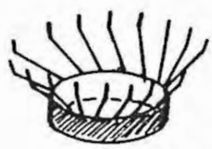
Most of the problems stem from the nature of the formations penetrated. Often they are made worse by the drilling practices used. **Boulders** and other unstable formations may have to be cased by **driving** the casing.

Sometimes an attempt to run casing makes the driller aware of serious problems that he had failed to detect before:

- **Crooked holes,** in particular **dog legs,** may prevent the casing from running. These holes must be reamed.
- **Poor mud control** often is revealed when the casing is being run through a permeable formation. The thick mud cake and the pressure differential (Chapter **12**) may "lock the casing" in place during the short time it takes to add another length.

Some of these problems are reduced and better conditions for a successful cement job are created if the casing is run with:

- **scratchers** to clear the mud cake, and
- **centralisers** to keep the casing in the centre of the hole.



SCRATCHER

CENTRALISER

The casing program

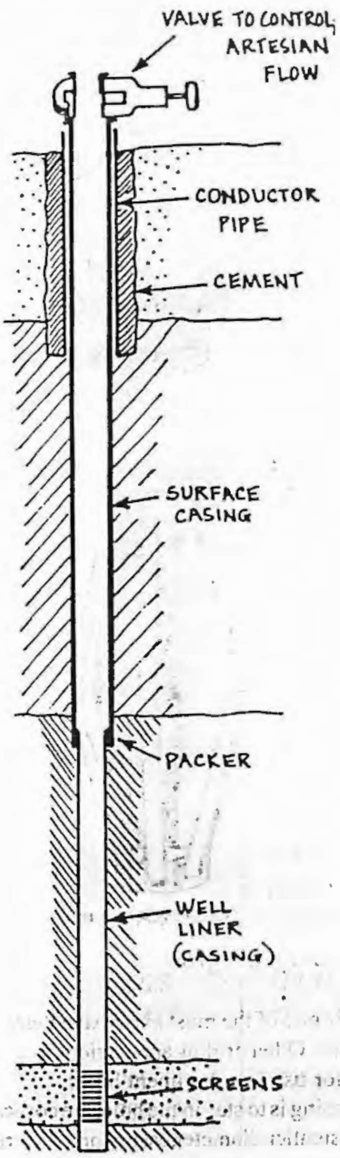
Casing is one of the most **expensive** items used in wells for oil or water. Other drilling applications can usually recover the casing for use in subsequent holes.

When casing is to stay in the hole, the cost can be reduced by running smaller diameter casing or a different type of casing. The minimum casing diameter and casing material type will be determined by the requirements for the completed well. Water drilling requirements are likely to call for a casing program as follows:

1. **A conductor pipe:** This casing controls loose surface formations and prevents erosion of the collar of the hole. It protects the hole against surface water inflow and reduces the chance of tools or rubbish falling into the hole.

2. **Surface casing:** This casing string is required when:

- surface waters must be sealed off,
- unstable formations interfere with drilling, or
- artesian flows are possible. In this case, the surface casing must be cemented in (**Chapter 6**).



3. **Well liner:** A liner may be sealed to the surface casing with a packer. If extended to the surface, it is called the **"well casing".** This string includes the well entry openings or screens. It is not used in some solid formations.

Casing and drill string failures

By far the largest proportion of these failures occurs at the joints. In most cases, the failure arises from the way that the joint was made up.

Tool joint problems usually relate to **torque.** When the torque required to break the joint exceeds the make-up torque, the list of possible causes is;

- insufficient make up torque.
- improper thread lubrication
- severe down-hole torque.

In the case of "severe downhole torque", the answer is to increase the make up torque by 10%.

Casing joint problems usually relate to instability in the hole or lack of joint strength. When drilling is carried on through casing, the casing is subject to blows from the drill string. Unless the casing is tight in the hole, the impacts will cause it to bend and maybe to unscrew or break at a weak weld.

Casing that is to follow the bit in a cable tool hole must be well tightened. The bottom joints in the string are often tack welded to eliminate the change of unscrewing. Problems often result from the bottom end of the casing hanging free in a rotary or diamond drill hole. The casing should be run or driven down until the shoe is firmly seated. If a seal cannot be achieved any other way, the shoe should be cemented.

Hole design

Efficient drilling is only possible in a carefully designed hole. The hole design or drilling plan establishes a clear objective for the driller and shows him how that objective is to be reached.

The hole design should encompass every aspect or stage of the drilling operation. However, in order to develop a drilling plan, all available information regarding the geology, hydrogeology, formation stability, etc., along with the drilling objectives, must first be collated.

From this information, it is often possible to determine approximate hole depth(s), hole and casing diameters, casing types, most appropriate type of drilling, sampling requirements/intervals, appropriate bit types, cementing requirements (including volumes) and a mud program.

Not only does this give the driller a clear understanding of what is involved in the project, but it also helps to ensure that materials necessary to "construct" the hole are on-site at the commencement of the job (or at the appropriate stage during the job).

CHAPTER FIVE
Well Screens — Their Use and Selection

SECTION 1

Prepared by:

Mr. W.J. O'Dea — Water Resources Commission
Mr. T. Brondgeest — Johnson Screen Division U.O.P. Pty. Limited
Mr. J.S. Hancock — Australian Groundwater Consultants Pty. Limited

1. Functions for a Well Screen

The simplest form of well construction is open hole, i.e. where the well is sunk into a geological formation which is water producing, but completely self supporting. Examples of such formations are crystalline rocks, and cemented sediments. Such formations, however, do not occur everywhere and with some exceptions, such as cavernous limestones and scoriaceous lavas, they do not have the high storage and water supply potential of unconsolidated, coarse sediments such as sands and gravels.

Where the latter sediments are encountered, a different bore construction is required to stabilize the formation and allow maximum bore and pumping efficiency, particularly in the case of thin, layered aquifers.

Early attempts at developing water supplies from sediments such as these included the hand digging of large diameter wells. The depth of these wells was, however, limited due to cost and water inflow problems. With the advent of drawlift pumps of small diameter, deeper wells were sunk using drilling rigs of various types. These bores were cased with metal casing and the water entered via slots or perforations cut over long lengths of pipe and having a width sufficient to exclude most of the fine sand.

Until the introduction of efficient screens, slotted casing has been the principal form of sand retention in the bore. In fact, in particularly favourable circumstances (i.e. great aquifer thickness and coarse gravel and sand), slotted casing is still used with advantage.

However, such conditions do not commonly occur and the need remained for some form of inlet structure which would have:

a) strength to withstand the tension and compression stresses applying during construction and use in the well,

b) a concentrated open area to permit high water inflows from relatively thin aquifers,

c) a capacity to selectively filter out sand initially, whilst supporting the remaining formation, and

d) the ability to be backwashed and jetted without damage to the structure.

Properly constructed well screens answer these requisites.

2. Types of Well Screens

Essentially there are five types of well screens. These include:

- slotted casing,
- wire mesh
- perforated or punched sheet metal,
- special application screens, and
- wrapped wire screens.

Variations on these, and combinations have also been constructed in polyvinyl chloride (P.V.C.), fibreglass and laminated wood.

2.1 Slotted Casing

Casing slotted in the field, either by using a cutting torch before inserting into the borehole or a casing perforator on casing at site, produces a makeshift screen which has the following limitations:

a) openings cannot be closely spaced, thus reducing the open area,

b) openings are inaccurate and vary in size, and are produced with rough edges which cause corrosion and impede flow, and

c) openings cannot normally be cut small enough to control fine or medium sand particles in sand pumping bores.

Machine slotted screens can be manufactured with an open area (expressed as a percent of total area), of up to 30%; however, the straight cut slots tend to pack up and open area is considerably reduced under operating conditions. The larger open area reduces the strength of this type of screen, which has therefore, limited use.

Slotted P.V.C. etc., have the same limitations, especially strength.

2.2 Wire Mesh Screens

The earliest screens manufactured and perhaps the simplest, were made out of stainless steel and bronze wire mesh, wrapped around a coarse slotted or perforated metal tube, then braised or welded down a vertical seam. (Fig. 73). They had the advantage of a much increased open area over slotted casing, and had the strength characteristics of the supporting slotted cylinder. They were found, however, to be weak under back-washing and bore developing pressure and subject to severe blinding of the small square inlet openings in the wire mesh (Fig. 73). In some waters, encrustation was a severe problem and rapid declines in water level at high yields were caused by turbulent flow conditions developing in the mesh void spaces. These screens are seldom used now, though the practice of supporting the wire mesh away from the support cylinder on vertical rods did much to improve their open area and inlet capabilities.

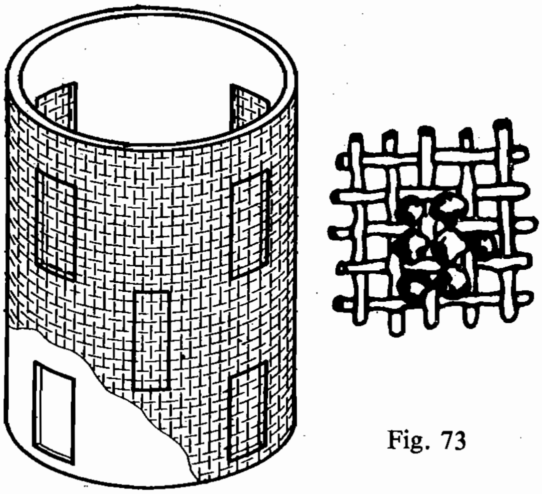


Fig. 73

2.3 Perforated or Punched Screens

Sheet metal punched into louvres or holes (Figures 74 and 75) and then rolled into a cylinder, has been widely used in some areas for developing water supplies from unconsolidated sediments. The screens have a low open area, but are better than slotted casing.

Where the louvre slot is used, the strength of the screen in tension is maintained to some extent, though strength in compression is limited. In general, the metal punched is fairly light gauge (normally 3mm), resulting in inherent weakness.

The worst feature of this form of screen is that it is very difficult to develop, since water backwashed out through the screens loses most of its energy in circumferential motion between the slots. High pressure jetting is non-effective and thus, the screen is only useful where clean, very coarse aquifers exist which do not require development.

A machine perforated slot (bridge slot) (Fig. 75), has a higher strength than slotted casing and the aperture formed has better non-clogging properties. The apertures can be manufactured to a minimum opening of 0.7 mm and the open area normally varies between 20% and 32%. Under certain conditions, this type of screen can be the most economical available.

Louvre type well screen is also manufactured in a similar manner to the machine slotted bridge screen and its application is normally limited to gravel pack bores.

These screens are normally inexpensive and are much better than slotted casing. They need to be run in long lengths commonly in large diameter (over 300 mm) gravel packed wells. In comparing this form of screen with others, it is essential to take into account the cost of extra lengths required, the extra diameter of the wells and the gravel packing necessary. In the right circumstances they have a place.

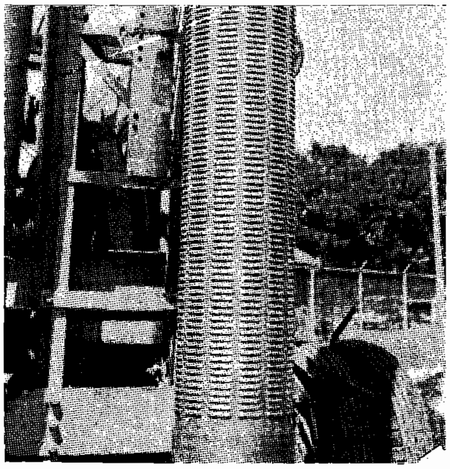


Fig. 74

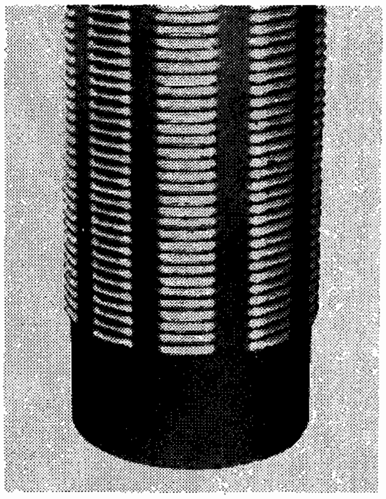


Fig. 75

2.4 Special Application Screens
Resin Bonded Gravel and Pre-packed Double Well Screens.

In recent years, in order to develop fine sands or variable sands in a corrosive environment, resin bonded gravel screens and pre-packed double well screens have been developed.

These screens, 50 mm thick or more, are normally made up on coarse, well-rounded, quartz gravel, formed around a metal frame and bonded by a resin compound which is poured into a mould, coating the gravel and bonding the pebbles at their points of contact. Alternatively, the gravel may be held between two retaining screens.

The use of resins in this type of screen reduces the original gravel permeability by between 30% and 40%, but the remaining permeability is normally still higher than that of the aquifer material.

These forms of screen may have little tensile strength, but normally have adequate hoop and column strength. They can only be used in bores drilled with clean water, as they are virtually impossible to develop. Under normal conditions with gentle valve surge development, the aquifer formation moves into, but not through, the gravel and the final permeability of the screen is that of the aquifer.

These types of screens are undesirable for high yield bores, however, where sands must be developed and this cannot be adequately achieved by any other technique, then they have a place.

2.5 Wrapped Wire Screens

Wire wound screens represent the end product of a long period of evolvement which commenced effectively in the United States at the turn of the century.

The screen consists of a wedge profile wire of various dimensions, resistance welded to a cylindrical body made up of various numbers and cross-sections of longitudinally arranged metal rods which are, in turn, welded on to cylindrical ring couplings at either end (Figure 76).

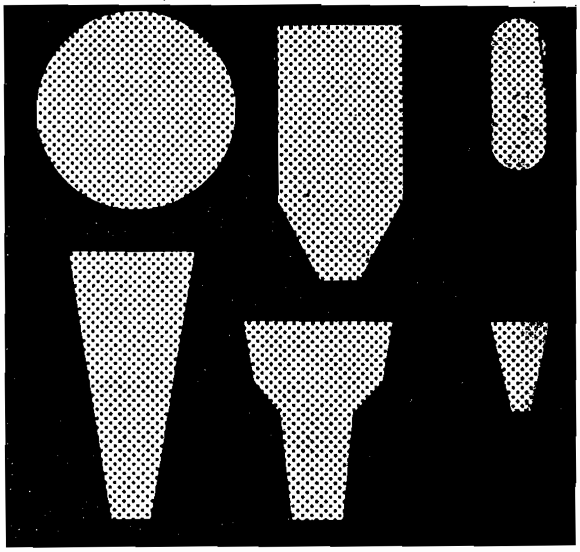


Fig. 77

The tensile strength of the screen is dependent on the number and cross-sections of the vertical support rods, whilst the column strength is dependent on the same rods, plus a factor dependent on the profile of the wrapping wire and the depth of the resistance weld. The hoop strength of the screen is dependent on the wrapping wire and the frequency of coupling rings (Fig. 77).

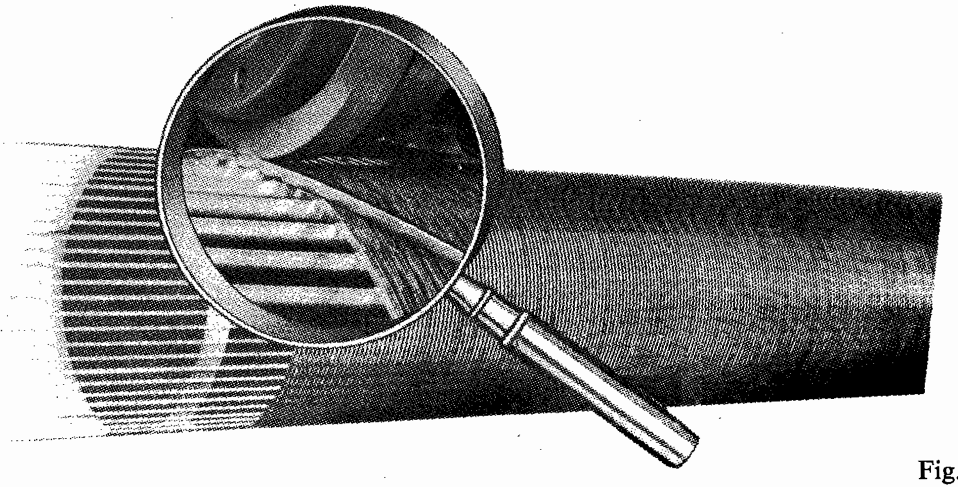


Fig. 76

The process of manufacture makes it possible to maintain the slot aperture constant on any one screen, but it can be varied to make screens to suit any sand or gravel size. The wrapping wire has a wedge profile which is flat on the outside and produces an expanding slot on the inside. This shape makes jetting and back-washing operations more effective and avoids the screen being clogged by fine particles (Fig. 78).

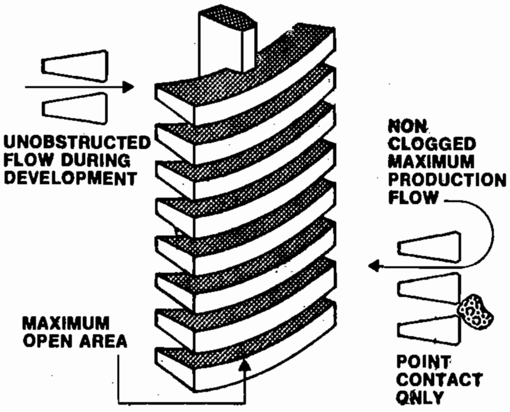


Fig. 78

The open area for water entry with this form of screen is generally higher than that for other screen varieties. Thus, shorter lengths of screen may be used, set opposite the best aquifer sections only, to achieve production. Also, the slot is open radially, thereby reducing well loss factors at the screen.

Some screens are manufactured with the wire wound on perforated pipe, thus reducing the open area, but increasing the overall strength of the screen.

Other screens use round or rectangular wrapping wire which clogs in the same manner as a mesh screen. Another variation is that the wrapping wire is only welded to the supporting frame, either on one or two support bars, or only on the connecting ring. These practices greatly reduce the strength of the screen.

Of all the screen types currently manufactured, continuous aperture wire wound screens are the most efficient, and for normal applications, the most economic unit currently available for use in high yield wells drilled in unconsolidated sediments. To obtain the best results in useage and life of these screens, it is, however, essential to exercise care in the selection of the particular screen required.

3. Selection of Well Screens

The selection of the best screen or screen combination depends on matching the screen to suit the working requirements of the final well, the design of the final well, and the physical environment in which the well is being established. This ultimately resolves itself into decisions on the material to be used, the dimensions of the screen and its components, and the aperture or apertures appropriate.

These decisions cannot be made without some preliminary knowledge of the groundwater regime of the area. Such knowledge may be resultant on a full scale investigation programme, a professional assessment of the likely situation, or a conservative estimate based on some field studies.

3.1 Material Selection

The first factor to be decided when selecting a screen is the material of which it should be constructed. Commonly, Australian screens are made in AISI Type 304, 308 and 316 stainless steel, in Cusilman Bronze, mild steel and in some instances, in Monel Metal. The selection of the material will depend on the life required in the bore, the type of water which is likely to be encountered, the depth at which the screen will be set and the other materials being used in the bore. (see Tables, Chapter 8).

3.2 Mild Steel Screens

Mild steel screens are commonly used in hard, low salinity waters where the corrosion index is low, or with exploration programmes, where it is desirable to keep expenditure to a minimum. Even on the latter operations, the use of better quality materials is often advisable so that the same screen can be used many times, being pulled in and out of bores as required. Mild steel screens are commonly manufactured only in light pattern construction, and do not have the strength to be pulled and run repeatedly, without risk of damage.

3.3 Stainless Steel

Type 304 is the most widely used material for screens in Australia, both in brackish water and acid water installations. It is a high strength material and, after pickling to produce a passive surface against corrosion, the screens have shown good life characteristics.

Type 316 stainless steel is only used in very aggressive waters and where an equivalent non-corrosive casing material is used, e.g. asbestos cement, fibreglass or P.V.C. This initial cost of the material is high, but the life in such situations is the important factor.

Given accurate and detailed water analyses, reputable screen manufacturers will normally guarantee their materials against corrosion for periods up to 20 years.

3.4 Dimensions of the Screen

Having selected the material best suited to the intended application, the dimensions of the screen used need to be considered. The factors involved in this decision are the yield required and bore design.

It is always advisable, where possible, for the screen to be internally flush with the casing being used, as this minimizes the possibility of damage to the screen due to objects being dropped down the bore during development, or in later useage. Further, this brings the outside of the screen closer to the wall of the drilled well which provides for lateral support to be achieved rapidly and for development to be more effective.

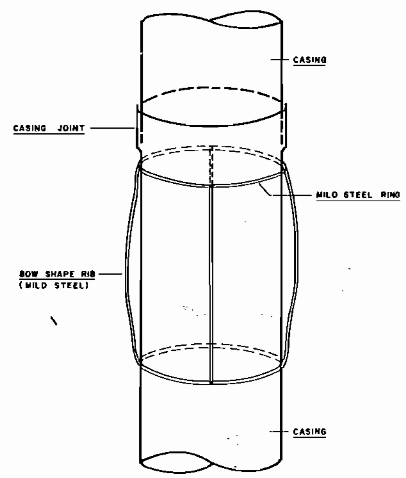
Where screens are run and set inside an established casing, such as occurs with cable tool drilling, the internal dimensions should be as large as possible, bearing in mind the strength requirements of the screen in compression and the maximum outside diameter limitations.

The actual dimensions of the component parts of the screen will vary depending on the material used and the manner in which the screens are to be set, i.e. in tension or compression. All continuous slot aperture screens manufactured have greater tensile strength than column strength and hence, if long lengths are to be run, it is best that they be run and held in tension. Screen manufacturers will give details of the strength ratings of their screens, dependent on the material used, the profile of the rods and wrapping wires and the maximum uncoupled lengths. These should be checked to ensure that they are commensurate with the requirements of the bore design.

In designing a bore, the strong and weak points of the screens should be carefully studied and, if an oversize hole has to be drilled for gravel packing or some other reason, the casing centralizers should be used to give lateral support to the screen string (Fig. 79).

Hoop strength of the screens is an important factor, but one which is very hard to specify or test. The collapse strength requirement of casing

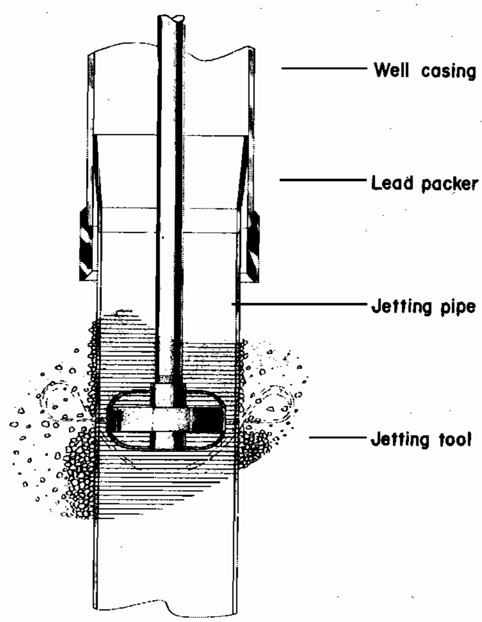
CASING CENTRALIZER



Casing centralizer is made from six mild steel strips of 1" x ⅛" in size. Two strips are firstly formed into two seperate rings and is set at a distance of 18" apart. Four other strips are then formed into bow shape ribs and welded onto rings, forming a cage shape centralizer.

As casing is lowered down the hole, the centralizer is then slipped over the casing, it catches the side wall of the hole, slides along casing and is held in position at casing joint.

Fig. 79



High-velocity, horizontal jetting technique creates turbulence around well screen which effectively loosens fine material and brings it into the well.

Fig. 80

is specified in the American Deep Well Specification as being equal to the full hydrostatic pressure applied externally at the deepest depth at which the casing may be set. Screens can be blinded completely by filter cake and clay and thus, be subjected to stresses which may result in collapse. Full hydrostatic pressure is seldom, if ever, applied to screens in a deep setting.

During development of screens, it is important that before any substantial extraction of water is made in the bore, some attempt be made to clear blockage of the screens. This can be achieved by high pressure water jetting. (Figures 80 & 81). The use of degradable drilling fluids also minimizes the danger. The radial collapse strength of the screen specified for a particular job, should not need to be more than the hydrostatic pressure equivalent to the maximum drawdown which can reasonable be expected during drilling, e.g. maximum airlifting depth, minus static water level.

A form of failure which must not be confused with radial collapse due to insufficient hoop strength, is from gravel packed wells or wells drilled oversize. The failure referred to is lateral shearing of the screen which commonly occurs immediately below a coupling. This form of failure results from the impact of slumping materials, or the establishment of high lateral pressures due to unevenly placed or bridged gravel pack. It is undesirable to design screens to withstand these forces which must be considered to result from poor drilling practice, rather than poor screen design.

3.5 Aperture Selection

The most critical decision made concerning the screens to be used in any particular well, is that of the aperture or slot opening size.

The aperture selected is normally large enough to permit between 40% and 60% of the size range of the aquifer sand or gravel to enter the bore to be removed during development. Thus, the aperture selected is entirely dependent on the grain size analysis of samples collected during drilling (see Fig. 82 — Sand Analysis Sheet).

It is of critical importance that the samples be collected from accurately known depths, and that they should be representative of the formation. Cable tool percussion drilling is undoubtedly the most accurate method of sample collection, but it is possible to obtain quite reasonable samples from hydraulic rotary drilled wells using a variety of techniques, e.g. shale shakers, channel and baffle collectors, etc. It is important in hydraulic rotary drilling that the samples be backed up by electrical and gamma radiation logs, to permit accurate identification of the aquifer zone (see Figure 83 — Example of Geophysical Logs).

Having selected the aquifer zones and sited the screens in depth, it is necessary to study the size distribution of the sand grains, not only for the zone to be screened, but also for any sand zones which overlie the selected zone. Development can cause slumping and "bleeding" of fine sands down the annulus outside the casing. This can result in a bore which will continually pump some sand. This sand will damage the pump equipment and may create a nuisance in surface installations.

For sands which are well sorted, i.e. have a coefficient of uniformity of 2, the screen aperture should be selected conservatively to retain 55%-60% of the sand sizes. Where the sands are less well sorted, the screen aperture can be selected back to 40% retained (see Figure 82).

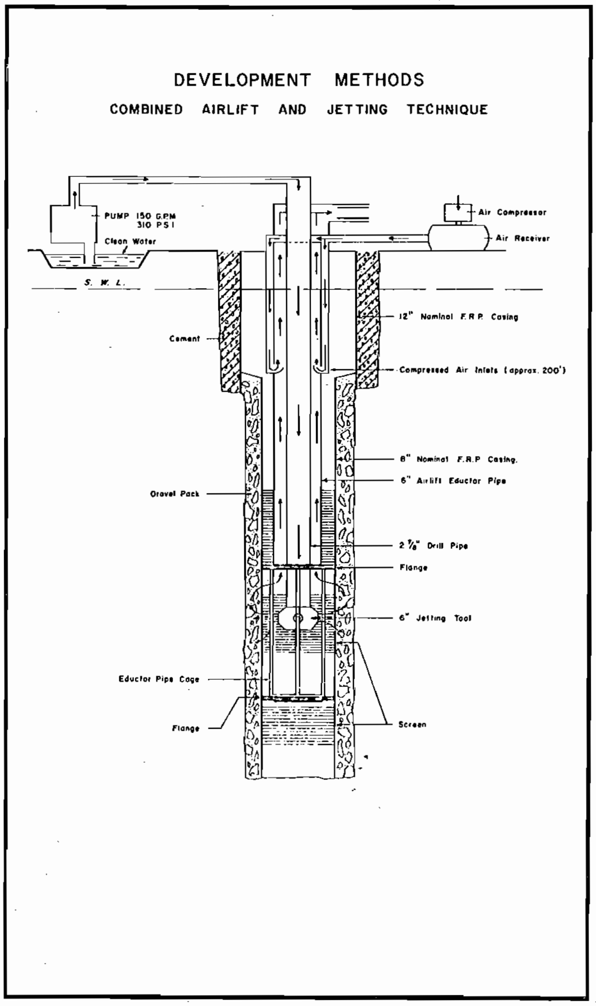


Fig. 81

Fig. 82

SAND ANALYSIS SHEET No. 1

PAGE 1 OF 3

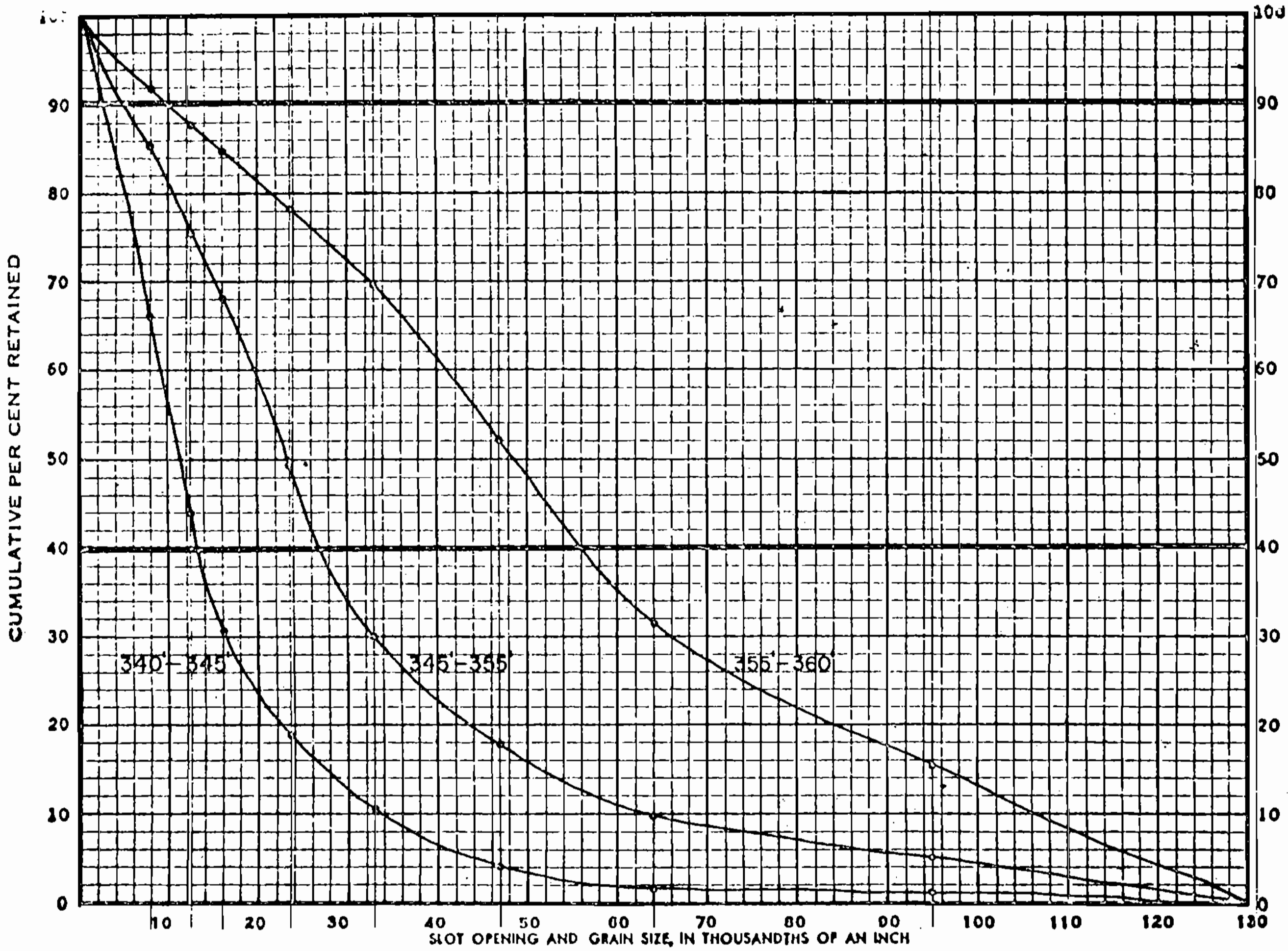
JOB WAKOOL N.S.W. RICE IRRIGATION PROJECT DATE 13 · 3 · 74

SUPERVISOR W. MORTON ASSISTANT F. CAROSONE JOB No. 1272 / 74 - 14

FROM WELL OF Mr. M. BAMBONETTI BORE No. 2

Remarks 337'-363' SAND: YELLOW, UNCONSOLIDATED, QUARTZOSE, WELL ROUNDED, SORTED.

BORE DIAMETER 12 1/4 INS. SCREEN ZONE 345 - 360 Ft.



SIEVE OPENINGS	Cumulative Per Cent Retained					
	340 — 345 ft.		345 — 355 ft.		355 — 360 ft.	
·131 Ins	0	0	0	0	0	0
·095 "	2	1	10·42	5·21	31·50	15·75
·064 "	1·6	1·8	9·18	9·8	31·82	31·66
·047 "	4·6	4·1	16·0	17·8	40·68	52·00
·033 "	12·3	10·25	24·48	30·04	35·02	69·51
·0237 "	18·9	19·7	38·72	43·4	17·38	78·2
·016 "	21·42	30·41	37·42	68·11	12·84	84·62
·0125 "	27·18	44·0	15·06	75·64	6·56	87·9
·008 "	44·2	66·1	19·72	85·5	8·2	92·0
Resid.	67·8	100%	29·00	100%	16·0	100%
SAMPLE WEIGHT, Grms.	200 Grm		200 Grm.		200 Grm.	

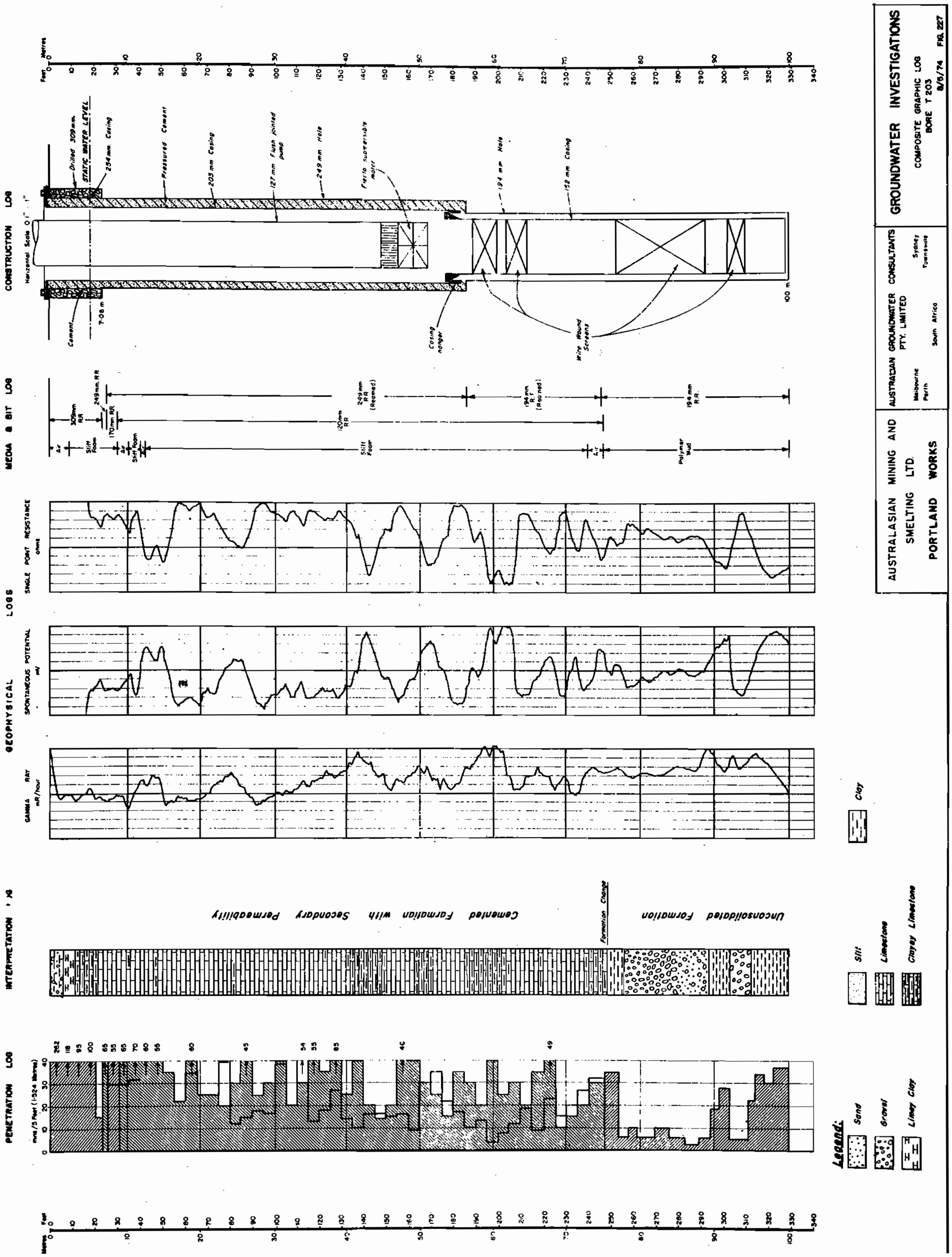
Notes: Samples Collected by Hydralic Rotary Rig from baffle plated Channel. Samples Washed through 200 mesh Screen.

Recommended Slot Opening: 345 to 350 ft — 0·020 Ins.
350 to 355 ft — 0·025 Ins.
355 to 360 ft — 0·041 Ins.

Recommended Screen: Dia. 10 IN. I.D. Length 15 Ft.

By: D. MERTENS

Fig. 83



GROUNDWATER INVESTIGATIONS
COMPOSITE GRAPHIC LOG
BORE T 203
AUSTRALASIAN GROUNDWATER CONSULTANTS PTY. LIMITED
Melbourne Perth South Africa Sydney Townsville
AUSTRALASIAN MINING AND SMELTING LTD.
PORTLAND WORKS
CONSTRUCTION LOG
MEDIA & BIT LOG
GEOPHYSICAL LOGS
SINGLE POINT RESISTANCE
SPONTANEOUS POTENTIAL
GAMMA RAY
INTERPRETATION
PENETRATION LOG
Cemented Formation with Secondary Permeability
Unconsolidated Formation
Formation Change
STATIC WATER LEVEL
Pressured Cement
203 mm Casing
249 mm Hole
194 mm Hole
152 mm Casing
Casing hanger
Wire Wound Screens
Cement
Legend:
Sand
Gravel
Limey Clay
Silt
Limestone
Clayey Limestone
Clay
Feet
Metres

6-2M2 - 8

Care should always be exercised in well sorted sands to avoid selecting the screen aperture of a section of the size analysis curve which includes a small size range variation for a large change in the percentage retained. Apertures in this range are very suspect, since slight inaccuracies in sampling can cause major changes in the percentage of size retained by the screen, producing either a bore which is difficult to develop, or one which pumps sand.

A general guide to aperture selection is as follows:

Aquifer Sand Type	Coefficient of Uniformity	Overlying Bed	Aperture Size % Retained of Aquifer Sand
Poorly sorted	$>$ 6	Firm	30
Poorly sorted	$>$ 6	Soft	50
Well sorted	$<$ 3	Firm	40
Well sorted	$<$ 3	Soft	60

Advice on aperture selection is available from the Association, Government authorities, screen manufacturers and consultants.

3.6 Length of Screen

Having established that a particular aquifer or aquifer sequence is capable of yielding a given water supply to a bore, the length of screen necessary depends on the thickness of aquifer available and then on the quantity of water required.

Experience indicates that best bore performances are obtained with an entrance velocity through the screens ranging from 0.61 to 3.66 m/minute. This can be calculated with the following simple formula:

$$\text{Entrance Velocity} = \frac{\text{anticipated bore yield in } m^3/\text{minute}}{\text{open area of screens in } m^2}$$

To obtain the required open area, the formula changes into:

$$\text{Open area in } m^2 = \frac{\text{anticipated bore yield in } m^3/\text{minute}}{\text{entrance velocity} = m/\text{minute}}$$

The screen manufacturer will supply the open area per metre of each type of screen and then, the necessary length required to obtain that open area is easily calculated.

Example:

Yield	- $180m^3/h = 3m^3/\text{minute}$ (660 ig/m)
Entrance Velocity	- 1.83m/minute (most commonly chosen)
Screen	- 8" or 200mm, heavy pattern pipe size
Aperture	- 0.050" or 1.3mm
Open Area	- **116.9 sq. inches/foot or 0.247m²/m**

$$\text{Open Area Required} = \frac{3m^3/\text{minute}}{1.83m/\text{minute}} = 1.64m^2$$

$$\text{Length Required} = \frac{1.64m^2}{0.247m^2/m} = 6.6m$$

Where a greater length of aquifer is available for screening than is necessary, then it is best to select the aquifer zones to be screened by ranking them in order of hydrological potential, in keeping with the bore design and pump requirements, by using such factors as are shown by:

Geophysical Logging	: the electrical resistivity value
	: the gamma radiation value
Mechanical Analysis	: the effective size, i.e. 90% retained size
	: the coefficient of uniformity
Aquifer Salinity	: if significant variations exist
Individual Aquifer Lengths	: in a stratified sequence
The Depth of Occurrence	: in a stratified sequence
The Hydrological System	: in a multi-system sequence

This procedure is of critical importance, particularly in bores drilled by hydraulic rotary techniques, because the geophysical log interpretation is essential for an accurate definition of bed boundaries (see Figure 83 — Composite Graphic Log). Advice should be sought in this matter from an authoritative source.

Having decided the length and the positioning of the screens, the casing and screen line must then be laid out accordingly, placing blank casing where necessary. Finally, the whole casing string is run sequentially and when landed and cleared, development can begin.

3.7 Economics

The well screen used in a bore normally has a cost between 5 to 10 times the cost of an equivalent length of blank casing of the same size. For this reason alone, it is essential to use a length of screen as short as practicable and to use the cheapest material capable of lasting the life of the well. To achieve this, one must use a screen in which the open area is maximized by design and aperture to the extent permissible by the geological conditions and the well design.

The ultimate economy of a well however, does not depend on initial capital cost, but on the long term operating and maintenance costs. These costs relate to the head against which the water must be lifted, the clarity of the water and the effects of corrosion and encrustations in the bore and, to some extent, in the pump.

A properly selected, constructed and designed well screen will achieve all these ends, if properly located by:

a) permitting effective development to be carried out, thereby improving the permeability adjacent to the bore and reducing the nett pumping lift,

b) avoiding high entrance velocities which result in turbulent flow, increases in drawdown, aperture erosion, and high corrosion rates due to compression and expansion effects which cause the release of encrusting compounds and corrosion gases, e.g. iron hydroxide and carbon dioxide, and

c) providing a stable filter to permit the entry of water free of sand.

World experience has shown these factors to be paramount in achieving continued and economic high yields of water from unconsolidated and semi-consolidated sediment aquifers at the lowest possible cost per unit volume.

4. Applications of Well Screens

Well screens are made in every size from 7.62 cm. to 50.8 cm. diameter and can be applied in wells of all sorts of types.

4.1 Natural Pack Wells

The commonest form of water well is one in which the screens and casing are run into a well which has the minimum clearance in drilled diameter necessary for their placement. These wells are referred to as natural pack wells, in that development of the bore after the screen is placed, produces a zone of higher permeability around the well by the removal of fines from the natural aquifer material.

No screen, apart from the continuous slot wire wound screens, can achieve this sort of development with anything near the same degree of efficiency, either because alternatives do not

6-2M3

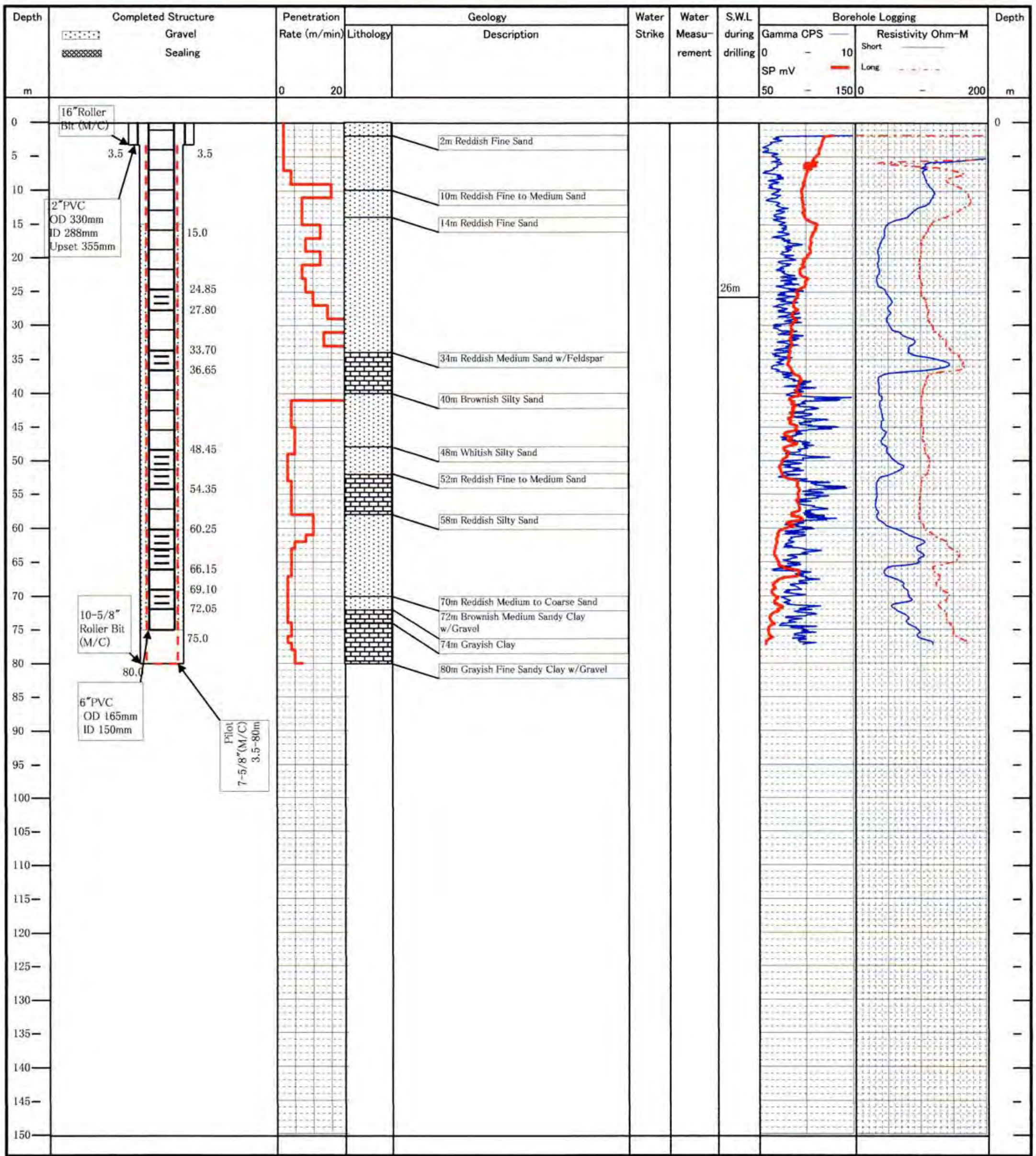
Form No.: QC-4-6
QC Item: Drilling Work
Form Name: Drilling Report

GPS Coordinates:

Logitude (E)	Latitude (S)
38-38-21.96	07-21-38.76

Elevation (m): 314

		Date of Submission:	5-Nov-07
BH No.	KSW-1-BH3	Date of Commenceme	8-Oct-07
BH Order	DD-009	Date of Completion	1-Nov-07
Borehole No.	CO 562/2007	Contractor	DDCA
Vil No.	KSW-1		
Village	Chole		
Village/Street	Chole		
District/Municipality	KISARAWE	Rig	Pat 301 TP / Schrar
Region	COAST	Driller	Elia Samuel / Melkiol
Scheme No.	KSW-1		
Scheme	Chole		



Remarks

The borehole did not produce any water.
It was judged to be unsuccessful.
The pumping test and the water quality analysis were not carried out.

Submitted By:	Inspected By:
Contractor	Consultant

6-2M4

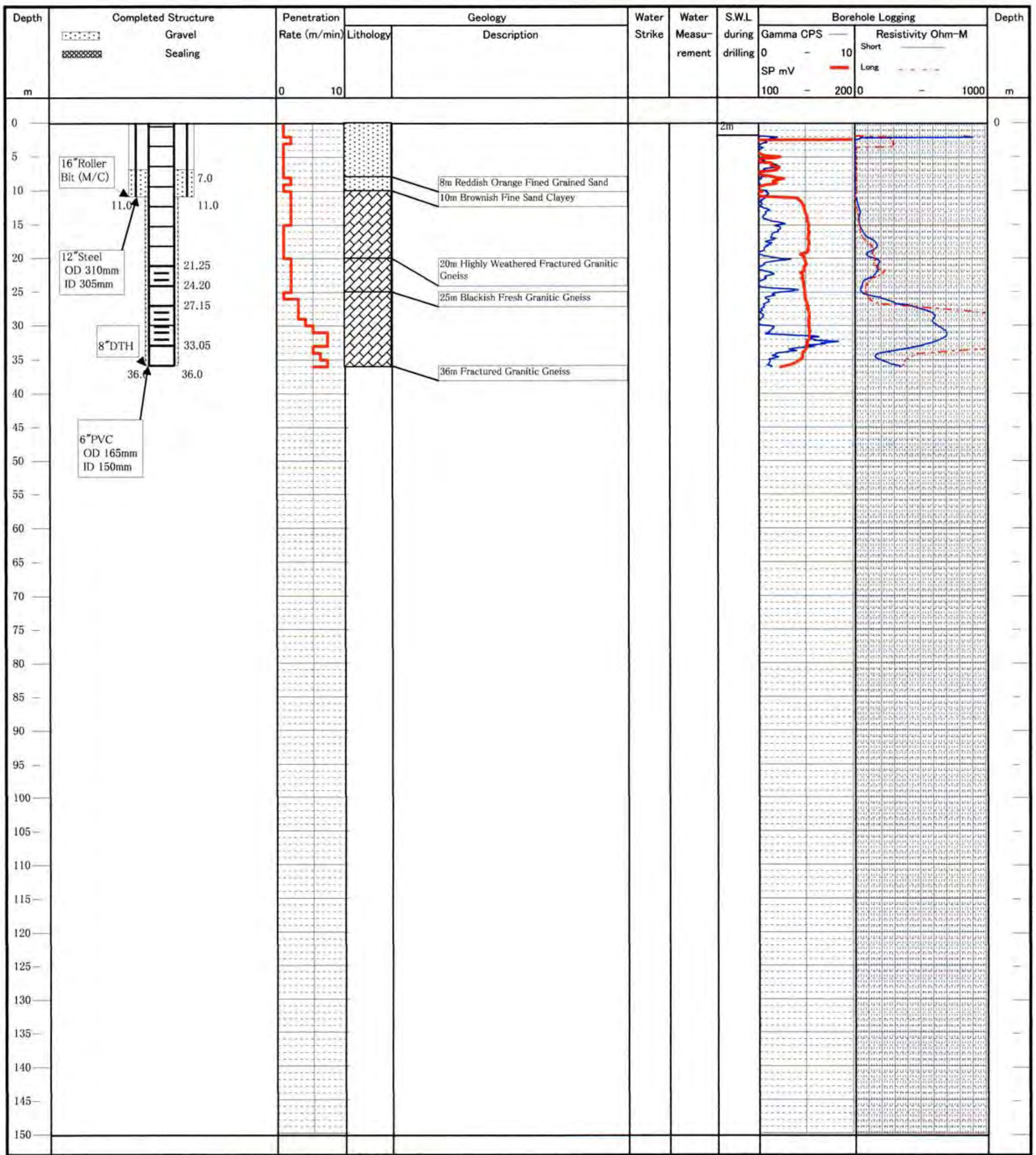
Form No.: QC-4-6
QC Item: Drilling Work
Form Name: Drilling Report

GPS Coordinates:

Logitude (E)	Latitude (S)
37-55-41.28	05-59-30.00

Elevation (m): 401

		Date of Submission:	5-Nov-07
BH No.	BGM-1-BH1	Date of Commenceme	21-Sep-07
BH Order	DD-008	Date of Completion	13-Oct-07
Borehole No.	CO 543/2007	Contractor	DDCA
Vil No.	BGM-1		
Village	Kibindu		
Village/Street	Kibindu		
District/Municipality	BAGAMOYO	Rig	Schramm 49 / Schra
Region	COAST	Driller	Steven Halinga / Kar
Scheme No.	BGM-1		
Scheme	Kibindu		



Remarks

The water was taken from the fractured gneiss deeper than 11m.
Surface steel casing remained in the borehole.
Borehole was judged to be successful.

Submitted By:	Inspected By:
Contractor	Consultant

Technical Area: 6 Casing Program / Installation

Item: 6-3 Role of centralizer

1: Objectives
To be able to explain and advise for use of centralizer and how to determine its installation depth.

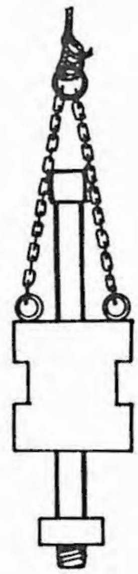
2. Contents
- Structure of centralizer
- Roll of centralizer
- Determination of centralizer position

3. Teaching Methods
(1) Explain structure and roll of centralizer.
(2) Explain how to determine centralizer position.

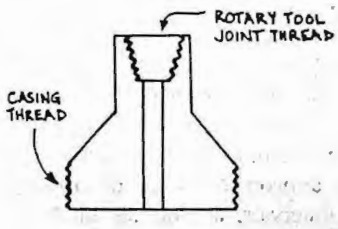
4. Materials
6-3M1 Drilling Chap. 7 P313

WASH DOWN SHOE

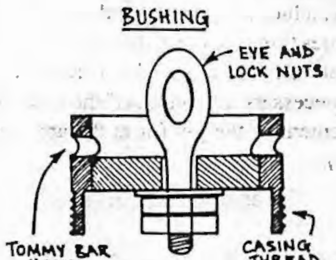
Rigs equipped for air circulation or air hammer operation can use a **pneumatic casing driver.** Some of these tools have the ability to pull casing as well as drive it. Some down hole hammer tools will also operate as casing drivers. Site investigation and diamond drills use a **monkey** casing system. The drive hammer is operated using a quick-drop winch or a cathead.



Casing bushes and hoist caps: To connect casing to the top drive or head or to the hoist, a bushing or a cap is used.



BUSHING



CAP

Running casing

Getting the hole cased can be a real problem. The problem is greatest when the down hole conditions are so bad the casing is the only answer.

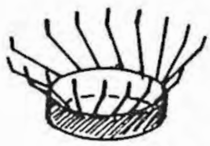
Most of the problems stem from the nature of the formations penetrated. Often they are made worse by the drilling practices used. **Boulders** and other unstable formations may have to be cased by **driving** the casing.

Sometimes an attempt to run casing makes the driller aware of serious problems that he had failed to detect before:

- **Crooked holes,** in particular **dog legs,** may prevent the casing from running. These holes must be reamed.
- **Poor mud control** often is revealed when the casing is being run through a permeable formation. The thick mud cake and the pressure differential (Chapter **12**) may "lock the casing" in place during the short time it takes to add another length.

Some of these problems are reduced and better conditions for a successful cement job are created if the casing is run with:

- **scratchers** to clear the mud cake, and
- **centralisers** to keep the casing in the centre of the hole.



SCRATCHER

CENTRALISER

The casing program

Casing is one of the most **expensive** items used in wells for oil or water. Other drilling applications can usually recover the casing for use in subsequent holes.

When casing is to stay in the hole, the cost can be reduced by running smaller diameter casing or a different

Technical Area: 6 Casing Program / Installation

Item: 6-4 Casing, screen pipe installation

1: Objectives

To be able to explain and advise for preparation and procedures of installation of casing, screen pipe.

2. Contents

- Preparation of casing, screen pipe on site
- Precautions during installation
- Depth calculation after installation
- Protection after installation

3. Teaching Methods

(1) Explain how to prepare casing, screen pipe on site prior to installation.

(2) Explain precautions for installtion of casing, screen pipes.

(3) Explain how to calculate the casing depth after installation.

(4) Explain how to protect the casing top after casing installation s.

4. Materials

6-4M1 Guidance on Casing, Screen Pipe Installation

6-4M1 GUIDANCE ON CASING, SCREEN PIPE INSTALLATION

(1) Casing Installation and Removal

Casing installed using one of the two Techniques

a) FORCING the forcing techniques available to drillers include

- Driving
- Jacking
- Pushing with the rig

b) LOWERING: is usually performed using the rig athough cranes and other devices are used. The loads involved in handling casing may be reduced by floating the casing down. Casing tends to float on the water or mud in the hole

Running the casing: points to consider when running casing

- When float shoe is to be used to assist in handling a heavy string of steel casing, the shoe must be made up tight and welded to the first joint of screen
- As the string is made up , Centralisers are fitted to every second unit
- Take care to align the casing. Threaded joints should be started very carefully to avoid cross-threading
- A float shoe fitted, the casing must be lowered very slowly to avoid forcing mud into the aquifer or fracturing the formation. If the casing floats water is pumped into the top of the casing
- Driving is performed on steel casing only

After having carried out the borehole logging and finalized the casing-screen installation plan, it is advised to once again check the open depth of the borehole before installation of the well assembly.

A PVC bottom cap with a length of 0.25 m will be installed at the lower end of the well assembly. On top of the bottom cap, usually a sump pipe or sedimentation pipe will be installed. On the lower end of the sedimentation pipe the first centralizer will be fixed. On top of the sedimentation pipe the lower screen section will be connected, with which length depends on the hydro-geological situation of the borehole. Due to the situation in the borehole one or more different screen sections can be installed.

When having reached the planned installation depth, the well assembly should still be in a hanging position, allowing the PVC material to straighten out completely and being centrically placed in the borehole.

1. PVC well assembly according to the plan laid out on site

2. Cutting bolts of centralizer

3. Installation of bottom plug & sump pipe

4. Centralizer

5. Cutting bolts of centralizer

6. Fixing lifting cap on the lower end screen

7. Fixing of camp to hold the pipes on the working place

Source: JICA's Water Supply Project in Swaziland

Figure 1 Work Procedure of Casing Installation

Technical Area: 7 Gravel Packing

Item: 7-1 Determination of gravel size

1: Objectives
To be able to explain and advise for how to determine gravel size suitable to well structure and aquifer formation.

2. Contents
- Determination of gravel size

3. Teaching Methods
(1) Explain partcile size distribution of gravel using sample curve.
(2) Explain how to determine particle size of gravel according to aquifer characteristics, screen size, hole diameter and discharge rate.

4. Materials
7-1M1 DDCA's Manual for Drilling Works
7-1M2 Drillers Training and Reference Manual Chap. 5 P175-P176

5 GRAVEL PACKING (TA CODE 7)

5.1 DETERMINATION OF GRAVEL SIZE (TA CODE 7-1)

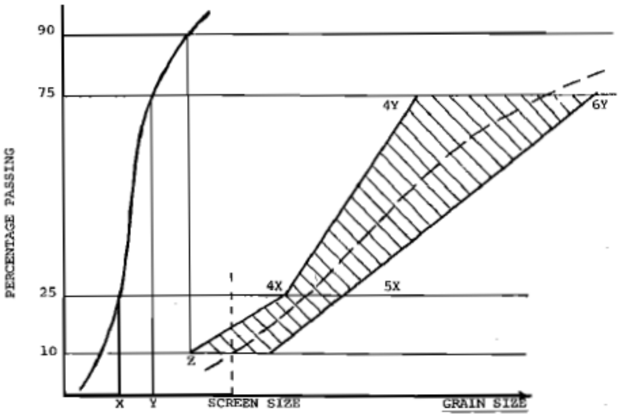
Various parameters shall be considered for the design of gravel pack such as aquifer characteristics,screen size, discharge rate, hole diameter and so on. The size of the gravel shall be principally less than the size of the slot of the screen. The velocity shall be considered upon the decision of the hole diameter so as not to cause the sand production.

The steps necessary to design a gravel pack are as follows (Refer to ***Figure 28***):

1. Read off the 25 % and 75 % grain size values of the percentage of material passing and multiply them by 4 and 5, and 4 and 6 respectively. Plot these results on the graph.
2. Draw connecting lines through 4X and 4Y and 5X and 6Y.
3. Transfer the position of the 90 % passing to the 10 % passing position for the same graph size. This point then becomes Z.
4. Complete the line 4Y – 4X –Z.

   An envelop has now been defined (shaded area). The gravel pack analyses should fall within this envelop (except at its extreme ends). Search around for suitable rounded gravel which will fall within this envelop or can easily be adjusted (by addition or subtraction of sand or gravel) into the envelop, e.g. broken curve – natural gravels of the ideal type are difficult or time consuming to find, hence the envelop.

   Select a screen size to pass 10 % of gravel pack and round up to nearest 0.1 mm (100 micron).



Source: National Waterwell & Drilling Association of Australia

Figure 1 Example of Gravel Pack Design

To sieve analyse a sand sample (Refer to ***Figure 29***):

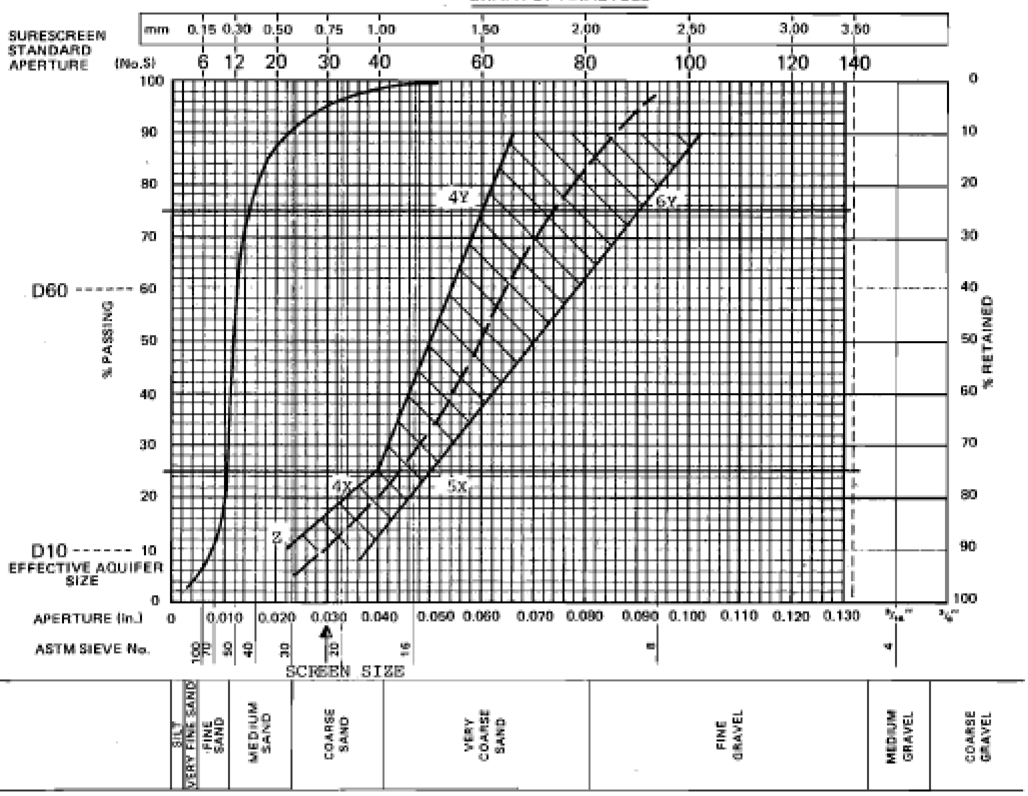
1. Select a sand sample and thoroughly dry it (a clean BBQ plate is ideal for drying). Extreme heat should be avoided since it may cause breakage of the grains. The sample quantity can be any amount, but about 0.8 to 1.0 kg is convenient.
2. Weight the sample.
3. Arrange sand sieves according to aperture, largest opening at the top, smallest at the bottom, and place pan on bottom. Pour in sand sample and shake sieves.
4. Weigh the quantity trapped on each size (largest to smallest) and the bottom pan.
5. Add the individual quantitie and compare the figure with the original smaple weight. If less than 5 % difference) proceed with calculation. If greater than 5 %, look for and correct the mistake, or start again.
6. Complete cumulative percentage retained as per Sieve Analysis sheet.
7. Plot sieve size versuscumulative percentage passing on Sieve Analysis sheet.

SIEVE ANALYSIS

TOTAL SAMPLE WEIGHT (gms)				
ASTM	APERTURE		CUMULATIVE	
SIEVE No.	in.	mm	WT. RETAINED (gms)	% RETAINED
3/8"	0.375	9.53		
4	0.187	4.75		
8	0.094	2.38		
16	0.047	1.19	9	1
20	0.033	0.84	35	4
30	0.023	0.60	78	9
40	0.016	0.42	183	21
50	0.012	0.30	409	47
70	0.008	0.21	765	88
100	0.006	0.15	810	93
TRAY			870	100

SUGGESTED SCREEN SLOT 0.60mm
% RETAINED 90% of pack material

GRAPH OF ANALYSES



Source: National Waterwell & Drilling Association of Australia

Figure 29 Example of Sieve Analysis Sheet

SECTION 3
SIMPLE GRAVEL PACK DESIGN
Surescreen Pty. Ltd. — Brisbane, Queensland

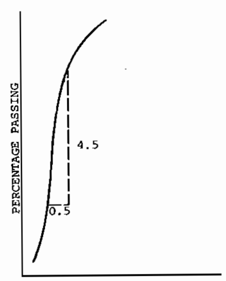
The methods of design and placement of a gravel pack in a tubewell are common points of discussion and contention between drillers and consultants alike. Most common methods of design can be complex and are more readily suited to be performed in an office or laboratory while in essence many designs must be carried out in the field by rig operators who must take into consideration the available pack materials, etc.

The result of such infield simplified design may be open to theoretical criticism although we consider it represents, on many occasions, the only practical answer.

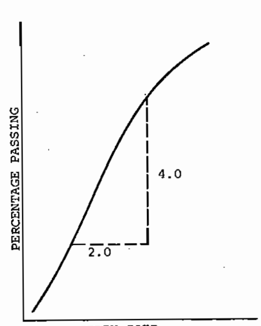
Following is an article prepared by Mr Graeme Port, Senior Engineer, Groundwater Section of the Water Division, Department of Transport and Works, Northern Territory, Australia. The original article has been slightly modified for use with "Surescreen" Sieve Analysis sheets. We consider this article describes a method of pack design that will be found helpful to all sectors of the well drilling industry.

The size and grading of the gravel pack and screen size are directly related to the size and uniformity of the aquifer material. Hence the first step in the design of a gravel pack is to sieve analyse the aquifer material.

Consider the following analyses:



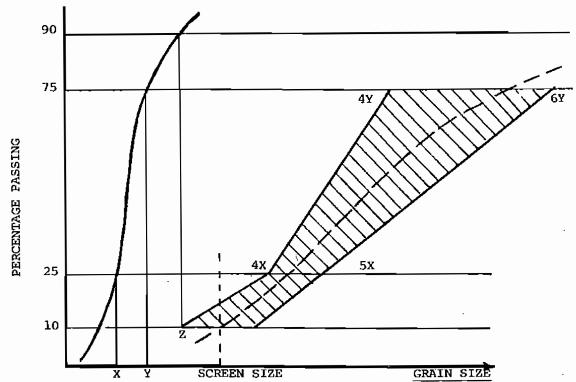
Analysis (a)



Analysis (b)

Analysis (a) has an arbitrary "Slope Ratio" in the major section of the curve of about 0.5 : 4.5. This type of sand should be gravel packed. Analysis (b) has an arbitrary "Slope Ratio" of about 2 : 4 and is suitable for normal screening and development. In general, a curve slope ratio of less that 1 : 4 indicates that gravel packing will produce a better tubewell.

Right, let's consider that the driller has found a sand aquifer, conducted a sieve analysis and arrived at a graph similar to Analysis (a) preceding. THE STEPS NECESSARY TO DESIGN A GRAVEL PACK ARE AS FOLLOWS:



1. Read off the 25% and 75% grain size values of the percentage of material passing and multiply them by 4 and 5, and 4 and 6 respectively.

Plot these results on the graph.

2. Draw connecting lines through 4X and 4Y and 5X and 6Y.
3. Transfer the position of the 90% passing to the 10% passing position for the same graph size. This point then becomes Z.
4. Complete the line 4Y – 4X – Z.

An envelope has now been defined (shaded area). The gravel pack analyses should fall within this envelope (except at its extreme ends). Search around for suitable rounded gravel which will fall within this envelope or can easily be adjusted (by addition **or subtraction** of sand or gravel) into the envelope, e.g. broken curve — natural gravels of the **ideal** type are difficult or time consuming to find, **hence the envelope.**

5. Select a screen size to pass 10% of gravel pack and round **up** to nearest 0.1mm (100 micron).

To sieve analyse a sand sample.

1. Select a sand sample and thoroughly dry it (a clean BBQ plate is ideal for drying). Extreme heat should be avoided since it may cause breakage of the grains. The sample quantity can be any amount, but about 0.8 to 1.0kg is convenient.
2. Weight the sample.
3. Arrange sand sieves according to aperture, largest opening at the top, smallest at the bottom, and place pan on bottom. Pour in sand sample and shake sieves.
4. Weigh the quantity trapped on each size (largest to smallest) and the bottom pan.
5. Add the individual quantities and compare the figure with the original sample weight. If less than 5% difference (5% of one kilogramme is 50 grammes) proceed with calculation. If greater than 5%, look for and correct the mistake, **or start again.**
6. Complete cumulative percentage retained as per attached Sieve Analysis sheet.
7. Plot sieve size versus cumulative percentage passing on Sand Analysis sheet.

SUGGESTED SCREEN SLOT 0.60mm

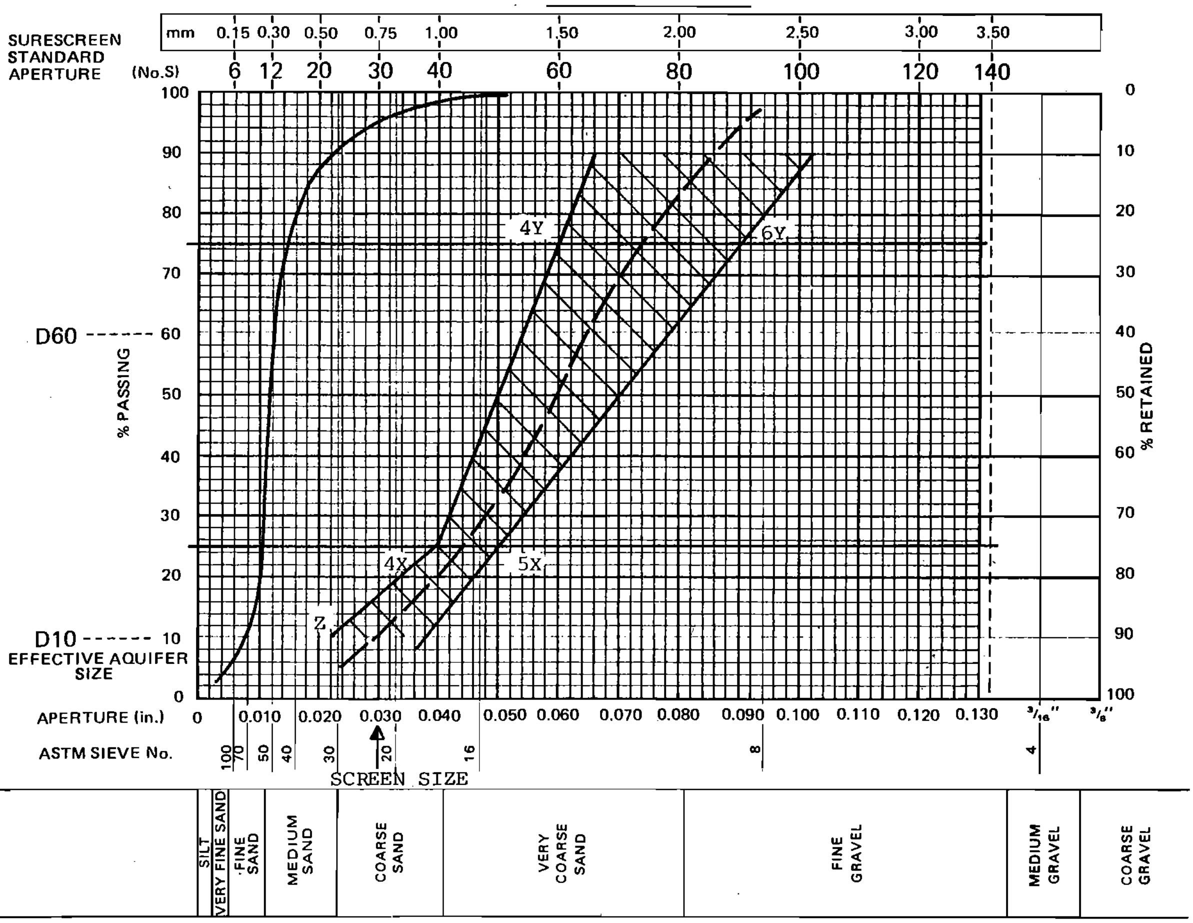
% RETAINED 90% of pack material

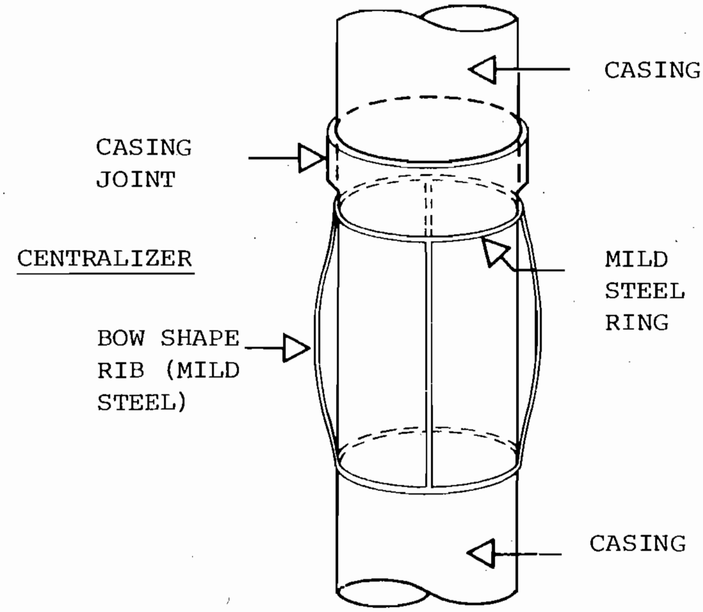
SIEVE ANALYSIS

TOTAL SAMPLE WEIGHT (gms)

ASTM SIEVE No.	APERTURE in.	APERTURE mm	CUMULATIVE WT. RETAINED (gms)	CUMULATIVE % RETAINED
3/8"	0.375	9.53		
4	0.187	4.75		
8	0.094	2.38		
16	0.047	1.19	9	1
20	0.033	0.84	35	4
30	0.023	0.60	78	9
40	0.016	0.42	183	21
50	0.012	0.30	409	47
70	0.008	0.21	765	88
100	0.006	0.15	810	93
TRAY			870	100

GRAPH OF ANALYSES





CONSTRUCTION NOTES

1. Casing and screens should be fitted with centralizers to ensure an even distribution of the pack material.
2. Screens should be held under tension to avoid distortion of slot geometry while gravel is placed.
3. Suitable pack thicknesses (mm)

Screen Diameter (approx)	Pack Thickness (approx)	Tubewell Diameter per metre of Well (M^3)	Volume of Pack Material
100	50	200	0.024
150	60	270	0.040
200	80	360	0.070
250	100	450	0.110

4. Quantity and placement of gravel pack.

A sump should always be provided (except for very long screen). 250mm to 1 metre is adequate.

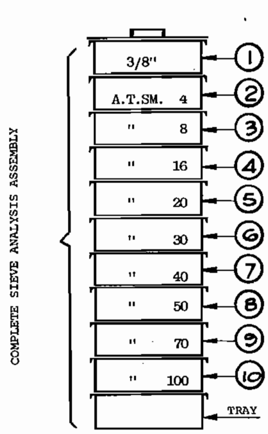
* Gravel should continue above the screen to allow for slumping & development sand losses in the aquifer.

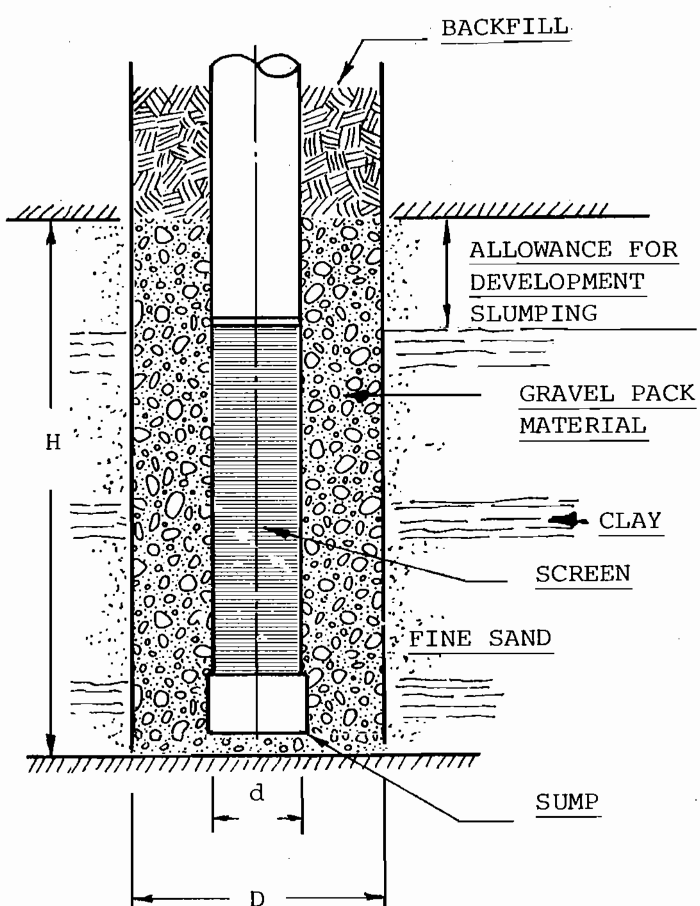
Quality of gravel (volume)

$$= \frac{\pi}{4} (D^2 - d^2) \times H$$

D, d, and H in metres will give a final volume in cubic metres.

(A 10 litre bucket holds 0.01 cubic metres)





Technical Area: 7 Gravel Packing

Item: 7-2 Calculation of gravel volume

1: Objectives

To be able to explain and advise for how to calculate gravel volume for the proper preparation on site.

2. Contents

- Calculation of annular volume
- Calculation of gravel volume

3. Teaching Methods

(1) Explain how to calculate annular volume.

(2) Explain how to calculate gravel volume.

4. Materials

7-2M1 DDCA's Manual for Drilling Works

5.2 CALCULATION OF GRAVEL VOLUME (TA CODE 7-2)

Drillers are required to acquire the calculation method of the volume of gravel including the safety factor to be considered according to the conditions of each borehole. The miscalculation of the gravel volume will bring about the interruption of the drilling work. Furthermore, insufficient volumeof the gravel can be the cause of the turbidity of the pumped water after the delivery to the client.

This section gives an example of the gravel calculation for a borehole design shown in ***Figure 30***. The borehole was drilled down to 100 m and casing was planned to be installed down to 90 m. The top of screen is 40 m and the gravel is to be packed up to 30 m from the ground level. The volume of the gravel is calculated as described below:

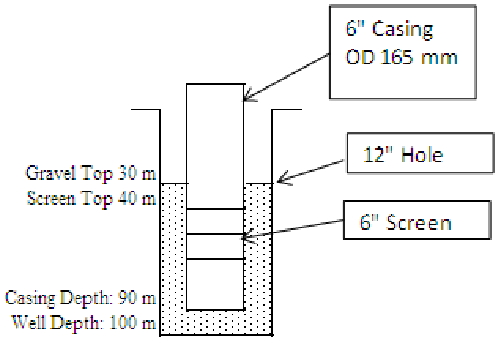


Figure 30 Example of the Gravel

1) Bore Volme

<u>12" Hole</u>

3.14 x (12 x 25.4)^2 /4,000

72.9 L/m

<u>6" PVC Casing OD 165 mm</u>

3.14 x 165^2/4,000

21.4 L/m

2) Annular Volume

<u>Between 12" Hole and 6" PVC Casing</u>

72.9 L/m - 21.4 L/m

51.5 L/m

3) Gravel Volume at the Bottom Uncased

72.9 L/m x (100 m - 90 m) x 1.2 (Safety Factor)

874.8 L

4) Gravel Volume In Annulus between 12" Hole and 6" PVC Casing

51.5 L/m x (90 m - 30 m) x 1.2 (Safety Factor)

3,708 L

5) Total Gravel Volume

874.8 L + 3,708 L

4,583 L

The gravel is to be packed in two parts of the borehole, i.e. the uncased bottom from 90 m to 100 m and the annular space between 12” hole and 6” PVC casing. With the consideration of the enlargement of the drilled hole according to the geological conditions, safety factor of 1.2 is taken. The total gravel volume is calculated as 4,583 L.

Technical Area: 7 Gravel Packing

Item: 7-3 Gravel packing

1: Objectives
To be able to explain and advise for gravel packing procedures and precautions to prevent from failure of packing.

2. Contents
- Gravel packing procedures
- Gravel volume measurement
- Precautions during gravel packing
- Measurement of gravel top
- Precautions after gravel packing

3. Teaching Methods
(1) Explain procedure of gravel packing and precautions for works using gravel packing procedure.
(2) Explain how to control gravel volume at quarry and on site using gravel packing procedure.
(3) Explain how to measure depth of gravel top using gravel packing procedure.
(4) Explain precautions after gravel packing especially for descente of gravel during and after well development and pumping test, using gravel packing procedures.

4. Materials
7-3M1 DDCA's Manual for Drilling Works

5.3 GRAVEL PACKING (TA CODE 7-3)

5.3.1 GRAVEL PACKING PROCEDURES

When the well assembly is successfully installed into the borehole and the assembly is still hanging in the hole, the annular space between casing and screens and the borehole wall has to be filled with filter gravel. The filter gravel is also called gravel pack or formation stabilizer. The gravel is normally well graded in relation to the grain size of the aquifer material and is to filter the entering groundwater and holding back fine material from the formation to enter the well. For borehole drilled into rock formation, a gravel pack with a grain-size of 3-5 or 3-6 should be installed.

Figure 31 Installation of Gravel Pack

The volume of the gravel to be poured into the well has to calculate accurately. The gravel pack shall be installed at least 10 m above the depth of the highest screen. The drilling diameter of 8 ½" equals a volume of 36.59 l/m. The volume of the PVC pipe with a diameter of 165 mm equals 21.37 l/m has to be deducted from the volume of the drilling diameter. The volume of the annular space comes then to 15.22 l/m. One sack of filter gravel has a volume of about 30 l. With one bag of filter gravel almost 2 m of annular space between pipes and borehole wall can be filled.

Figure 32 Measurement of Gravel Top

It is always good practice to have some 20 % more gravel on site than calculated, because some parts of the formation could have washed out fractures or has been caved out by the drilling process.

The installation of the gravel has to be done slowly and in careful manner to allow the gravel to pour into the borehole with a most even flow rate (See ***Figure 31***). This is to avoid bridge building of the gravel pack, which can have serious results, when not noticed and corrected. Should a gravel bridge being developed, then pump with some pressure clear water into the well pipes, which will enter through the screen openings into the annular space and will lift up the gravel bridge and allow it to settle down.

During the pouring of gravel mea sure the gravel level from time to time to avoid overfilling and bridging.

Figure 33 Installation of clay pellets

After the installed level of the gravel pack has been confirmed by measuring (See ***Figure 32***) and after allowing for certain additional time to have been settled fully, a clay sealing is installed on top of the gravel pack (See ***Figure 33***).

There are commercial clay (bentonite) pellets available, which are poured into the annular space the same way as the gravel has been installed. When the clay pellets are coming into contact with water, they are expanding their volume (of up to 45%) and therefore sealing off the annular space completely. The sink velocity of clay pellets is about 25-30 m/min.

A clay layer in the annular space of about 3 m should be sealing off the aquifer formation against any kind of surface water, which could contaminate the fresh water of the aquifer.

As described earlier, also the installation of the clay sealing has to be done slowly and carefully to avoid bridging of the material.

Technical Area: 8 Well Development
Item: 8-1 Well cleaning after drilling

1: Objectives To be able to explain and advise for several well cleaning methods to be selected according to well conditions, such as bailing, swabbing, air-lifting etc.
2. Contents - Several well cleaning method
3. Teaching Methods (1) Explain different methods of well cleaning using manual. (2) Explain procedures and precautions of well cleaning after drilling using well cleaning procedure.
4. Materials 8-1M1 DDCA's Manual for Drilling Works

6 WELL DEVELOPMENT (TA CODE 8)

6.1 WELL CLEANING AFTER DRILLING (TA CODE 8-1)

After the well-construction has been completed and the surface cementation could be hardened for more than 24 hours, the water well should be developed.

The well was dug into the ground and while the water well was completed, the surroundings of the well became certainly disturbed by the drilling process. Well development is the operation to re-generate the previous free-flow situation of the groundwater, in spite the fact that well pipes and artificial filter gravel has been installed into the ground. The development and pumping test team shall be equipped with the following equipment:

- An air-compressor with 8 bar pressure and 125 l/s air-volume
- Air injection pipe, which for 4” to 6” wells is usually a PE hose with a diameter of 40 mm to 50 mm and a length of 100 m with connection subs to the air-lift tool and to the compressor
- Airlift-tool, which is generally a metal pipe with diameter of 40 mm as well, and is Closed at the bottom end and having about 40 holes of diameter 4 mm around the length of the circumference of this pipe
- water level indicators with a length of 150 m
- 1 metal bucket with a content of 20 l for measurements of water discharge rates
- 1 outflow pipe of 1 m length with yield adjustment valve
- 1 Pick Up truck for transportation of personnel and material

There are various well development procedures carried out due to special requirements, special hydro-geological situation, well diameter and depth of the wells. For the rather shallow and slim wells drilled with depths of 100 m and 6” PVC well assembly installation with 8 ½” drilling diameter in hard rock formation only, a direct airlift procedure without the use of special conductor pipes, will be sufficient(***Figure 34***). The fine material can be removed from the fractures or contact zones (aquifers) and from the gravel pack. The development normally takes duration of 4-8 hours, which can be prolonged until the well will be free of sand. Compressed air to develop wells is widely used in unconsolidated, loose, sedimentary formation, as well as in hard rock formation.

Figure 34 Development by Single-Tube Air-Lifting

In air surging (or flushing) the air is injected into the well directly through a single air injection pipe (the well pipes are then quasi conductor pipes) to lift the water to the surface. When the water reaches the top of the casing on the ground, the air supply is shut off, allowing the aerated water column to fall. Air lift pumping (continuous airlifting) is used to pump the well periodically to remove fine material from the screen, gravel pack and from the borehole.

Air development should begin by determining that the groundwater can flow freely into the screen. Application of too much air volume into the borehole, when the screen and formation are still clogged by fine material can result in a collapsed screen. So in the beginning of air development the initial pumping rate has to be minimized and the air-injection pipe should be placed at a rather shallow submergence. Once the uninhibited flow of groundwater into the screen has been established, the injection pipe can be lowered close to the bottom of the well. Before blowing any water out of the well with a sudden large injection of air, the airlift should be operated at a reduced rate.

Airlifting from the well has to continue until the water is virtually free of sand. Normally the entire length of the screens has to be developed. The air-injection pipe is raised through the screen length by certain intervals. From time to time and at least at the end of the development the injection pipe has to be lowered again to the bottom of the well to blow out the last fine material which has been accumulated in the sump (sedimentation) pipe on top of the bottom cap.

Patience, intelligent observation, and the right tools are requested to develop a well correctly. Well development is not expensive, considering the often remarkable results that can be obtained in improving yields and eliminating sand- and fine material pumping. Similarly, aquifer development is often overlooked an effective way to increase yields substantially.

For the other various methods of the development, please refer to Section 13-2.

Technical Area: 8 Well Development

Item: 8-2 Single-tube method air-lifting

1: Objectives

To be able to explain and advise for single-tube method air-lifting which is popular method.

2. Contents

- Principles of single-tube method air-lifting
- Advantage and disadvantage

3. Teaching Methods

(1) Explain princiapal and procedures of single-tube air-lifting using manual.

(2) Explain advantage and disadvantage of single-tube air-lifting using manual.

4. Materials

8-2M1 DDCA's Manual for Drilling Works

6.2 SINGLE TUBE METHOD AIR LIFTING (TA CODE 8-2)

There are two major measures for air-lifting, i.e. single tube method and double tube method. As shown in ***Figure 35***, single-tube method is very simple and does not require very complicated equipment. However this methods transmits its hydraulic force directly to the casing, screen pipes. And sometimes, it damages the pipes, especially when the well depth is deep and water level is shallow. When it is applied. Installation depth of the air nozzle shall be gradually increased to decrease the shock upon the commencement of the air-lift pumping.

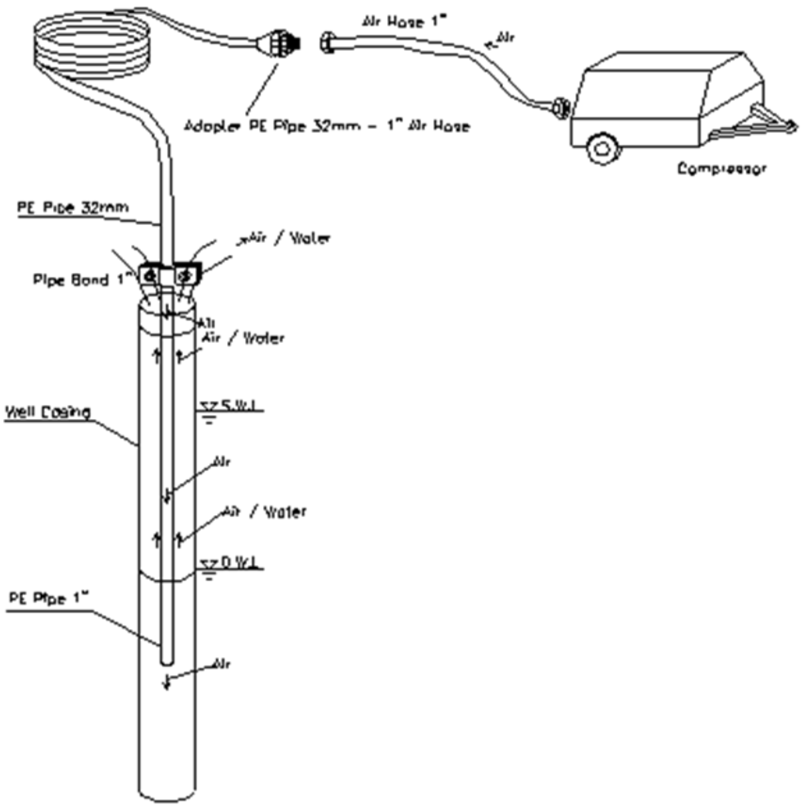


Figure 35 Single Tube Air-Lifting Method

Technical Area: 8 Well Development

Item: 8-3 Double-tube method air-lifting

1: Objectives

To be able to explain and advise for double-tube method air-lifting which is more safe methods than single-tube one.

2. Contents

- Principles of double-tube method air-lifting
- Advantage and disadvantage

3. Teaching Methods

(1) Explain princiapal and procedures of double-tube air-lifting using manual.

(2) Explain advantage and disadvantage of double-tube air-lifting using manual.

4. Materials

8-3M1 DDCA's Manual for Drilling Works

6.3 DOUBLE-TUBE METHOD AIR LIFTING (TA CODE 8-3)

The double-tube method requires more complexed equipment compairing to the single-tube method (See ***Figure 36***). However, there are several advantage for this mehod as follows:

- The shock upon the commencement is less than the one of the single tube method. As the air going up between the outer educator pipe and the inner air pipe.
- It is possible to measure the discharge rate and the dynamic water level if the proper air-lift manihold is used.

The disadvantage is that the crane truck is necessary to handle the pipes, as steel pipes are needed. The selection between the single-tube method and the double-tube method is examined according to the well design and geological conditions.

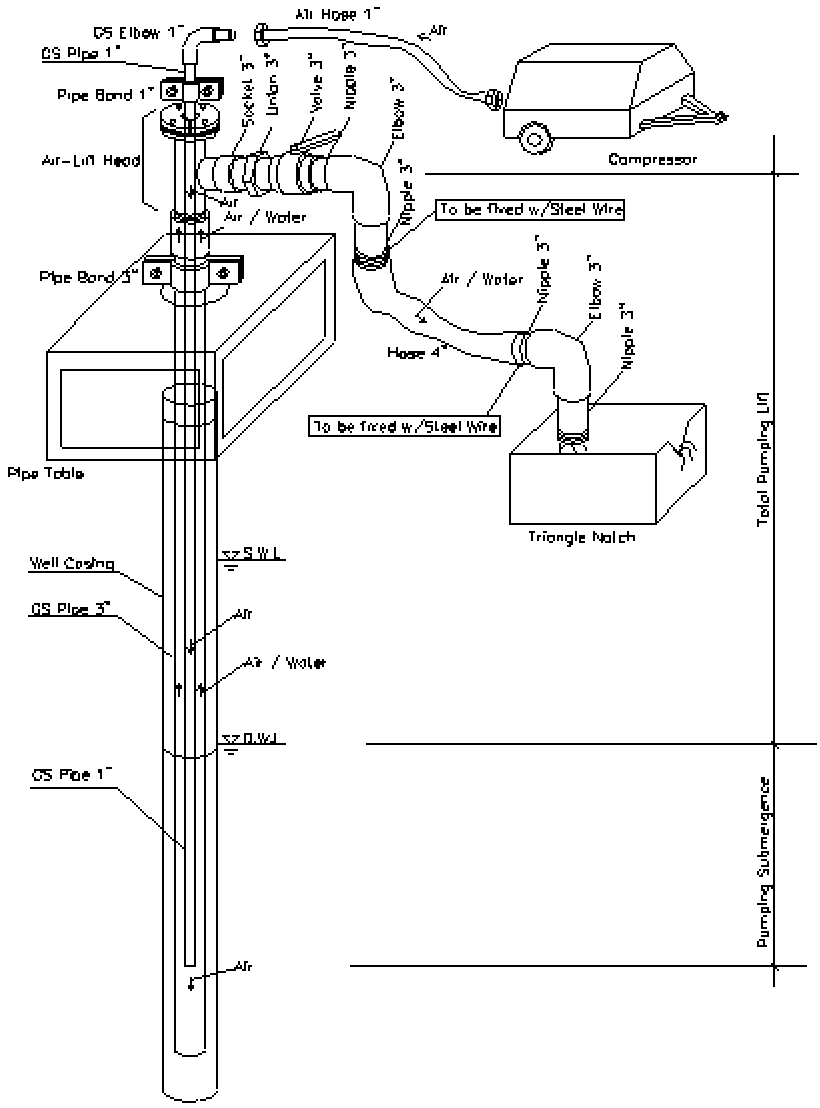


Figure 36 Double-Tube Air-Lifting Method

Technical Area: 9 Back-Filling & Surface Cementing

Item: 9-1 Back-filling

1: Objectives
To be able to explain and advise for procedures of back-filling.

2. Contents
- Back-filling procedures

3. Teaching Methods
(1) Explain procedure and precautions of back-filling using manual and MoW's drilling standard.

4. Materials
9-1M1 DDCA's Manual for Drilling Works

7 BACK-FILLING&SURFACE CEMENTING (TA CODE 9)

7.1 BACK-FILLING (TA CODE 9-1)

After having confirmed the top of the clay sealing by measurement, the annular space on top of the clay sealing has to be backfilled with drill cuttings up to a depth of 5 to 10 m below ground surface as required by the specification. It is not allowed to backfill using organic material. Also this backfilling has to be carried out slowly and carefully.

Water Resources Division (WRD) of Ministy of Water prepared the government specifications and regulations applicable to water well drilling and installation. The work specification of back filling is shown in this document. The document is distributed to all government agancies and private drilling companies which have registered to the drilling permit. The application of this document is necessary for DDCA to duly follow it. The full document is shown in ***Figure 37***.

TO: ALL GOVERNMENT AGENCIES, PRIVATE WATER WELL DRILLING COMPANIES, CONTRACTORS AND NON-GOVERNMENTAL ORGANIZATIONS

GOVERNMENT SPECIFICATIONS AND REGULATIONS APPLICABLE TO WATER WELL DRILLING AND INSTALLATION IN TANZANIA MAINLAND

1. All water well drilling operations in the country are to be undertaken by registered companies, contractors and NGOs with a water well drilling permit and certified drillers.
2. A Water Well Drilling Permit will be issued to a registered company, contractor, executive agency or NGO upon satisfying the following requirements:
   (i) Making application letter listing equipments, drill rigs and accessories as well as CVS of personnel should be attached.
   (ii) Physical inspection of the listed items and scrutinizing of personnel by Officers from the Ministry of water, Water Resources Division.
   (iii) Certification of drillers.
   Upon satisfying the Ministry requirements, a water well drilling permit will be issued.

   The Drilling Water Well Permit is of six months or one (1) year duration and is renewable upon continuing to meet the above requirements and showing satisfactory performance in the past year.
3. Any registered company, public executive agency or NGO with Ministry Water Well Drilling permit before embarking on water well drilling will make an application and be issued with Borehole Identification Number (s) for new water wells to be drilled.
4. No drilling activity in the country is to be undertaken without a Hydrogeological and Geophysical survey, the Technical Report of which must be submitted to the Basin Water

Figure 37 Government Specifications and Regulations Applicable to Water Well Drilling and Installation Method (1/4)

Officer of the respective Basin and a copy to the Ministry of Water, Water Resources Division.

5. Upon submission of the said Hydrogeological and Geophysical Technical report, a Water Well Drilling Clearance Permit will be issued by the Basin Water Officer to the prospective client. No client will be allowed to have a water well drilled in his/her property without such a permit.. A clearance permit will be given within seven days after submission of the Technical report.
6. Each new water well must be assigned an identification number and its geographical position given in UTM co-ordinates where possible, previously given to the recommended borehole site, and should not under any circumstances be changed by the driller.
7. On completion of the water well, the drilling technology to drill the well, changes in diameter, depths to each water strike, as well as the static water level from the ground surface must all be indicated in the completion forms.
8. If the upper section of a well is in unstable rock formation, temporary or permanent cementing/casing must be installed for all exploration or production wells respectively. A proper sanitary seal (or intermediate seals) must be placed to preserve, conserve and protect groundwater resources (its quality) and reservoir pressure potential. This should as well effectively prevent contaminated water to enter and mix with aquifer waters.
9. All boreholes should be well cased and screened to bottom of the borehole and plugged properly. No open boreholes will be allowed/ permitted.
10. In order to ensure that no interference occurs between a new well and existing wells or water body in the vicinity, the distance apart should be at least 300m for unconfined aquifers and 100m for confined aquifers.
11. While drilling, a site Hydrogeologist should properly collect drilling cuttings which will be a representative of depth intervals of 2.0m. Where there is change in rock composition (in between the said interval), this be noted in driller's report. Drill cuttings are kept in sample boxes at the drilling site for lithological logging. However, a small portion (250 gm) of each sample be placed in sample bag, properly labeled and sent to the respective Basin Office for storage and future use. However a water well completion Report detailing the well lithology should be prepared and a copy sent to Hydrogeology Section.
12. If any borehole geophysics is undertaken, all relevant details of the exercise be recorded and a report sent to the Basin Water Officer for further action and again a copy sent to the Water Resources Division.
13. All casings and screens to be installed in a production water well have to be properly chosen to prevent chemical and/or galvanic corrosion and thus guarantee structural integrity of the well, long life and good quality of water.
14. The selection of gravel pack material, with pear size grains and rounded shape has to be

Figure 37 Government Specifications and Regulations Applicable to Water Well Drilling and Installation Method (2/4)

installed into the angular space of the drilled well after having been washed and sieved. The material used has to ensure that well efficiency is not lower than internationally accepted Standards. The thickness of gravel pack installed shall likewise satisfy the same conditions.

15. Internationally accepted methods of well cleaning, development to clear and silt free state of water and step- draw down pumping test followed by a constant rate pumping test of at least 24 hours depending on the yield of the borehole shall be followed. Evaluation of pumping test results shall determine safe production limits and aquifer parameters, though actual abstraction of water shall not exceed levels set by the granted water right for the well. All records should be filled in a Completion form and sent to:-
    (a) Water Resources Division
    (b) Basin Water officer
    (c) Well owner

    Note:

    (i) This information would later be required when well rehabilitation, maintenance or Servicing works are due in years of its utility.
16. Any newly drilled borehole that is not to be put immediately into operation should be securely capped to protect it from vandalism or damage.
17. A water well shall be commissioned and put to its intended use after a step- draw down pumping test followed by a constant rate pumping test of at least 24 hours duration depending on the yield of the water well and immediately followed by a recovery test until initial SWL has been attained and thorough physical, chemical and bacteriological analysis of the water by the Central Water Laboratory or a recognized and qualified laboratory.
18. No groundwater abstraction shall commence until the well owner has been issued with a Water Permit by respective Basin Water Office
19. Water well disinfection must be undertaken after well installations and pumping test has been completed to ensure that the water will be safe for human consumption where internationally accepted standards shall apply as well.
20. Any abandoned drilled water well must be properly and perfectly back filled to protect and conserve ground water resources as well as to eliminate any hazards to human beings and animals.
21. Once a water well has been completed, a Completion Form (copy of which could be obtained from Water Resource Division or Basin Water Officer) must be filled in. To certify correctness of information, adherence to professional's ethics and good workmanship; it should be signed by the responsible Driller and countersigned by the Basin Water Officer or his representative. The Driller or Company shall then produce sufficient number of copies and distribute to the Well Owner, Water Resources Division

Figure 37 Government Specifications and Regulations Applicable to Water Well Drilling and Installation Method (3/4)

and respective Basin Water Officer.

Remarks: Finally, let it be known that groundwater resources are the Nation's Property. They must be conserved and well protected if safe and sustainable water supply in sufficient quantities and acceptable quality is to be guaranteed for present and future generations. To safeguard its waters therefore, the Government will not hesitate to take stern actions against person, institution or company which pollutes, over pumps a water well or leaves an abandoned water hole not properly back-filled. It is the responsibility of any water well drilling company or driller to fully understand National and International Standards applicable in water well drilling and installation practice which are safe to human, livestock, ecology and the environment.

The Ministry of Water has in this respect, through the enacted relevant laws and regulations, the capacity and duty to monitor, supervise, inspect, regulate and control the water well drilling activities by both Government and non-government water well drilling companies in TANZANIA MAINLAND.

Figure 37 Government Specifications and Regulations Applicable to Water Well Drilling and Installation Method (4/4)

Technical Area: 9 Back-Filling & Surface Cementing
Item: 9-2 Surface cementing

1: Objectives

To be able to explain and advise for how to calculate mixing of cement and water and how to place it.

2. Contents

- Calculation of cement volume
- Surface cementing procedures

3. Teaching Methods

(1) Explain how to calculate cement slurry mixing.

(2) Explain procedure and precaution of cemnting.

4. Materials

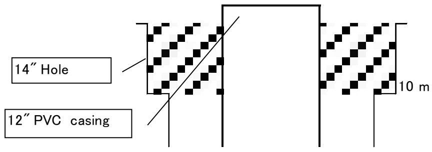
9-2M1 DDCA's Manual for Drilling Works

7.2 SURFACE CEMENTING (TA CODE 9-2)

On the backfilling material, cement slurry has to be installed. The slurry consists only of Portland cement and water. With a consistency of 25 l of water per one bag of 50 kg of cement the specific gravity of the slurry will be 1.8. Allow the cement slurry to harden for at least 24 hours before development works can be carried out in the borehole. ***Table 33*** shows example of cement mixing calculation, while ***Table 33*** shows work procedure of surface cementing.

Table 341 Example of Cement Mixing Calculation

1. Basic calculation of cement slurry



a. Cement type : Portland

SG 3.3

b. Specific gravity of slurry SG 1.8

c. Water ratio 568.2 L/ton CMT

Formula 1.8 = (1000+x) / (1000/ 3.3 +x)

d. Yeild of slurry / ton cement

: 1000/ 3.3 + 568.2 = 871.23 L/ton CMT

e. Yeild of slurry / 50 kg cement

: 50/ 3.3 + 28.41 = 43.562 L/50 kg CMT

2. Volume of Tools

Item	Outside	
	OD(mm)	(L/m)
14"hole	355.6	99.26
12 PVC casing	225	39.74
Annular volume	130.6	59.52

3. Slurry volume

a. Between 14" hole- 12" casing

59.52 L/m x (0 m〜 10 m) 10 m x 1.2 =

Total 714.24 L

÷ 43.56 L

= **16.4 bags of 50 kg cement**

Water 714.24 L / 28.41 L 50 kg cement

= 25.14044 L

1. Mixing of cement slurry

2. Slurry poured into the borehole

3. Fixing clamp on pulled out temporary casings

4. Removal of temporary casing from he well

5. Well casing equipped with temporary well cap

Source: JICA's Water Supply Project in Swaziland

Figure 38 Work Procedure of Surface Cementing

Technical Area: 10 Site Demobilization

Item: 10-1 Precautions upon site demobilization

1: Objectives

To be able to explain and advise for precautions upon site demobilization to prevent from damage to third parties and environment.

2. Contents

- Precautions upon site demobilization

3. Teaching Methods

(1) Explain precautions for site demobilization using site demobilization procedure.

4. Materials

10-1M1 Guidance on Site Demobilization

10-1M1 WORK INSTRUCTION ON PRECAUTION UPON SITE DEMOBILIZATION

(1) Check Items for Precaution upon Site Demobilization

- **Detaching of drilling equipment and camping facilities**
  - The working area should be transformed again as much as possible to its original condition such that wheel track and detaches are back-filled and the land is leveled (See ***Figure 1***).
  - No industrial waste like plastic bags, cement bags or other non-organic waste should be left behind, when leaving of the site after completion of the drilling- and well construction works.
- **Demobilization of Equipment and Materials**
  - The top of casing pipe should be closed by cap such as fitted with steel cover without pad lock, fitted with steel cover with pad lock, fitted with wooden cover, closing by welding it with gas burner. The top of casing should not be remained open to protect contermination of borehole from outside.
  - The schedule of the demobilization should be informed to the client and neighbouring habitats beforehand.
  - The condition of site recovery should be well agreed with the client before starting drilling work.

Figure 1 Site condition backfilled and leveled

(2) Importannce on protection from well contamination

Figure 2 shows counts of common bacteria detected by well type thorough the survey on contamination conditions under the Project in May 2012. The condition such as protection methods of well heads and usage condition (under observation, production or abandoned) was investigated. The survey were conducted to 56 wells in total in Dar es Salaam Region (49 wells), Morogoro Region (4 wells) and Dodoma Region (3 wells). For 33 wells out of the target wells, water quality analysis was carried out. The average number of common bacteria at abandoned wells was significantly higher than those at an observation well and production wells. It seems that abandoned wells are in an environment where common bacteria can easily propagate due to the lack of water inflow from the aquifer by pumping well. At 30 wells (91 %) out of 33 of which the quality was analyzed, fecal coliform were detected. It is supposed that more fecal coliform propagate in the abandoned wells than in observation and production wells. Consequently, it was concluded that aquifer and other production wells would be contaminated by water from such contamination source is concerned.

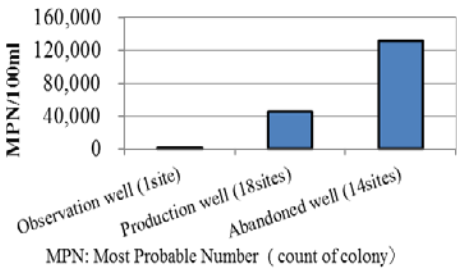


Figure 2 Average of common bacteria at Each Well Condition

Figure 3 shows the average value of ammonia by conditions of well heads. The elevation at unprotected well heads was distinct comparing to those at protected ones. Ammonia contents in groundwater mainly originate from bodies of both plants and animals and/or faces of animals and human. The elevated ammonia contents seem to be caused by inflow of domestic sewerage water from the well head which is improperly protected.

Such contamination can be prevented by proper construction and protection of well heads upon the construction. Therefore, the proper design for well head protection in completion of drilling work is very important.

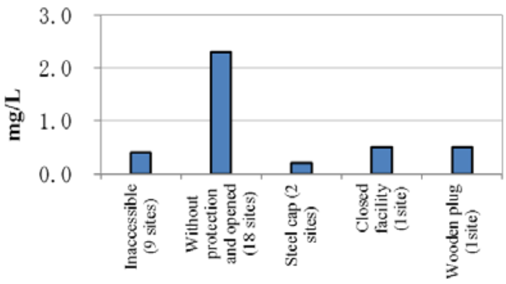


Figure 3 Average of Ammonia by Each Condition of Well Head Protection

Technical Area: 11 Well Investigation

Item: 11-1 Necessary information of well rehabilitation plan

1: Objectives
To be able to explain and advise for information about well, pump and water supply facility is necessary to formulate rehabilitation plan.

2. Contents
- Information of well
- Information of Pump
- Information of Water supply facility

3. Teaching Methods
(1) Explain necessary information to be collected for well rehabilitation related to well, pump and water supply facilities using manual.

4. Materials
11-1M1 Guidance on Necessary Information of Rehabilitation Plan

11-1M1 GUIDANCE ON NECESSARY INFORMATION OF REHABILITATION PLAN

(1) CAUSES OF WELL MALFUNCTIONNING

The typical causes of well malfunctioning are as follows:

- Falling of pump or tools into the well disturbes the installation of another pump
- Deterioration of well equipment i.e. casings screens or gravel
- Malfunctionning of pump
- Malfunctionning of control panel of pump
- Malfunctionning of generator

Many wells are abandoned when the above well malfunctioning happen due to technical and/or economic reasons. Certain well malfunctioning can be resotred if the proper techniques are applied in a reasonable cost.

In order to make a proper well rehabilitation plan, the diagnosis of such well malfunctioning is necessary. Therefore, drillers in charge of the well rehabilitation shall understand the principles of of the various causes of malfunctioning in the respects of mechanics and well structures.

(2) WATER SUPPLY SCHEMES IN TANZANIA

Two major types of water supply schemes with groundwater sources are handpump well and piped water supply schemes. Their typical structures are shown in Figure 1 and 2.

Understanding of the technical specifications of each component is important for the well diagnosis, because in many cases well malfunctioning happens due to the improper design and/or use.

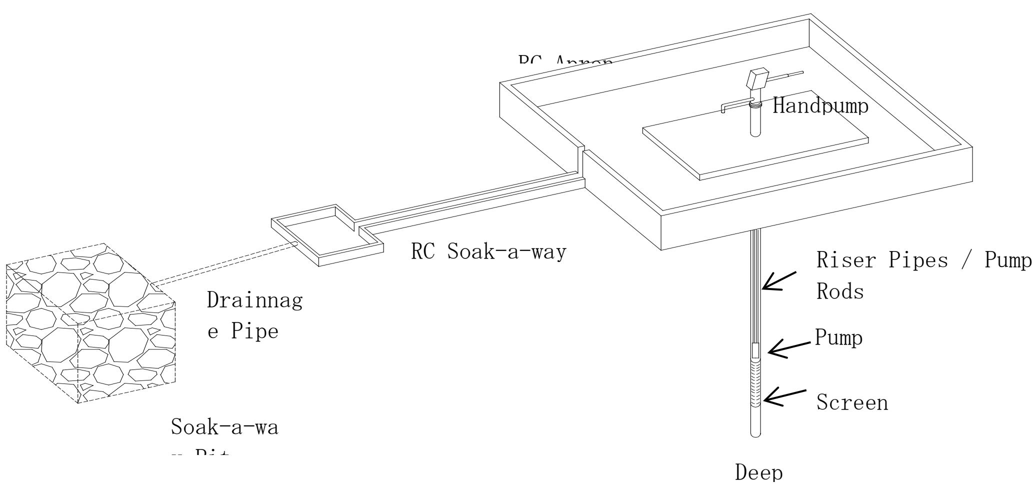


Figure 1 Typical Structure of Handpump Well

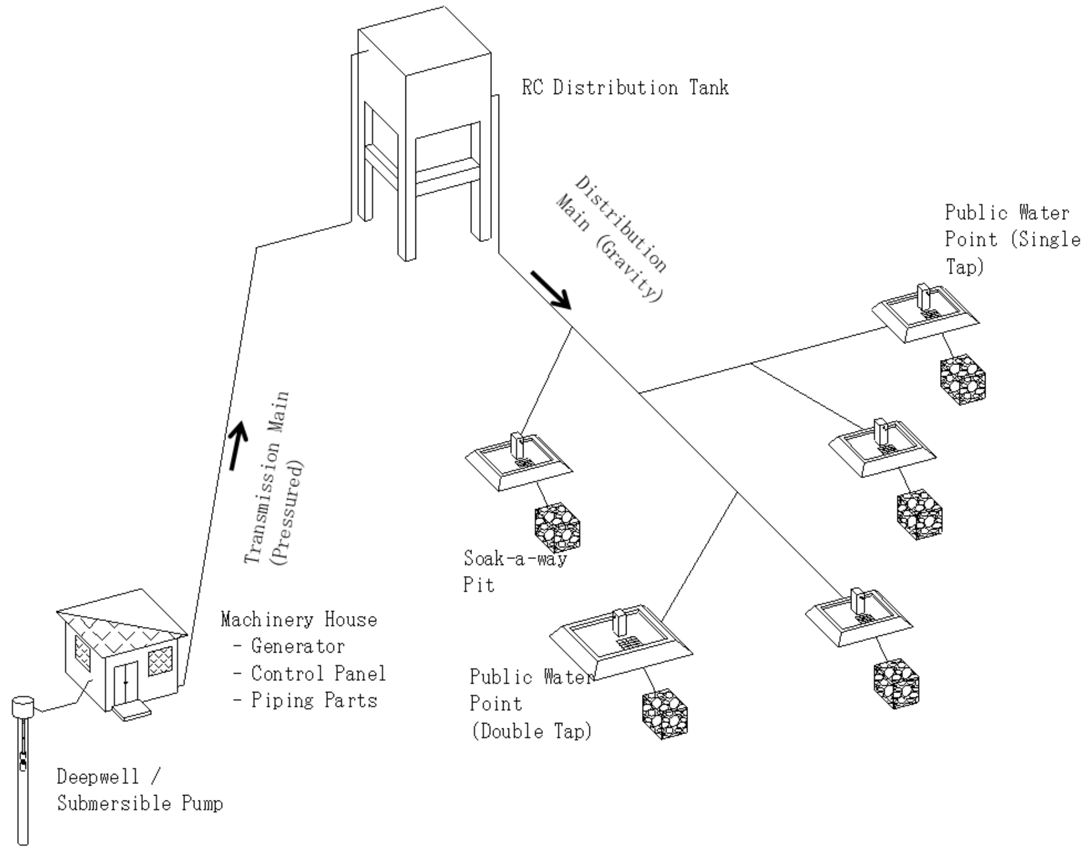


Figure 2 Typical Structure of Piped Water Supply Scheme

1.2.3 COMPONENTS OF PIPED WATER SUPPLY SCHEMES

Generally, piped water supply scheme in Tanzania is composed of the simple component as follows:

(1) Water Source:

Major water source is waterwells equipped with casing, screen, gravel. The casing and screen are made of mild steel, stainless steel, or PVC. The diameter of the casing varies from 4” to 10”. Beside the waterwell for the handpump, the casing diameter is more than 6”.

(2) Transmission Facilities:

For the piped water supply schemes, the water is transmitted to the ground/elevated tank by the diesel well pump or the submersible well pump powered by the diesel engine or the diesel generator.

The pump is manually controlled or controlled by low-level/high-level water sensor in the tank, the pressure switch driven by the ball tap etc.

The trend of the type of the pump is now shifting to the electrical submersible pump.

The galvanized steel pipe, the PVC pipe, the polyethylene pipe are used as the transmission pipes.

(3) Distribution Facilities:

The water is distributed by gravity from the steel/concrete distribution tank to each water tap through galvanized steel/PVC/polyethylene distribution pipes.

(4) Supply Facilities:

From the distribution main and the branch, the water is supply to the users by water taps. Sometimes the water meter is used for each tap or the group of taps for the calculation of the water consumption.

1.2.4 MALFUNCTION OF PIPED WATER SUPPLY SCHEMES

The piped water supply scheme shall keep its design performance in the respect of "Water Quantity (shall be sufficient for the daily demand of the supply area)", "Pressure (Water Head at the water supply points)" and "Water Quality (to be conformed to the water quality standards of Sudan)".

Generally, the piped water supply scheme is delivered to the users, after the confirmation of the appropriateness of the above major parameters through the test operation and the water quality analysis.

The performance of the piped water supply scheme is going to deteriorate naturally after the certain period of use. In case that the proper maintenance and/or rehabilitation is not executed, the performance will continue to deteriorate and the piped water supply scheme will finally come to be unfunctionning.

There are several causes of the malfunctioning of the piped water supply scheme, and in often the case, such causes from different origins combine and then accelerate the deterioration of the piped water supply scheme.

The failures happen on each water supply facilities with the various causes and the phenomena, as shown in the figure below:

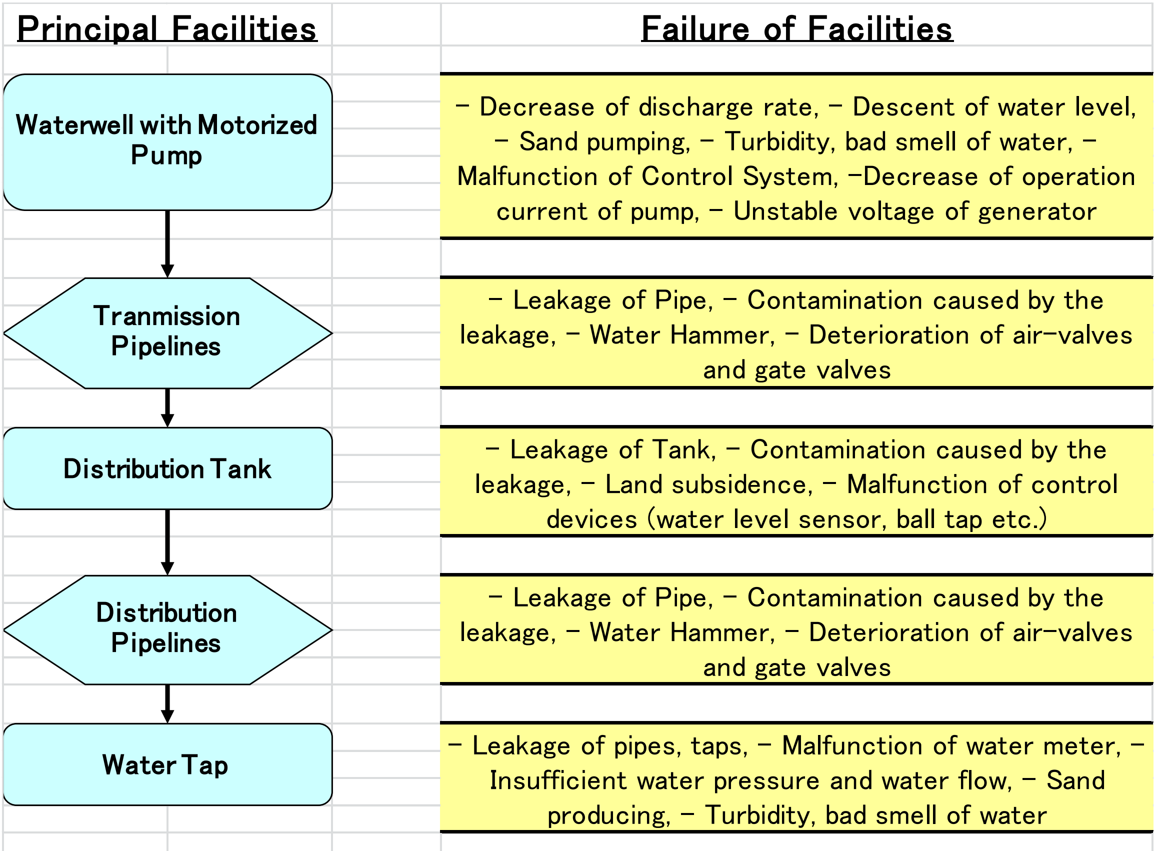


Figure 3 Failure of Each Part of Piped Water Supply System

In the flow of the above figure, the well with motorized pump is the very beginning of the water supply system. Therefore, any problem on the waterwell with motorized pump has a serious effect on the performance of the following facilities.

It is often emphasized that the importance of the electrical and mechanical maintenance of the well (e.g. the pump and the generator). However, the well tends to be considered as "maintenance free" facilities, since its underground conditions are not to be seen to the users. As a result of the use of the waterwell without the monitoring and the maintenance, the deterioration of the well structure proceed to deteriorate and the span of life becomes much shorter than expected in many wells.

1.2.5 Mechanical and Electrical Respects of Well Rehabilitation Plan

The diagnosis of the cause of the failure of well performance shall be carried out in both respects of mechanical and electrical and the well problem. Sometimes it is easy, but, sometime difficult, to identify that the failure of the water producing system is originated from mechanical and electrical reason. Furthermore, the mechanical and electrical failure often originated from the well problem. Please refer to Figure 4 Examples of Diagnosis of Well Failure.

As mentioned above, to make a proper well diagnosis, drillers shall have the adequate knowledge in mechanical and electrical system of pump to identify the reason of the failure. And it is preferable that they have basic skill in simple maintenance and repair of the electrical pump and the generator, though the serious problem shall be handed to the experts.

In case of the mechanical and electrical failure is caused by the well problem, the repeat of the repair-break down process will happen. Therefore well diagnosis by drillers in the respect of the well problems is important to achieve the principal solution of the well failure and also the prolongation of the life span of the waterwell.

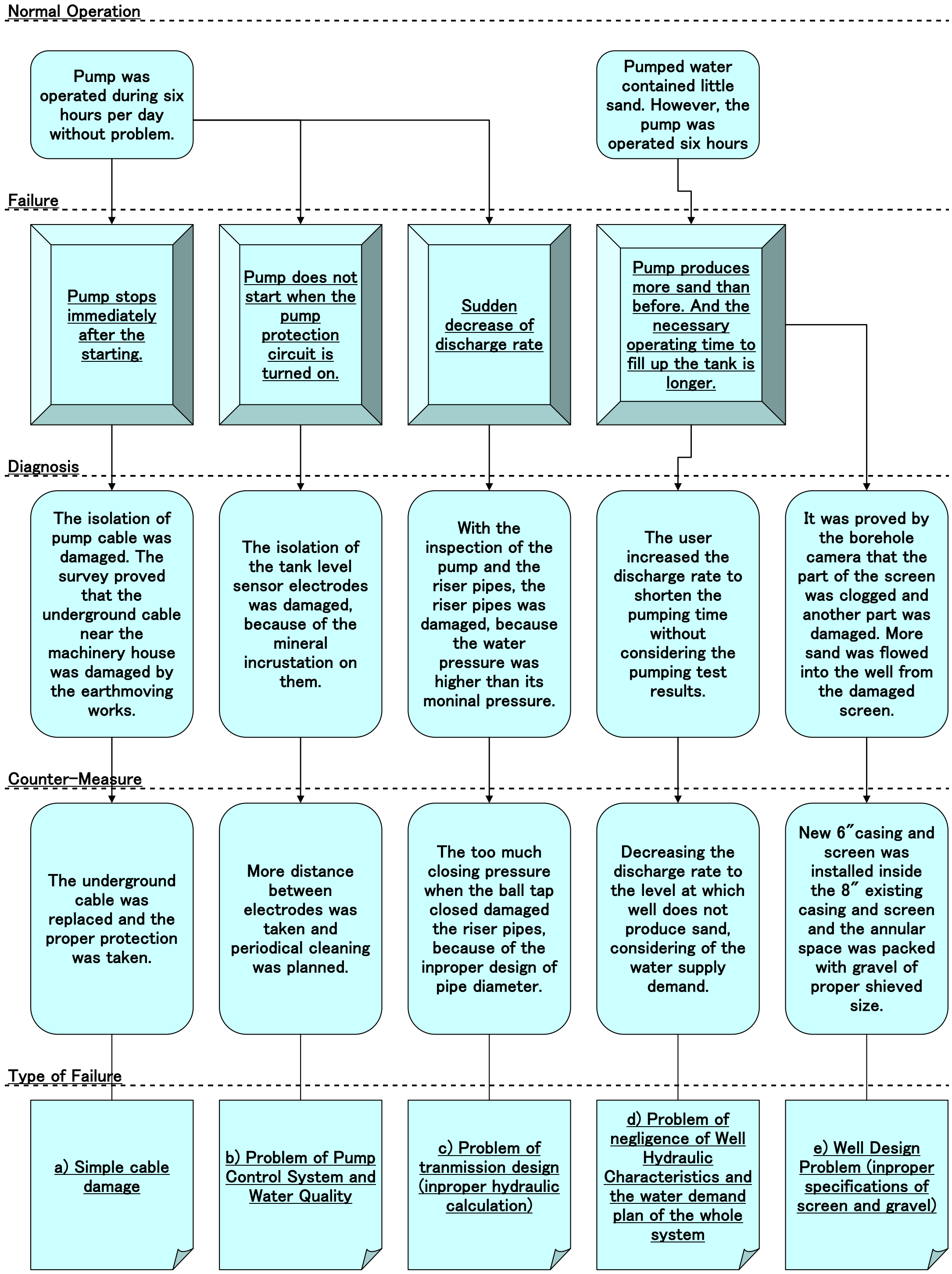


Figure 4 Examples of Diagnosis of Waterwell Failure

1.2.6 FAILURE OF WATERWELL

Drillers shall learn the various phenomena and the causes of the waterwell failure such as the following:

- decrease of discharge rate of waterwell (by chemical incrustation, biofoulding, screen and formation clogging etc.)
- Plugging the formation around the well screen
- Sand pumping
- Collapse of well casing and screen (by corrosion, construction defects etc.)
- Aquifer damage (by overpumping etc.)

Drillers shall learn the above phenomena and their causes and the deterioration processes, in order to improve the accuracy of his well diagnosis, since he shall introduce the most possible conclusion from the limited information which can be obtained from the targeted well.

1.2.7 DATA MANAGEMENT OF REPRODUCING

The proper data management of the water supply scheme shall be ensured before the implementation of the field well diagnosis and rehabilitation plan. The lack of data makes difficult the implementation of the well diagnosis and thus the rehabilitation plan and the implementation cannot be effective.

The records and information indispensable for the proper rehabilitation plan are as listed in Table-2. Unfortunately, in many water supply schemes, such information was lost or not recorded when it was constructed, as the importance of keeping such record had not been recognized. Drillers shall take the following steps to ensure the necessary information for the well rehabilitation plan:

(1) To confirm whether each water supply scheme is with enough information such as shown in Table-2.

(2) If the information is not sufficient, the effort to collect such record shall be taken.

(3) For the new construction of the water supply schemes proper record keeping system shall be established.

(4) For the existing water supply schemes without proper record, the activities of the data reproducing shall be planned and implemented.

These activities shall include the following items:

- For the waterwell

  collection of hydrogeological data around the waterwell, cleaning and test pumping to obtain the current capacity and conditions of waterwell, water quality analysis, observation by borehole camera etc.

- For the pump and generator

  Specification of pump, generator, serial number, setting depth, materials and diameter of riser pipes shall be investigated and shall be recorded.

- For the whole water supply system

  If the water supply design documents are lost, re-design shall be carried out and the renewed operation & maintenance plan of the water supply system shall be based on the proper water supply design. The drawings of the structures and topographical survey may be also to be carried out.

Please refer to Appendix (Apdx-1 to 9) for the various examples of the records concerning the water supply scheme operation.

Table-1 Necessary Items to be kept for Well Rehabilitation Plan

Facility	Record Items
Waterwell	- Drilling Record (well depth, drilled diameter, drilling method, mud agent, geological log, borehole logging, depth of water loss, water strike, water level during drilling etc.)
	- Casing Record (casing diameter, thickness, material, casing depth, casing shoe, centralizer, screen position, opening shape, gravel shieved size, gravel depth etc.)
	- Development Record (development method, air-lift record, water level, water quality, discharge rate)
	- Pumping Test Record (water level, discharge rate, specific capacity, pumping and recovery time, water quality, sand contents etc.)
	- Operation Record (daily record of water level, discharge rate, water quality, sand content etc.)
Submersible Pump and Control System	- Installation Record (speicification of pump, riser pipes, serial numbers of pump and motor, installation design (hydraulic calculation), installation depth, protection and monitoring appurtenances etc.)
	- Operation Record (daily record of current, voltage, discharge rate, pressure, maintenance record etc.)
Generator	- Installation Record (speicification of generator, power supply design(capacity calculation) etc.)
	- Operation Record (daily record of current, voltage, frequency, fuel consumption, maintenance record etc.)
Whole Water Supply System	- Specifications of each facility (waterwell with motorized pump, machinery house, transmission pipeline, distribution pipe, distribution tank, distribution pipeline, water taps), Design documents (demand calculation, hydraulic calculation, work drawings etc) etc.

1.2.8 Well Rehabilitation Plan and Implementation

Under the conditions that the necessary information for well management exists or was reproduced by the investigation activities, the well diagnosis is implemented and the well rehabilitation plan is formulated.

As mentioned above, a well rehabilitation plan can be formulated effectively only in case that the water supply scheme has the sufficient available information to facilitate the accurate well diagnosis.

The process of the well rehabilitation plan shall include the following steps, as shown in Figure 5:

1) Data Provision Stage:

For existing water supply scheme - Collection of the existing data and data reproducing by the well investigation (pumping test, borehole camera, water quality analysis etc.).

For new construction of water supply scheme – establishment of the proper data record.

2) Well Diagnosis and Well Maintenance Plan

The activities of the regular maintenance and the well rehabilitation shall be planned.

For the troubled wells, the proper well diagnosis shall be carried out to select the most suitable rehabilitation measures.

3) Implementation of Well Maintenance & Rehabilitation

According to the well maintenance plan, the activities of well maintenance and rehabilitation works are carried out.

The Well Rehabilitation is achieved sometime with the simple cleaning method by the air-lifting and/or by the pumping. For the more complicated well problem, the several rehabilitation method will be used such as the follows:

- Chemical treatment with acid, chlorine etc. to cope with the incrustation, biofouling etc.
- Physical method, which directly remove the sand sedimentation, incrusted scale, bio-film etc. (bailing, air-lifting, pumping, swabbing, jetting etc.)
- Repair of mechanical failure of casing and screen (plug back cementing, casing replacement, double casing etc.)

The above measures are described in the following chapters.

The process of the well rehabilitation shall be always checked and be improved through the PDCA (Plan-Do-Check-Act) cycle. Furthermore, the feedback of the improvement of the well rehabilitation process shall be provided on the whole process of the water supply scheme construction processes (Planning, Design, Construction, O&M).

Drillers are expected to have an understanding of their role in the field of the well rehabilitation and to device the most suitable system of the well rehabilitation according to each condition of wells.

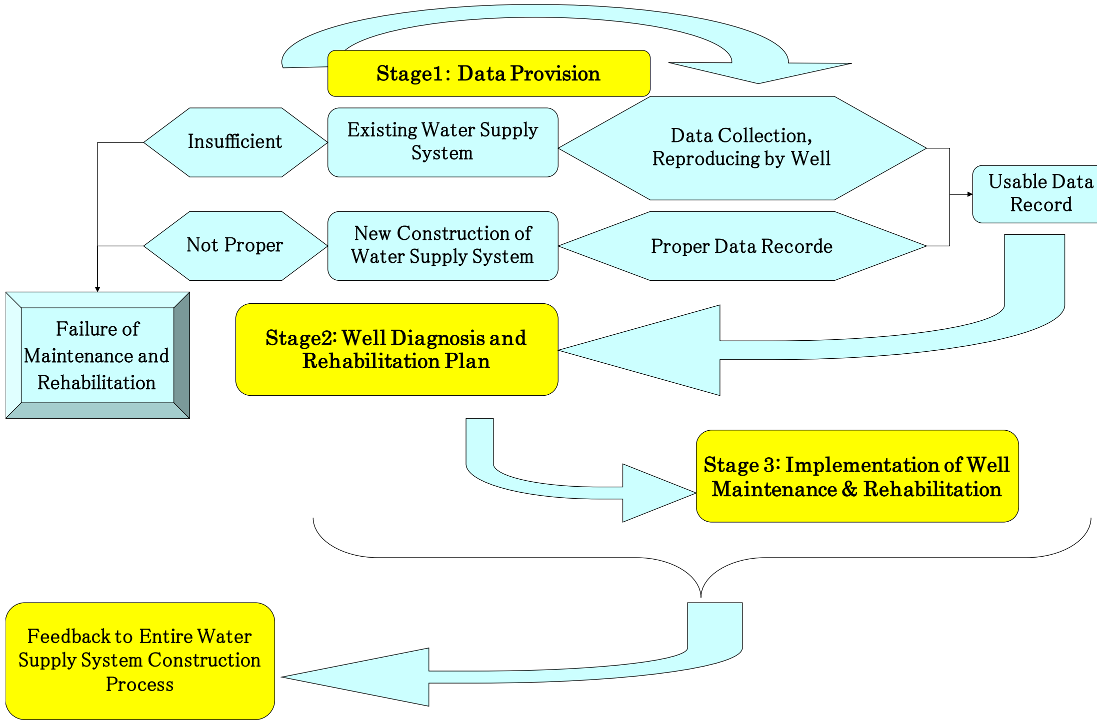


Figure 5 Importance of Data Provision

Technical Area: 11 Well Investigation

Item: 11-2 Well rehibilitation plan

1: Objectives
To be able to explain and advise for necessary contents of well rehabilitation including data provision and work contents.

2. Contents
- Data provision
- Well diagnosis
- Well cleaning
- Pumping test
- Well camera

3. Teaching Methods
(1) Explain purpose and contents of well rehabilitation plan using manual.

4. Materials
11-2M1 Guidance on Well Rehabilitation Plan

11-2M1 WELL REHABILITATION PLAN

Provision of necessary information of the target water supply facilities including water well is important not only for the well rehabilitation plan but also for the usual well maintenance.

For wells without proper records, the following procedures shall be carried out.

- Data Provision
- Preliminary Investigation
- Well Cleaning
- Well Camera
- Pumping Test

- **Data Provision**

  Existing data shall be collected as much as possible in order to formulate the proper well rehabilitation plan. Please see Section 11-1 for the further details.

- **Preliminary Investigation**

  Together with the collection of existing information, the following simple field investigation shall be carried out:

  - Checking the conditions of pump operation, well cover, concrete pad, control panel, power supply, etc.
  - Measuring the static water level, pumping yield and dynamic water level, if pump is operable
  - Measure the water quality by portable field kits for pH, Alcalinity, Iron, Manganese, sand contents etc.

- **Well Cleaning**

  A well shall be cleaned up by means of air-lifting, pumping etc., prior to the use of the expensive equipment such as well camera, pumping test equipment etc. Please see Section 13-2 for the further details.

- **Well Camera**

  Well camera is a useful tool which enable the comprehension of the exact conditions of the inside of the well. Please see Section 13-3 for the further details.

- **Pumping Test**

  A well to be rehabilitated shall be tested by pumping test to grasp the actual capacity of the well. The parameters such as water levels, discharge rate, well loss coefficient shall be estimated and recorded. Periodical records of such parameters are necessary for the proper well maintenance. Please see Section 14 for the further details.

The causes of malfunctioning of water supply schemes are not limited to well problem. As described in Section 1-11, the major causes are the troubles of well, pump control panel and power supply and pipelines. Upon the request of well rehabilitation by a client, drillers shall identify whether the malfunctioning is caused by well problem or other causes. If the cause of malfunctioning is not caused by the well troubles, drillers shall consult to other experts of each field for further detailed well diagnosis.

As a results of the above procedures, the drillers can acquire a picture of the actual status of the well to be rehabilitated. By using such information, well rehabilitation plan shall be formulated. For the detailed methods of well rehabilitation, please refer to Section 13-2.

Technical Area: 12 Tool Fishing

Item: 12-1 Tool fishing plan

1: Objectives
To be able to explain and advise for necessary contents of tool fishing including down-hole investigation and work plan.

2. Contents
- Data collection
- Down-hole investigation
- Fishing plan

3. Teaching Methods
(1) Explain pupose and contents of tool fishing plan using manual.

4. Materials
12-1M1 DDCA's manual of Tool Fishing and Well Rehabilitation

12 TOOL FISHING (TA CODE 12)

12.1 TOOL FISHING PLAN (TA CODE 12-1)

For wells with fallen tools and/or materials which disturb the proper installation of alternative pump, such obstacles in a well shall be at first removed from a well by “Tool Fishing”.

Prior to the formulation of tool fishing plan, the following preliminary investigation shall be conducted:

12.1.1 DATA COLLECTION

- Collection of well and water supply scheme.
- Detailed specifications of fallen materials such as diameters, lengths, shape, materials.
- If the fallen material is a pump, specifications of auxially tools such as riser pipes and cables shall be obtained too.
- The remaining parts of fallen materials are also the important information source. In case the riser pipe of the pump is cut at certain point on the riser pipe, the length of the fallen pump and riser pipes in the well can be calculated by measuring the remaining parts of the riser main. Furthermore, the observation of the cut point is important to estimate the shape of the top of the fallen riser pipe.
- Well structure information such as depth, diameter, length, materials and whether or not production hole is cased.

With the integral analysis of the above information, the proper tool fishing plan shall be prepared.

12.1.2 DOWN-HOLE INVESTIGATION

After the maximum efforts to collect the data, the condition of the top of the fallen materials shall be investigated by following measures:

- Confirm reachable depth by water level sensor
- Confirm reachable depth by pipes or rods
- Run into the hole, investigating device such as plate with nails
- Run into the hole, well camera

From the collected data and the results of the above down-hole investigation, the illustration of the down-hole situation of the fallen material shall be drawn up as shown in ***Figure 1*** and suitable tool fishing plan shall be prepared.

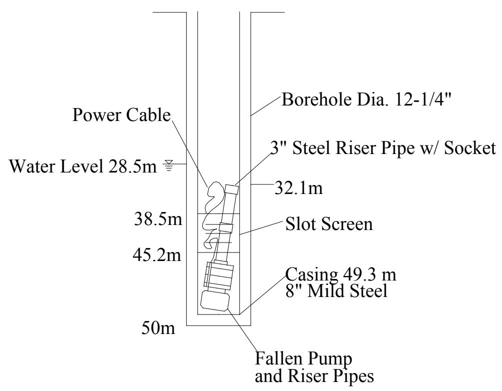


Figure 1 Analysed Image of Fallen

12.1.3 WELL CLEANING

If a well is not cased, collapsed bore wall may be sedimented above and/or around fallen materials. Prior to tool fishing works, such sedimentation shall be removed by the following measures:

(1) Removal of sedimentation above fallen material

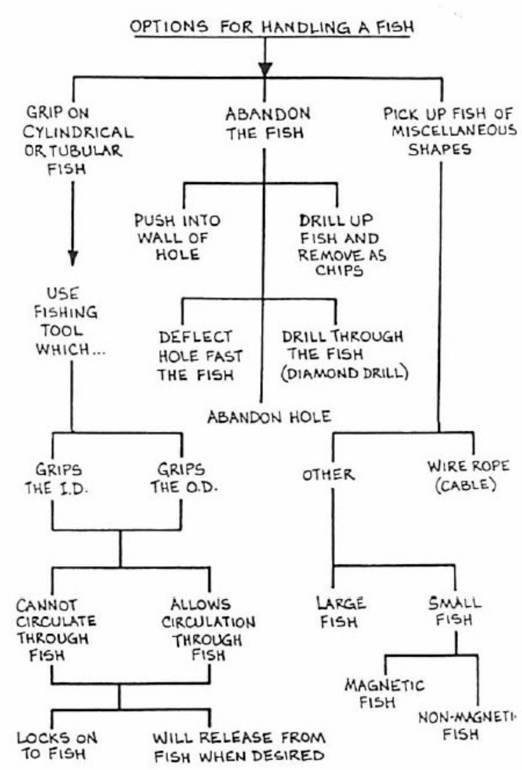
Air-lifting, bailing, reaming with rotary bit etc are used.

(2) Removal of sedimentation around fallen material

Sedimentation shall be reamed by casing pipes. If the fallen material leans one side of the hole, it must be straightened up using spud.

12.1.3 FISHING PLAN

Based on the results of the data collection and the down-hole investigation, the fishing plan shall be planned. This plan shall include the necessary equipment, tools, materials, consumables, work procedures, staff organizations and so on. Proper fishing art and tools shall be selected as well. ***Figure 2*** shows the decision tree of fishing tools.



Source: Australian Driling Industry Trining Committee

Figure 2 Decision Tree of Fishing Tool Selection

Technical Area: 12 Tool Fishing

Item: 12-2 Fishing tools

1: Objectives
To be able to explain and advise for type of several fishing tools and their use.

2. Contents
- Type and use of fishing tools

3. Teaching Methods
(1) Explan various types of fishing tools and their use using manual.

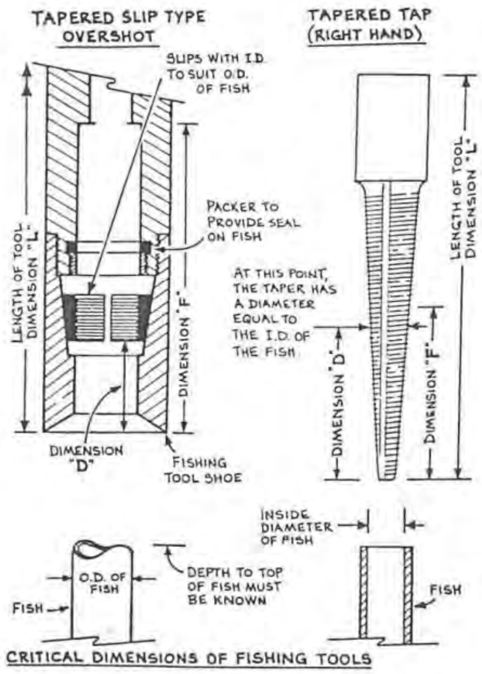
4. Materials
12-2M1 DDCA's manual of Tool Fishing and Well Rehabilitationg
12-2M2 Drilling Chap. 12 P534-P541

12.2 FISHING TOOLS (TA CODE 12-2)

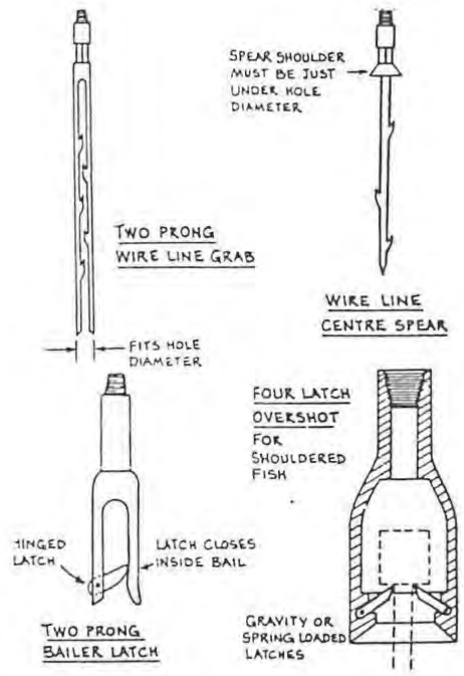
There are many types of fishing tools as shown in ***Figure 3*** and ***Figure 4***. These tools are selected depending on the purpose of each stage of tool fishing works.

Each fishing tool is manufacture for certain range of dimension of fallen materials. It is not possible to keep stock of fishing tools for all types and dimensions of fallen materials.

Therefore, the skills for manufacturing "order-made" fishing tools to be fit to the target fallen material and down-hole conditions is important, too.



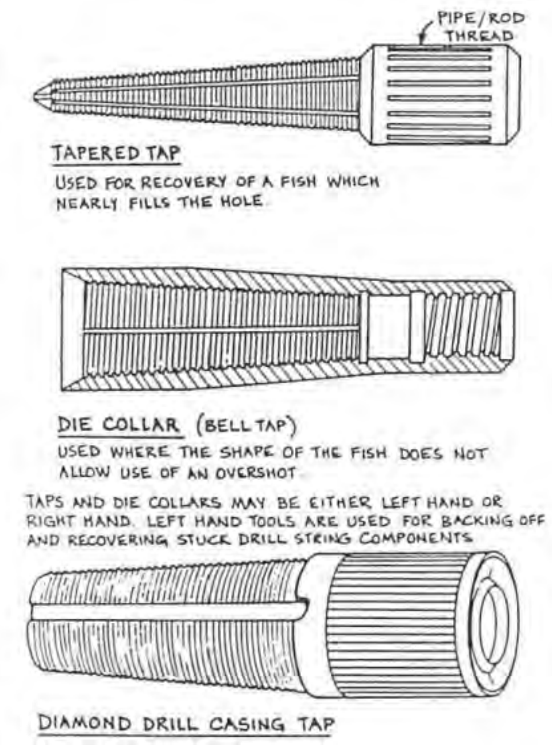
Engaging the Fish



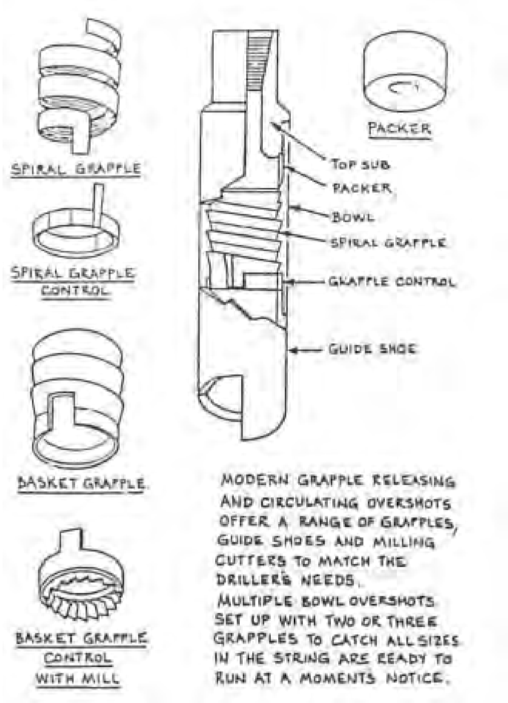
Hooks and Latching Tools

Source: Australian Driling Industry Trining Committee

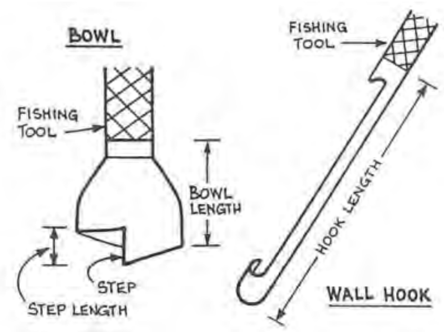
Figure 3 Fishing Tools (1/2)



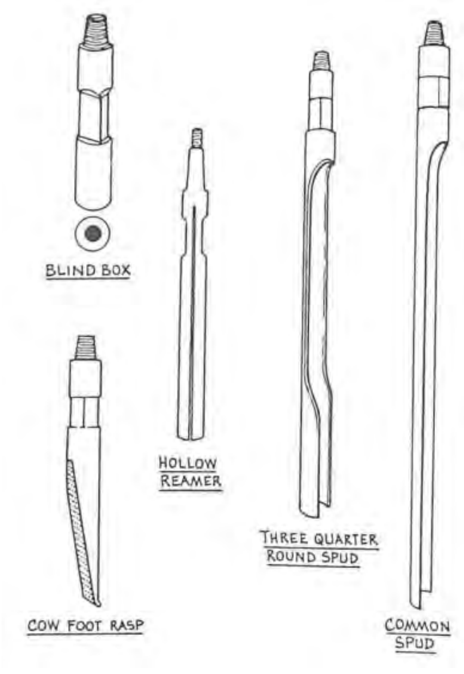
Taps and Die Collar



Grapple Overshot



Tools for Catching



Tools to Straighten the Fish

Source: Australian Driling Industry Trining Committee

Figure 4 Fishing Tools (2/2)

reducing drill string damage (Chapter 3).

Good practices in drill string handling are a major factor in prolonging the life of the string and avoiding failures (Chapter 7). Correct makeup torque, correct positioning of wrenches and slips, and avoiding shock loading all contribute to good performance.

We sometimes hear the jocular remark: "That fellow must be one of the country's greatest experts on fishing jobs; he sure gets plenty of practice". The fact is that a good driller is one who has a greater understanding of "what's happening" down the hole at all times. Because of this understanding, he is more likely to be able to solve the problem of "how to get the fish out of the hole."

The "greatest expert" probably has one thing going for him. He may have the innovative flair to see things from another point of view and thus solve the problem that has confounded everyone else.

Knowledge of "what's happening" when a failure does occur will prevent damage to the top end of the fish. A clean straight hole is more likely to retain the fish in a position that allows easy recovery.

Caved holes and dog-legged holes can cause the top of the fish to be held embedded in the wall of the hole.

Knowledge: size, shape and attitude of fish

In Chapter 10, emphasis was placed on the need for precise records of the shape and dimensions of all tools and equipment run into the hole. When a tool or part of the drill string has fractured, the shape of the fracture on the top side of the break can be examined. This will provide some idea of the shape of the top of the fish.

If the drilling action is allowed to continue after the fracture occurred, the shape of the top of the fish could be considerably distorted. To obtain information about the fish, one of the **down hole inspection** tools (Chapter 9, impression block, downhole camera) should be run.

A down hole inspection tool will also provide information on the attitude of the fish. It may be standing straight up in the centre of the hole; it may be against one side or even embedded in the wall of the hole or lying in a cave.

A driller who is conscious of the possibility that tools or parts of the drill string will be lost down the hole will make up the string so that lost parts of it are more easily recovered. Tools and groups of tools are designed so that:

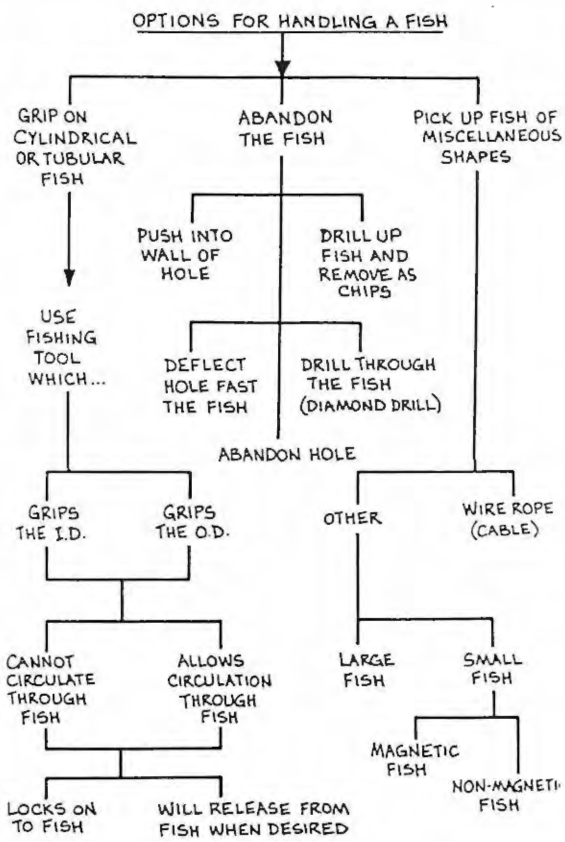
1. the size, either inside or outside, is suitable for gripping using a fishing tool, working inside the intended hole diameter.
2. the shape will allow a positive grip, yet a grip that can be released, if necessary.
3. the proportions of the tool (or combinations of tools) are such that the tool will stand or lie in an accessible position in the hole to be drilled, bearing in mind the size of the hole and the direction it will take.

For example: A short sub should not be run on the bit in a large hole. If either of the sub threads should fail (and this is a real possibility), the driller is left with a short cylindrical object which could lie crosswise in the hole.

The art of fishing

Selection of a fishing tool

The options for methods of taking hold of a fish and pulling it out of the hole, or otherwise dealing with it, are limited only by the driller's imagination. This "decision tree" flow chart shows options in a fishing situation:



Fishing calls for innovations, since no two situations can be alike. Drillers have been known to get a hold on a fish by welding or even by an epoxy resin joint. The more usual methods of gripping the fish:

- Friction grip.
- A hook or set of hooks.
- Magnetic grip.
- Weighted or spring loaded latches.
- Taps and die collars.
- Rolling or tapered seat slips.
- Helical grapple.
- Enclosing barrel or junk basket.

So that the fishing tool can pass over or into the fish and take a firm grip on it, burrs or damaged parts of the fish may have to be cut off or dressed to shape. Some fishing tools include a milling shoe to do this. Remember, all fishing tools run in the hole are themselves potential "fish". A complete record of all such tools must be maintained, and all tools must incorporate appropriate facilities for recovery.

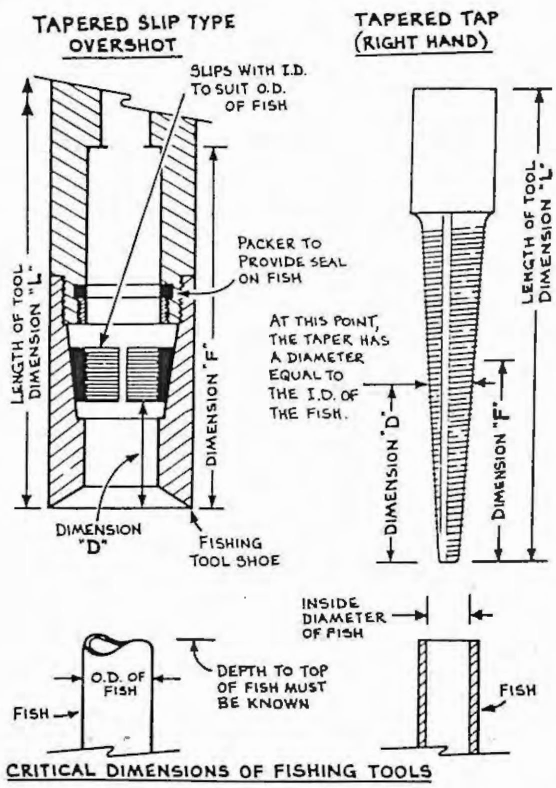
Engaging the fish

Except for bit parts, the most common fish are tubular or cylindrical. Most drilling tools, both cable tool and rotary, as well as the the rotary drill string, come into this category.

The exact sizes of the fish will be recorded in the tool record and be available to the driller. The position and condition of the top of the fish are established by running an impression block or other inspection tools. If the top of the fish has been damaged or distorted, a milling tool is used to dress it to shape.

To be sure that the fishing tool is engaging the fish correctly, these dimensions must be recorded:

Dimension "L" - The full length of the tool (necessary so that the depth to the bottom of the tool is known).
Dimension "D" - The distance that the tool must be past the top of the fish before the gripping mechanism contacts the fish.
Dimension "F" - The limit on travel of the fishing tool past the fish, if the tool is correctly engaged.



CRITICAL DIMENSIONS OF FISHING TOOLS

Gripping the tool

Fishing tools vary considerably in detail but all have features in common. The lengths identified as Dimensions "L", "D" and "F" for the tool selected must be recognised and measured.

In general, when running a fishing tool, a driller will follow these steps:

1. The tool is run into the hole, to a position just above the fish.
2. The drill string or cable is marked at the point where the bottom of the fishing tool will be level with the top of the fish.
3. A second mark is made a distance equal to Dimension "D" above Mark 1. This Mark D shows the depth when the gripping mechanism will engage the fish.
4. A third mark is made a distance to Dimension "F" above Mark 1. This Mark F shows the full depth that the fishing tool can go before loading weight on the fish.
5. The drill string is then lowered to Mark 1. The string is manipulated gently (lowering and/or turning) to "feel" the top of the fish. The tool may "hang-up" on the top of the fish. If so, it is turned or manipulated gently until it "falls off".
6. Once past the top of the fish, continue lowering, watching, and feeling for a contact with the fish as the string moves down to Mark D.
7. If contact is made at Mark D, lowering continues slowly as the action to grip the fish is performed (e.g. a Left Hand tap is rotated, by hand, in an anti clockwise (counter clockwise) direction).
8. If no contact is made at Mark D, continue lowering to Mark F, the finish of the contact zone. If no contact at Mark F, pull the string up, turn it a little, and start again at Step 5.
9. If the tool was successfully engaged at Step 7, the fish will start to take weight when the string reaches Mark F.

Handling the fishing string

In most cases, fishing will be performed using the drill string already in use. When the fish is a fractured part of the string left in the hole, the remainder of the string should be inspected very carefully. Check for potential failures of the type that has already occurred. After checking, the joints must be carefully greased and made up using the correct torque.

Fishing strings frequently will incorporate fishing jars and a safety joint as well as the fishing tool (see Section 8). Any tools added to the string, must be measured and their dimensions recorded.

If the string is to be used for recovering parts of the fish (by "backing off" rods or joints of pipe), a **left hand** fishing string is desirable. Diamond drillers sometimes lock the joints between rods using **resin** and a blow torch. This allows the rod string to transmit reverse rotation torque.

Any fishing string including a bent rod or a large fishing bowl is prone to "hang up" on the walls of the hole. Such strings must be run very carefully; they must be "eased" into the hole.

Overcoming downhole problems

Pulling the fish

Although the fishing tool may appear to have engaged the fish correctly, there is no way of being sure that the tool has a good hold. If the fish is in any way stuck, the hold will be tested when pulling the fish free. But if the fish is free in the hole, although it is picked up, it may not be held securely.

The fishing string should be pulled slowly, with emphasis on smoothness, especially when it's being lowered into the slips or clamp. The pipe in the hole should never be rotated.

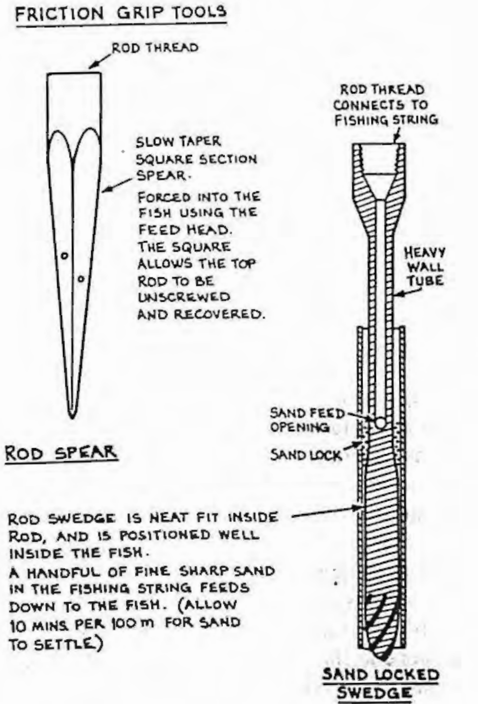
As soon as the fish reaches the collar of the hole, a **safety clamp** should be fitted to the fish so that, even if it slips out of the fishing tool, it will not drop back down the hole.

Section 8 Fishing tools and operations

- Friction grip tools
- Hooks and latching tools
- Taps and collars
- Slip type spears and overshots
- Freeing the fish
- Preparation of a cable tool fish
- Latching a difficult fish
- Hole stability "a must"
- Anticipating the problem
- The problem solved

Fishing tools come in a variety of forms, many of them hand-fabricated and unique. They can be categorised both for discussion and to aid you in selecting or fabricating your own.

FRICTION GRIP TOOLS



Friction grip tools

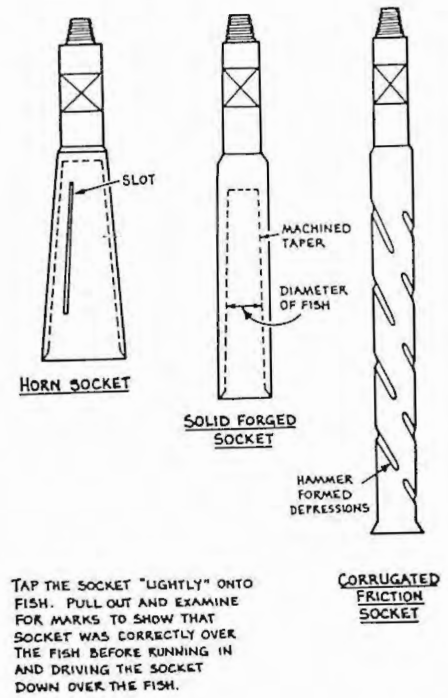
Friction grip tools are seldom used by large hole rotary drillers. Rotary fish can be very heavy, and fish in rotary holes may require a considerable pull to free them from the grip of the mud cake.

Diamond drillers and cable tool drillers find value in the use of a cheap, easily operated and usually effective **friction grip tool**. This type is also handy in capturing pump bowl assemblies and column pipe sections in wells.

Horn socket and corrugated socket

These are frequently used by cable tool drillers. Long stroke fishing jars are used to drive the sockets over the fish. Only a few light strokes are necessary using a stem above the jars. The horn socket and the corrugated socket are "distorted" when driven over the fish. The "spring" in the tool provides the holding force. The **solid forged socket** is driven solidly to make a firm friction grip. The solid socket will allow jarring to free a stuck fish.

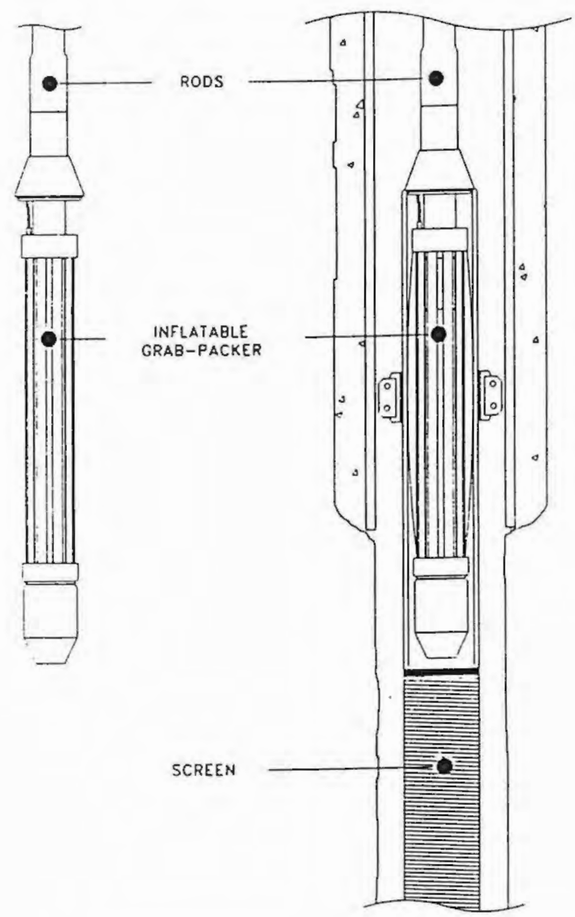
CABLE TOOL FRICTION SOCKETS



Grab packer

The grab packer is a tool specifically designed for fishing of screen, plastic and light wall casing. It comprises an inflatable packer with carborundum-coated, high tensile steel strips running the full length of the packer. When inflated inside a screen or pipe, the packer pressure pushes the external strips against the pipe wall to create a high capacity frictional anchor without deforming or scoring the fish. Pulling loads in excess of 50 tonnes is possible with this system with no danger of damaging the top of the screen or casing.

GRAB PACKER FISHING TOOL



Provided courtesy of AGE Developments

Application: fishing for diamond drill rods: The small clearances in a diamond drill hole provide the advantage that a fish is kept in alignment with the hole. Against this, the small clearances cause several difficulties.

- Fishing tools sufficiently robust to grip the outside of the rods cannot fit in the hole.
- Tools taking a strong grip inside the rods are likely to split the rod or distort it and expand the rod to lock it against the walls of the hole.

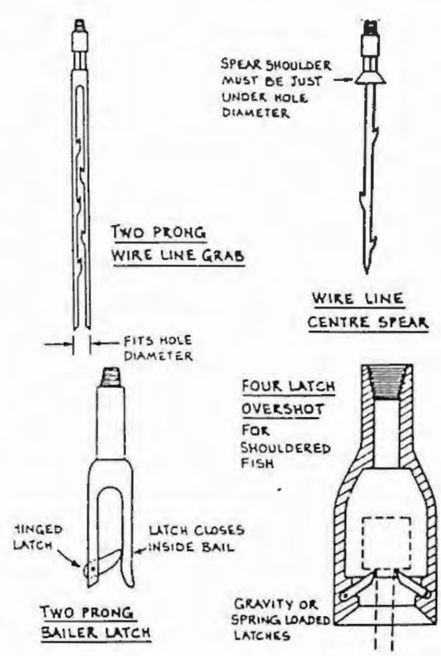
To avoid these difficulties, fish for a lost rod by attempting to make up another rod into it. If the thread is damaged or the rod has broken, back off and remove the top rod of the fish, using a **rod spear.** The balance of the fish may be picked up by connecting the threads.

The **spear** may be run on a **left hand** rod string. Otherwise, **resin** the threads. **Dip** the heated pins in molten resin and make up into a heated box. The joints must be heated again when breaking out.

Hooks and latching tools

Recovery of lost wire line drilling cable, bailer line and logging cables is required. **The centre spear** is used when a long length of cable is in a cased hole. The spear shoulder will keep the cable below the spear, but care must be exercised to avoid hooking the cable too far below its free end. A "wad" of cable in the hole cannot be pulled out. It is better to attempt to hook the top of the cable and miss than to dive deep into the cable and stick the spear. The two-three-pronged grabs are used in the open hole or when only one or two metres of cable attached to the tools has been left in the hole.

Latching-type tools are used to recover fish with a **bail** or a prominent **shoulder** at the top end. The tool is "worked down" over the fish so that the latch will fall into place. Sometimes, these fishing tools are equipped with sharp-edged latches with springs to push the latch and make it "bite" into the fish. Latch-type tools can be broken free of the fish by jarring.

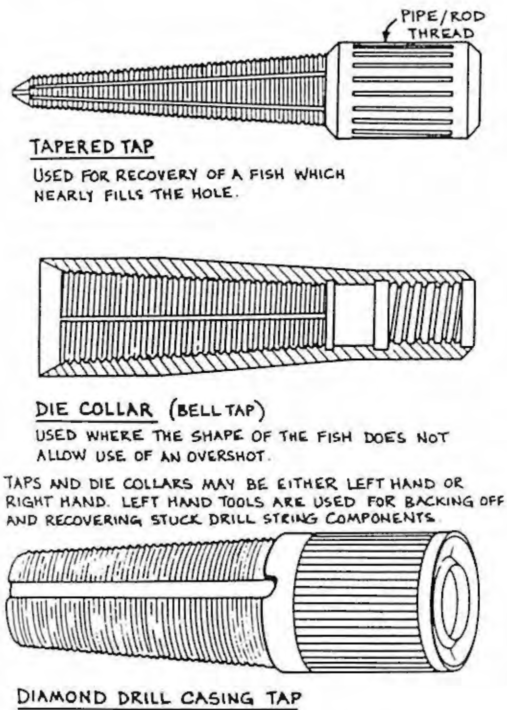


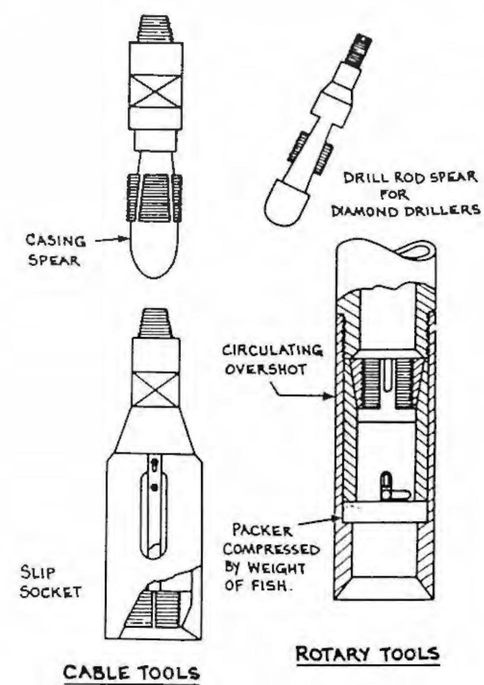
Taps and die collars

All the rotary types of drilling make use of taps and die collars. These relatively cheap and easily operated tools all suffer from the serious drawback that when they're made up tightly, they cannot be released from the fish. In rotary mud holes, they should always be run with a **safety joint.**

The thin section bell taps and small tapered taps, designed for picking up diamond drill rod couplings, are very prone to breakage. In most cases, they cause an unnecessary complication of an otherwise simple fishing job.

Overcoming downhole problems





Beware of hardened steel on taps and die collars that may:

(1) cause embrittlement and failure.
(2) be difficult to catch if the tool itself becomes part of the "fish".

When making-up a tap or die collar, the fishing string should be rotated slowly by hand. Weight should not be applied. Allow the tool to pull itself into or over the fish.

Taps and dies are designed to allow circulation through the tools to clear the fish as the tool is engaged. The seal between the tool and the fish is unlikely to be good enough to ensure circulation around the fish.

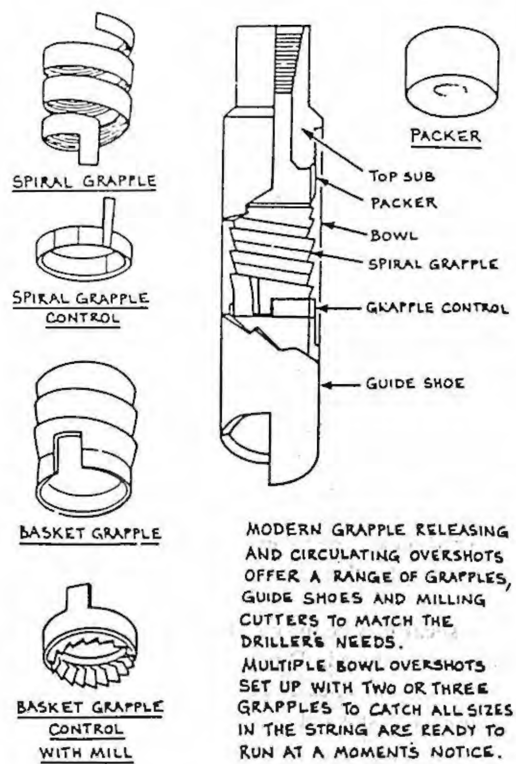
Slip type spears and overshots

Slip-type spears are used to fish lost drill pipes or rods and casing. Releasing-type slip spears are used to handle and position liners in the hole. Slip-type tools are available for running on the cable tool string, rotary strings and diamond drill strings.

Rotary spears and overshots incorporate packers, which seal between the tool and the fish. Once the tool is "set", circulation can be established around the fish to assist in recovering it from the hole.

The various manufacturers provide different methods of "tripping" or "locking" the slips so that the releasing-type tools can be removed from the fish, if necessary. The driller should be thoroughly familiar with the method of releasing and practice it on the surface, before running the tool into the hole.

Use of grapple overshots: The procedures involved in picking up a fish are greatly simplified if the driller can have available on the rig a tool that will catch any of the components of the drill string. When the tool joint diameter is larger than the pipe diameter, the chances of successfully catching a fish are improved if the one tool will catch both diameters.



As an overshot is lowered towards the fish, the circulation should be started, to flush out the tool and wash the top of the fish.

Some grapple-type tools must be rotated slowly as they are lowered over the fish (or removed from it). When a pull is taken, without rotation, the grapple will take hold of the fish.

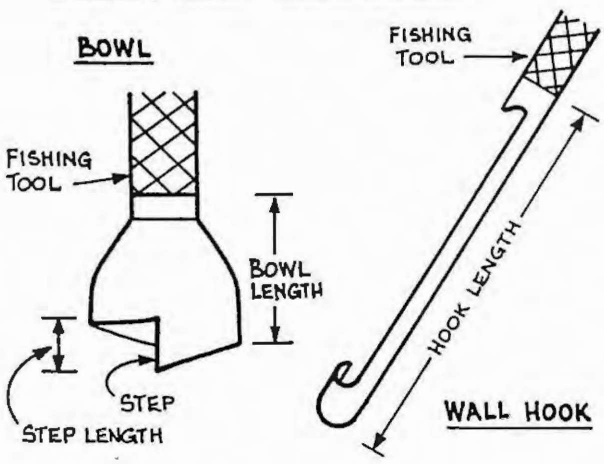
The standard guide shoe may be replaced with a bowl or wall hook-type shoe (see "Latching a Difficult Fish" ahead). Milling cutters inside the shoe will remove burrs from the fish. If the tool holds up at the depth where the milling cutter contacts the fish, the mill is rotated very slowly to cut the fish.

Down hole inspection tools assist the driller to get some idea of the way the fish is lying.

A **stepped toe** on the fishing tool may allow the tool to be worked down between the fish and the wall of the hole. In this way, the fish is "stood up". The tool will then go down over the fish and take grip. Special shoes, such as **bowls and wall hooks**, can be made easily to stand up the fish. The fishing tool may be run below a bent pipe to reach into a cave:

A knuckle joint permits control over a wall hook as it feels for the fish.

TOOLS FOR CATCHING THE FISH



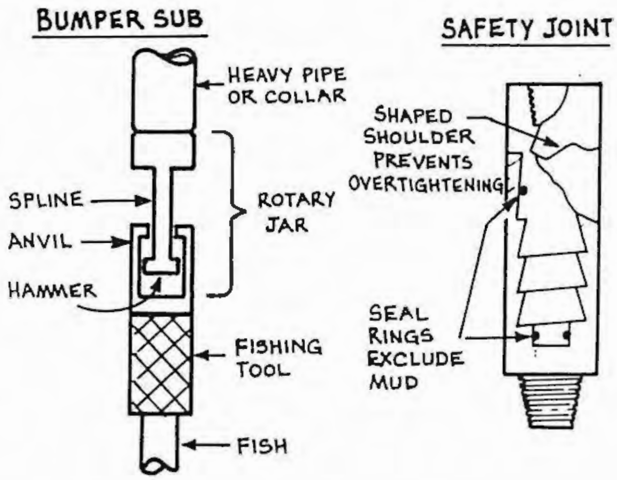
Freeing the fish

Not only is the "difficult fish" hard to catch but it is likely to be hard to free from its position.

Rotary and cable tool drillers have a range of **jarring** tools available to them:

- Bumper subs (or internal jars). These allow free sliding motion over a short distance. The hoisting and lowering of drill collars, run above the bumper, deliver a hammer blow.
- Rotary jars. The sliding motion of the tool remains locked while the desired tension or thrust is built up in the string. The tool then "trips" to deliver a sharp blow. Some models allow the trip-loading to be adjusted by varying the torque on the tool while it is down the hole.
- Long stroke or fishing jars (cable tool). The jars are installed between the fishing tool and the fishing stem. The weight of the stem above the fishing jars is the effective force that jars loose the stuck tools. The stem should be connected with a stiff socket.

Rotary safety joints: These joints are designed to transmit full drilling loads and torques. The robust thread is grease lubricated and the circulating fluids are kept out of the joint by ring seals. The joint unscrews easily when rotated backwards. The joint is easily stabbed and madeup down the hole.

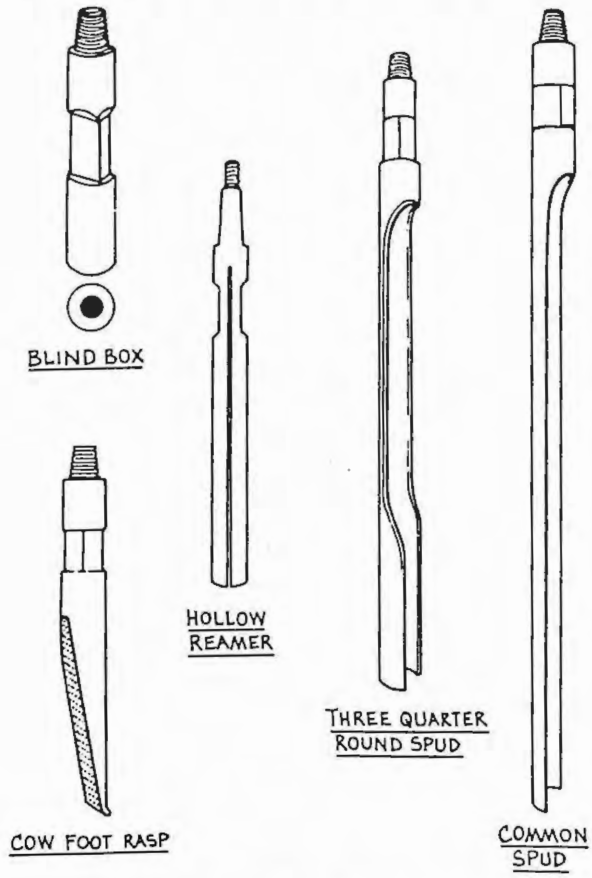


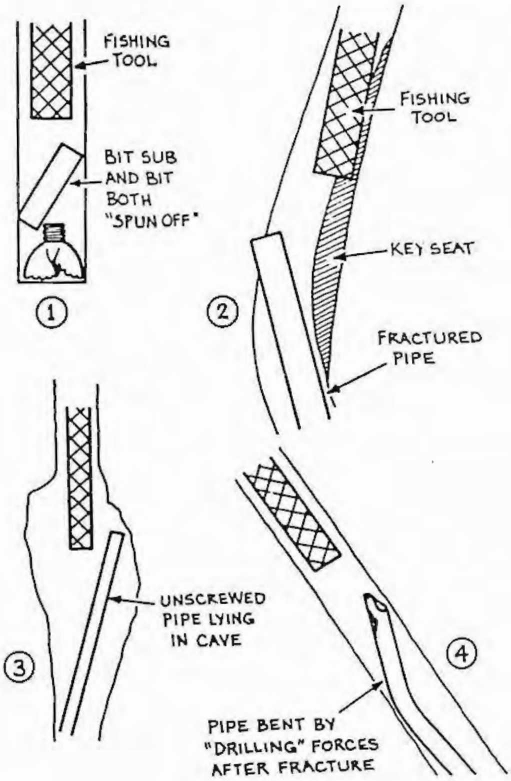
Preparation of a cable tool fish

Cable tool drilling cable is not difficult to cut with the correct tool. Usually the cable is cut close to the underground swivel to allow the fishing tools to catch the socket. The wireline knife is run on the sand line.

Care must be taken to avoid allowing the sand line to be tangled around the drilling cable; this can be assisted by ensuring that the drilling line is kept taut.

Overcoming downhole problems





When the drilling cable has failed or has been cut close to the swivel, any frayed strands of cable must be cleaned off. The **blind box** is run in a fashion similar to a drilling bit to cut off strands of cable and clear cavings from around the fish. A fish which has become burred or damaged is dressed using a **cow foot rasp**.

When a cable tool bit, broken off in the hole, becomes buried in cavings or falls to one side of the hole, it must be straightened up and the hole cleared out.

To stand up the bit and start clearing the hole, a **hollow reamer** is used. This tool is spudded gently over the fish. The 2, 3 or 4 wings of the reamer open out to hole size.

A **three-quarter round spud** is used also for this purpose. To clear out right to the bottom of a bit or around a full string of tools, a **common spud** is used. The spuds are run on a babcock fixed rope socket with a short stem above the jars.

Latching a difficult fish

A fish is not difficult to engage when it is standing reasonably upright in a straight hole, free of enlargement or caving. Latching on to a fish can present much more of a problem when the fish:

- is lying at an angle in the hole,
- is in a crooked hole,
- has fallen into a cave,
- has been damaged or bent.

Hole stability " a must"

Fishing operations cannot proceed if the hole is caving in over the fish. The value of running a safety joint lies in the driller's ability to free the upper part of the drill string from the bit and drill collars which are most likely to become stuck.

The hole must be stable to permit:

- the string to be pulled.
- a fishing string of **jars** and **drill collars** to be made up above the pin section of the safety joint.
- the safety joint to be stabbed and made up to connect the fishing string to the stuck drill collars.

Many fishing problems are caused by lack of adequate control over the drilling fluid. As the fishing proceeds, a continual effort must be made to adjust the drilling fluid in order to improve hole stability.

Where hole instability results from caving or movement of the formation (and not from mud cake buildup causing differential sticking), the fish may be cut free by **washing over**. The "wash-over string" essentially is a casing string capable of transmitting rotary torque to a shoe bit. The "wash-over" operation has the effect of reaming over the fish so that the fish is no longer affected by the hole instability.

Hole stability in a cable tool hole must be achieved by driving the casing down over the fish. Once the casing is in place, fishing can proceed efficiently in the cased hole.

When stability cannot be achieved, the driller has no choice but to abandon the unstable part of the hole. A new hole may be drilled by deflecting the hole above the fish.

Most **wireline** drill strings are of a suitable size to allow the hole to continue, using a drill string of the next smaller size. The stuck wireline string, in effect, becomes casing. However, before continuing the hole with the next smaller size equipment, the landing ring and bit of the stuck core barrel must first be drilled through. This can be a slow process, and of course there is the risk of getting the second drill string stuck inside the larger core barrel.

Anticipating the problem

The skill of anticipation is the ability to **recognise what's going to happen.** If a driller can anticipate what is likely to happen next, he's well equipped to handle the problem when it occurs.

For example, the solution to the problem of **hole deviation** lies in recognising that the deviation is likely. The hole is planned so that the deviation can be tolerated or so that the deviation is controlled within acceptable limits.

If hole instability is correctly anticipated, the driller will have a casing program that allows the problem formations to be cased off before they cause trouble. A drilling fluid, designed to complement the casing program, will be in use.

Mechanical problems usually result from wear and high loadings. A driller who recognises that the rig and equipment are approaching a **stage** of failure, should implement a plan of detailed inspections and regular maintenance.

In this chapter, we have seen how the driller's skills in problem solving are an important factor in all of his duties. It has been said that **fishing** is something of an **art**. This is true to the extent that it requires a driller with a perception of what is happening downhole and a knowledge of the various options available to deal with the situation. Thus, drillers must seek knowledge of the technical aspects of a drilling operation, and they must practice the skills required to be innovative in their approach to drilling problem solving.

Much of the success in solving fishing problems comes from the driller's ability and experience to select the correct tools and adopt the best technique for each particular problem.

The problem solved

Almost any fishing problem, like almost any drilling problem, can be solved if sufficient money and time are available. The driller must be aware of the costs of continuing a nonproductive activity like fishing. The costs must be balanced against the possible benefits and the loss involved in abandoning the tools and perhaps drilling another hole.

A driller does not always need to run an expensive fishing tool to pick up a fish. If, for example, a joint has spun-off, by far the best way of fishing it is to manipulate the string to stab the joint and make it up again down the hole. If this can be done, always pull the string and inspect the joint before drilling on.

With the skills acquired by experience and by taking advantage of information sources such as this drilling manual, the driller can make the best use of available equipment and methods, and take steps to make the job site safer, more organised, and more efficient.

Technical Area: 13 Well Rehabilitatation

Item: 13-1 Phenomenan and causes of well deterioration

1: Objectives

To be able to explain and advise for several type of well deterioration such as incrustation on screen, sand production etc. and their causes.

2. Contents

- Deterioration of casing
- Rust-colored water
- Sand production
- Incrustation on screen

3. Teaching Methods

(1) Explain phenomenan and causes of well deterioration such as rust-colored water, sand production, incrustation on screen, using manual.

4. Materials

13-1M1 DDCA's manual of Tool Fishing and Well Rehabilitation

13 WELL REHABILITATION (TA CODE 13)

13.1 PHENOMENAN AND CAUSES OF WELL DETERIORATION (TA CODE 13-1)

13.1.1 WELL FAILURE BY INCRUSTATION

Chemical and biological incrustations are major causes of well failure. Water quality chiefly determines the occurrence of incrustation. The surface characteristics of the screen itself may also play a part in regulating the rate at which incrustation occurs. If the screen is constructed of rough-surface metal, for example, incrustants may build up at a faster rate. The kind and amount of dissolved minerals and gases in natural waters determine their tendency to deposit mineral matter as incrustation.

Groundwater normally moves slowly and remains in contact with the minerals of the aquifer material for hundreds or thousands of years in a quasi-chemical equilibrium with its environment. Any change in the physical or chemical conditions (such as pumping a well) upsets the equilibrium and may cause precipitation of relatively insoluble materials.

The incrustation often forms a hard, brittle, cement- like deposit similar to the scale found in water pipes. It may also be soft, paste-like sludge or gelatinous material, depending on conditions.

The major forms of incrustation include:

- Precipitation of calcium and magnesium carbonates or their sulfates.
- Precipitation of iron and manganese compounds, primarily their hydroxides or hydrated oxides.
- Slime-producing iron bacteria or other slime-forming organisms (biofouling).

(1) Causes of Carbonate Incrustation:

Chemical incrustation usually results from the precipitation of carbonates, mainly of calcium, from groundwater in the proximity of the well screen. Other substances, such as aluminium silicates and iron compounds, may also be entrapped in the scale-like carbonates that cement sand grains together around the screen. The deposits fill the voids, and the flow of water into the well is reduced proportionately.

The explanation is that calcium carbonate can be carried in solution in proportion to the amount of dissolved carbon dioxide in the groundwater. The ability of water to hold carbon dioxide in solution varies with pressure – the higher the pressure, the higher the concentration of carbon dioxide.

When water is pumped from a well in an unconfined aquifer the hydrostatic pressure in the deeper portions of the aquifer is decreased with greatest change being at the well.

Because of the reduction in pressure, some carbon dioxide is released from the water. When this occurs, the water is unable to carry its full load of dissolved calcium carbonate and part of this material is precipitated onto the well screen and in the formation material adjacent to the well screen.

Pumping a well in a confined aquifer produces a similar pressure reduction and resulting precipitation.

Formation of calcium carbonate precipitate from calcium bicarbonate is the classic example:

$$Ca(HCO_3)_2 \quad \rightarrow -\Delta P \rightarrow \quad CaCO_3\downarrow + CO_2\uparrow + H_2O$$

where ΔP is a change in pressure.

Solubility of calcium bicarbonate is 1300 mg/l while the solubility of calcium carbonate is 13 mg/l. Carbon dioxide (CO_2) escapes when the head, or pressure, is reduced.

Magnesium bicarbonate changes to magnesium carbonate in the same manner when the carbon dioxide is released, but magnesium carbonate incrustation occurs only in special instances because it is still soluble at concentrations over 5000 mg/l (Kemmer, 1979). Precipitation occurs, therefore, only when the carbonate concentration exceeds this level.

(2) Causes of Iron and Manganese Incrustation:

Many rocks throughout the world contain iron and manganese, and are the source of iron and manganese ions found in groundwater if the pH is about 5 or less.

Velocity- induced pressure changes due to pumping can disturb the chemical equilibrium of the groundwater and result in the deposition of insoluble iron and manganese hydroxides. These hydroxides are gel-like and may occupy relatively large volumes. Over time, they harden into scale deposits.

Dissolved iron is affected by pressure reduction as follows:

$$Fe(HCO_3)_2 \rightarrow -\Delta P \rightarrow Fe(OH)_2\downarrow + 2CO_2\uparrow$$

The solubility of ferrous hydroxide (on the right side of the equation) is less than 20 mg/l. If oxygen is introduced by aeration during pumping, additional precipitation of ferric hydroxide occurs:

$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3\downarrow$$

The solubility of ferric hydroxide is less than 0.01 mg/l.

Soluble manganese becomes insoluble in the same way as iron:

$$2Mn(HCO_3)_2 + O_2 + 2H_2O \rightarrow 2Mn(OH)_4\downarrow + 4CO_2\uparrow$$

Further oxidation of the hydroxides of iron and manganese, or an increase in pH, causes the formation of hydrated oxides containing these ions. Ferrous iron in solution, for example, can react with oxygen to form ferric oxide:

$$2Fe^{+2} + 4HCO_3^- + H_2O + 1/2O_2 = Fe_2O_3 + 4CO_2 + 3H_2O$$

The ferric oxide is a reddish brown deposit similar to rust, whereas the hydrated ferrous oxide is a black sludge.

The insoluble manganese oxide is also black or dark brown.

Iron and manganese deposits are often found associated with calcium and magnesium carbonate scale.

In the cone of depression around a well in an unconfined aquifer, air enters the voids and oxidizes iron in the films of water adhering to individual sand grains. If pumping is started and stopped intermittently, a coating of iron oxide can build up, thereby gradually reducing the void space in this part of the formation. This action reduces the formation's storage capacity in the vicinity of the well, and the cone of depression enlarges more rapidly than it would otherwise.

(3) Well Failure Caused by Iron Bacteria:

Iron bacteria occur widely in wells open to the atmosphere when sufficient iron and/or manganese are present in the groundwater in conjunction with dissolved organic material, bicarbonate, or carbon dioxide.

The principal forms of iron bacteria plug wells by enzymatically catalyzing the oxidation of iron (and manganese), using the energy to promote the growth of threadlike slimes, and accumulating large amounts of ferric hydroxide in the slime.

In this process, the bacteria obtain their energy by oxidizing ferrous ions to ferric ions, which are then precipitated as hydrated ferric hydroxide on or in their mucilaginous sheaths. Precipitation of the iron and the rapid growth of the bacteria create a voluminous material that quickly plugs the screen pores of the sediment surrounding the well bore.

Sometimes the explosive growth rates of iron bacteria can render a well virtually useless within a matter of months.

Many other forms of iron bacteria induce the precipitation of iron through nonenzymatic means. Found almost everywhere in both water and soil, these bacteria promote precipitation of iron by:

- Raising the pH of the water through metabolic and photosynthetic processes.
- Changing the redox potential of the water by algal photosynthesis. In this process, oxygen given off by plants increases the redox potential, thereby causing the precipitation of iron.
- Liberating chelated iron by inducing a breakdown in the bond between iron and oxalate, citrate, humic acids, or tannins.

Many forms of enzymatic bacteria that could grow in water wells prefer water with the following general physical and chemical characteristics:

- Has an iron content of 1 to 25 mg/l and contains only traces of organic matter.
- Low in oxygen, typically in the 0.1 to 1.0 mg/l range.
- Usually fresh.
- Contains over 20 mg/l carbon dioxide.
- Has a redox potential in the range of 200 to 300 millivolts (mv).
- Has a pH in the range of 6 to 7.6.
- Has a temperature from 40 to 60^0F (4.4 to 15.6^0C).

There are, however, other forms of iron bacteria that can grow in waters having extremely low pH (2 to 6) and much higher temperatures [60 to 185^0F (15.6 to 85^0C)]

A second classification of iron bacteria is the one based on the physical form of the organisms. There are three general forms:

- The capsulated coccoid form which consists of numerous short rods surrounded by a mucoid capsule. The deposit surrounding the capsule is hydrous ferric oxide, a rust-brown precipitate.
- The stalked iron-fixing bacteria composed of twisted bands resembling a ribbon or chain with a bean-shaped bacterial cell at the end of the twisted stalk.
- The filamentous group that take different shapes and structures.

Under each form are numerous genera and species.

If the presence of iron bacteria is suspected in a well, samples of the organism can be obtained by a filtering device attached to the discharge of the pump for one week. The water passing through the filter during this period leaves a dark brown precipitate on the porcelain cover which can be examined for iron bacteria by a qualified laboratory.

Another method of sample collection is to examine the material scraped from valves or pump discharge lines from suspected wells, pump shaft seals, water closets, or small steel objects suspended temporarily in the well.

However, unless a microscope of at least 1000X is available, it is best to send the samples to a laboratory or firm familiar with iron bacteria identification.

(4) Prevention and Treatment of Incrustation Problems:

So far, means of preventing the incrustation of well screens has not been found. One unique method does exist, however, that is designed to reduce the amount of iron incrusting materials reaching the well screen. This method, called the Vyredox System, uses a series of injection wells located in a circle around the production well. Oxygenated water is injected into the wells to oxidize iron in solution and promote the growth of iron bacteria so that little iron reaches the production well.

For most wells where incrusting material cannot be removed before reaching the well, several actions can be taken to delay incrustation and make it a less serious problem:

- The well screen should be designed to have the maximum possible inlet area to reduce the flow velocity to a minimum through the screen openings.
- The well should be developed thoroughly.
- The pumping rate may be reduced and the pumping period increased, thereby decreasing entrance velocities.
- The pumping load may be divided among a larger number of smaller diameter wells instead of obtaining all of the supply from only one or a few larger diameter wells.
- A more frequent maintenance or cleaning procedure – by qualified water well contractor- should be undertaken wherever local experience shows considerable difficulty from incrustation.

In localities where incrustation is prevalent, samples of the incrusting material and water should be analyzed. The proportions of the various materials shown by the analyses should indicate the kind of treatment and the type of chemicals that would be most successful in recovering well yield.

13.1.2 WELL FAILURE FROM CORROSION:

Metals are generally extracted from ores of stable mineral compounds that are in physical and chemical harmony with their natural environment. In the elemental state most metals are not inherently stable.

In the environment, elemental metals naturally revert back into more stable mineral compounds.

This completely natural process is called corrosion. It changes the physical and chemical properties of metals, frequently destroys the usefulness of of fabricated metallic articles or structures, and may, over time, reduce or destroy metal products.

Corrosion can severely limit the useful life of water wells in four ways:

- Enlargement of screen slots or development of holes in the casing, followed by sand pumping.
- Reduction in strength, followed by failure of well screen or casing.
- Deposition of corrosion products, thereby blocking screen-slot openings and reducing yield.
- Inflow of low-quality water caused by corrosion of the casing.

(1) Chemical and Electrochemical Corrosion:

Corrosion results from chemical and electrochemical processes. Chemical corrosion occurs when a particular constituent is present in water in sufficient concentration to cause rapid removal of material over broad areas. Commonly these constituents are carbon dioxide, oxygen, hydrogen sulfide, hydrochloric acid, chloride, and sulfuric acid.

Chemical corrosion can cause severe damage in wells, regardless of the amount of total dissolved solids. The number of wells affected by chemical corrosion is, however, small compared to those affected by electrochemical corrosion.

In electrochemical corrosion, flow of an electric current facilitates the corrosive attack on a metal. Two conditions are necessary:

- A difference of an electrical potential on metal surfaces.
- Water containing enough dissolved solids to be a conductive fluid (electrolyte).

A potential (electrical) difference may develop between two different kinds of metals, or between nearby but separate areas on the surface of the same metal.

Difference in potential on the same steel pipe, for example, can occur:

- At heat affected areas around welded joints.
- At heated areas around torch-cut slots.
- At work-hardened areas around machine-cut slots.
- At cut surfaces of exposed threads at pipe joints.
- At breaks in surface coatings such as paint and mill scale.

In the above cases both a cathode and an anode develop, and metal is removed from the anode.

Bimetallic corrosion results when two different metals are in contact and immersed in an electrolyte. A galvanic cell is created an corrosion occurs. A well screen made of two different metals, such as low-carbon steel and stainless steel, will be damaged because the mild-steel portion is corroded by the galvanic action.

When electrochemical corrosion takes place, corrosion products may be deposited at the cathode. These deposits are usually voluminous. If iron or steel is corroded, the corrosion products are iron combined with other elements and are normally ferric hydroxide or ferric oxide.

Deposition of corrosion products that results in blocked screen-slot openings and reduced well yields is evidence of electrochemical corrosion.

Technical Area: 13 Well Rehabilitatation

Item: 13-2 Methods of well rehabilitation

1: Objectives

To be able to explain and advise for several methods of well rehabilitation such as mechanical and chemical cleaning, sedimentation removal etc.

2. Contents

- Mechanical cleaning
- Chemical cleaning
- Sedimentation removal
- Double-casing method

3. Teaching Methods

(1) Explain various methods of well rehabilitation including mechanical and chemical cleaning, sedimentation removal and double-casing, using manual.

4. Materials

13-2M1 DDCA's manual of Tool Fishing and Well Rehabilitation

13.2 METHODS OF WELL REHABILITATION (TA CODE 13-2)

13.2.1 GENERAL

The major purposes of well rehabilitation are:

(1) To revive the well yield by cleaning the clogged screen and neighbouring aquifer

(2) To remove the sedimentation of sand at the bottom of a well

(3) To repair the damaged screen and/or casing which produce sand and/or clay into the pumped water

For above (1), mechanical methods such as air-lifting, bailing, brushing, swabbing etc., and chemical methods using acid are used.

For (2) air-lifting or bailing is used.

The countermeasures for (3) need more complex and expensive process. Double-casing methods are commonly used if the diameter of internal casing to be installed is sufficiently enough to install the pump. Principles of the above methods are described below.

13.2.2 MECHANICAL CLEANING

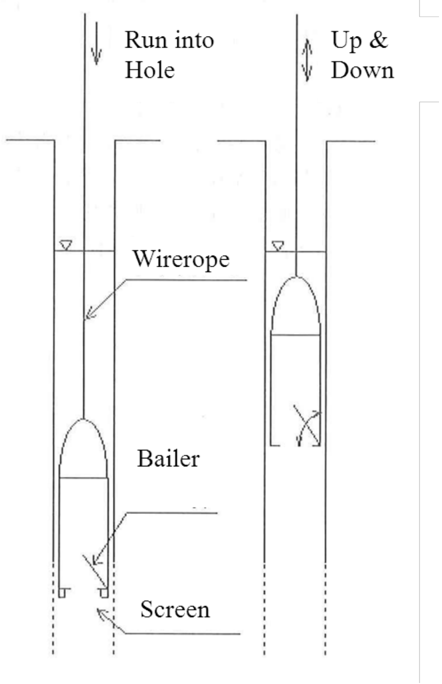
Mechanical cleaning is the method of removing scale, sand, silt which clogs the screen and neighbouring aquifer by hydraulic force and/or direct physical contact of cleaning devises. The following methods are generaly used (See ***Figure 5*** and ***Figure 6***).

(1) Bailing

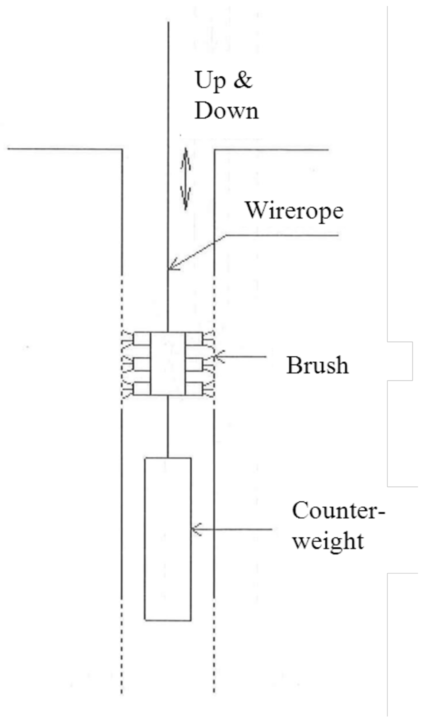
(2) Brushing

(3) Jetting

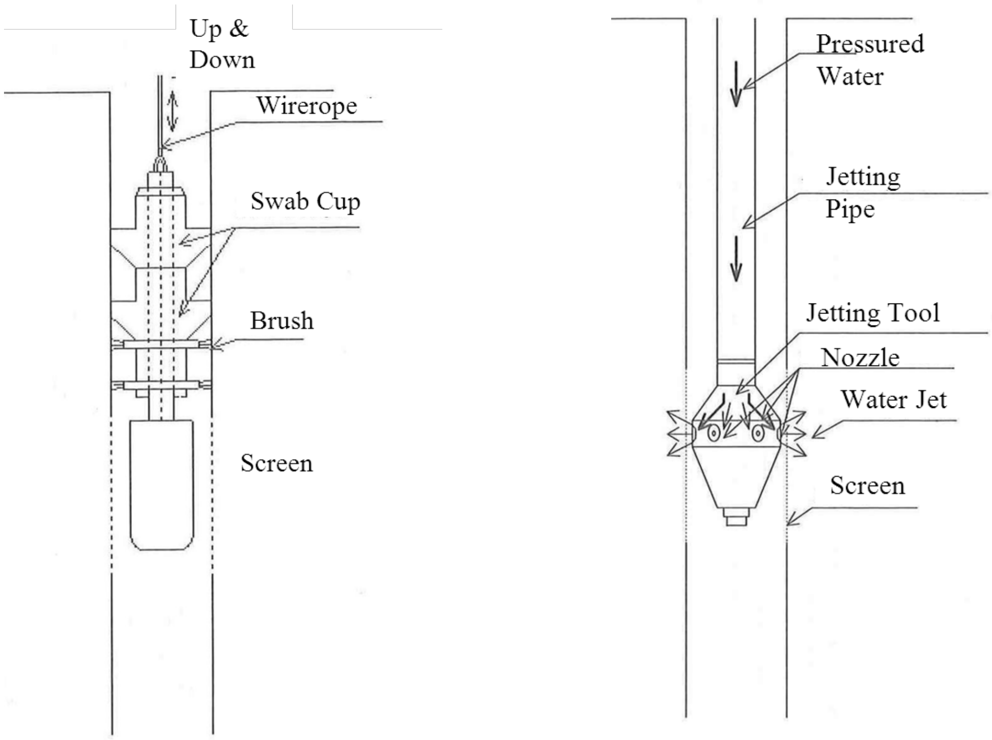
(4) Pumping/Water Injection



Bailing

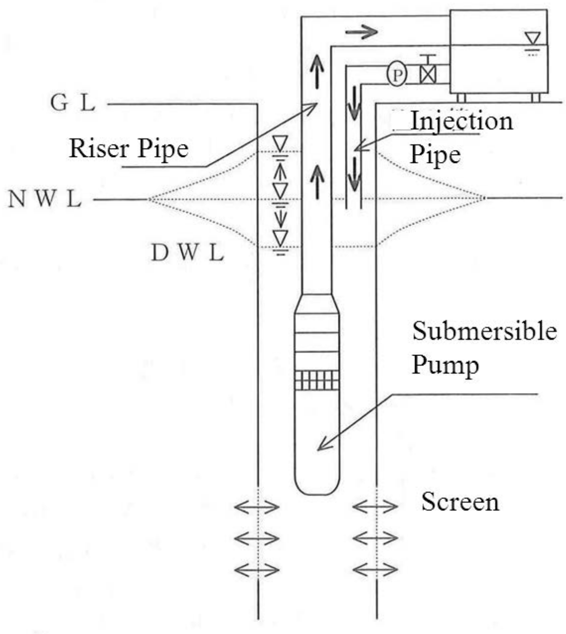


Swabbing



Source: National Water Well Association of Japan

Figure 5 Mechanical Cleaning (1/2)



Pumping/Water Injection

Source: National Water Well Association of Japan

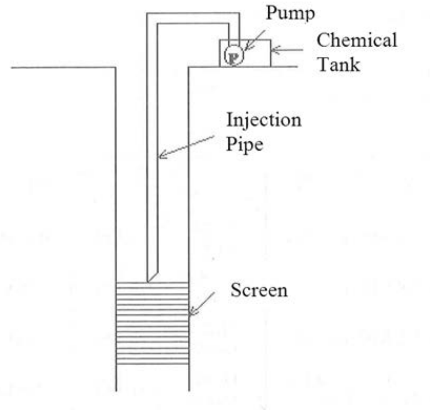
Figure 6 Mechanical Cleaning (2/2)

13.2.3 CHEMICAL CLEANING

Mechanical methods are effective for the cleaning of the scales on the suface of screen and casing. However, the effects often do not reach to the inside of the neighbouring aquifer. In this case, chemical method is used together with mechanical method.

Various types of chemical agent for the well rehabilitation are available for the purposes of the decomposition of scale, disinfection of iron bacteria etc.

The instruments of chemical injection are shown in ***Figure 7***.



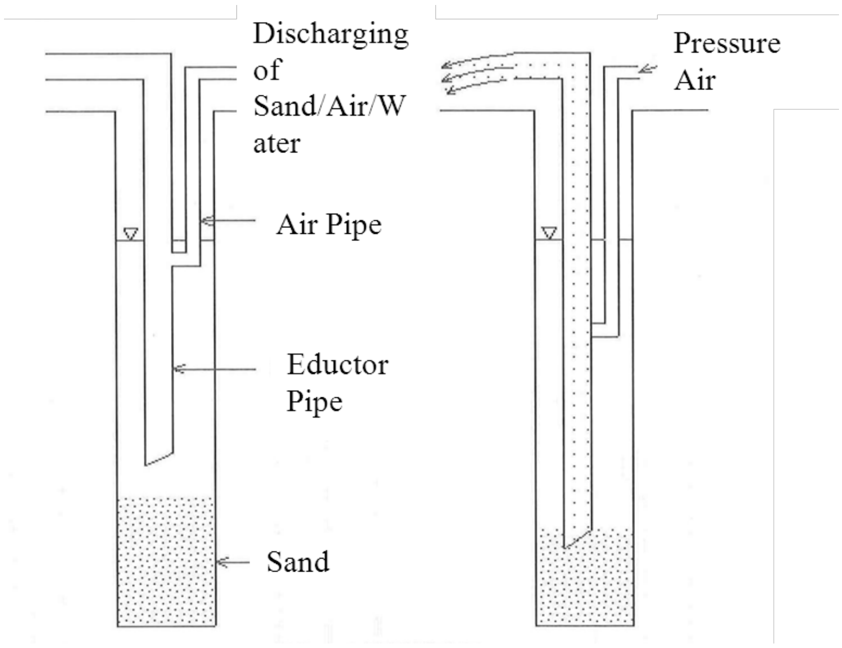
Source National Water Well Association of Japan

Figure 7 Installation of Chemical Cleaning

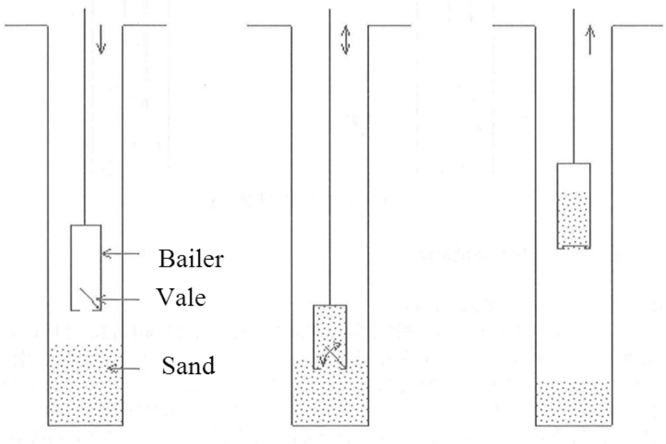
13.2.4 SEDIMENTATION REMOVAL

The pumped water contains certain amount of sand. The sand is deposited at the bottom of well during the pumping operation. This sand deposit may cause the elvation of sand content in the pumped water and/or decrease of water yield due the clogging of screen.

The deposited of sand shall be periodically removed by the measures of air-lifting and/or bailing (See ***Figure 8***)



Air-Lifting Method



Bailing Method

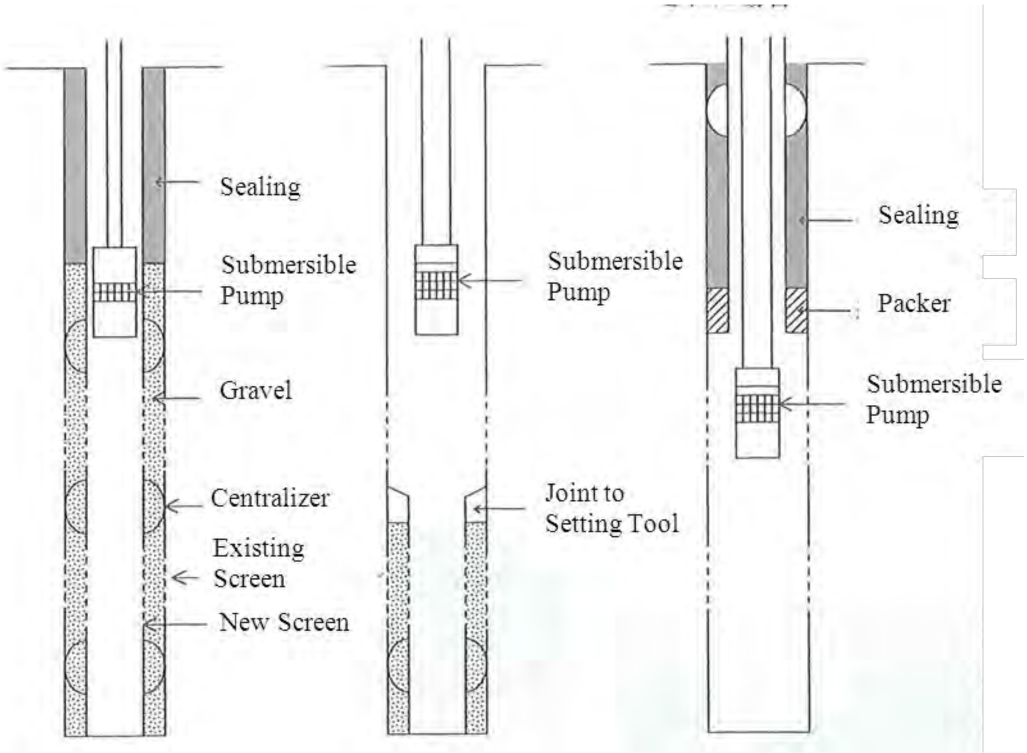
Source National Water Well Association of Japan

Figure 8 Sedimentation Removal Method

13.2.5 DOUBLE-CASING METHOD

Especially for steel casing and screen, the holes on casing and screen occur by corrosion. These holes will be expanded gradually. One of the popular counter-measure to repair the holes on casing and screen is double-casing method.

Smaller casing and screen are installed inside the existing casing and screen as shown in ***Figure 9***.



Source National Water Well Association of Japan

Figure 9 Double-Casing Method

Technical Area: 13 Well Rehabilitatation

Item: 13-3 Usage of well camera

1: Objectives
To be able to explain and advise for usage of well camera to observe inside conditions of well.

2. Contents
- Usage of well camera

3. Teaching Methods
(1) Explain how to use well camera for well investigation using manual.

4. Materials
13-3M1 DDCA's manual of Tool Fishing and Well Rehabilitation

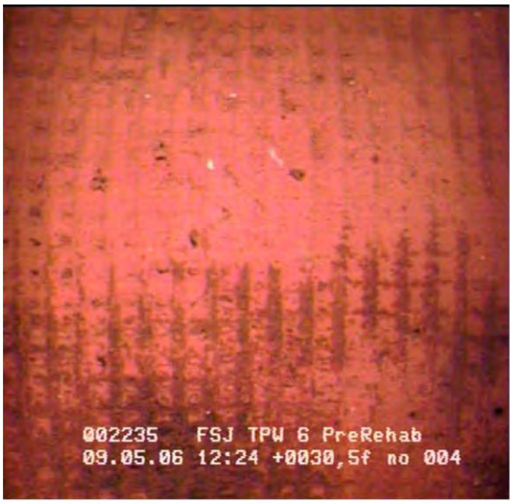
113.3 USAGE OF WELL CAMERA (TA CODE 13-3)

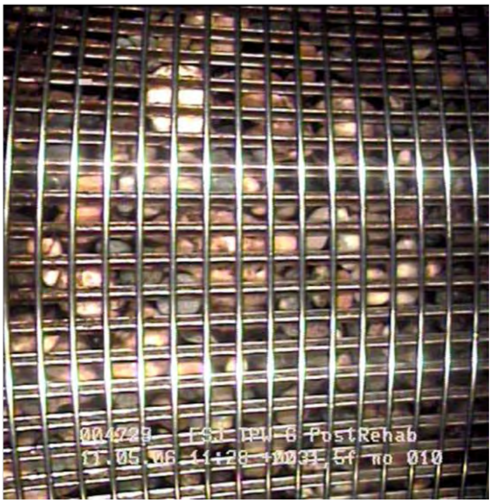
Well camera is very useful tool which can obtain the following information:

- Condition of the casing and screen in a well
- Screen position, casing diameter, casing materials

Figure 8 clearly shows the difference of the conditions of the screen before and after the well rehabilitation, by well camera.

- DDCA is now procuring one (1) set of well camera for the purposes of the well investigation.





Source: Golder Associates Ltd – Kamloops (2006)

Figure 10 Well Screen Before and after treatment of Incrustation

Technical Area: 14 Pumping Test

Item: 14-1 Purpose and methods of Pumping Test

1: Objectives

To be able to explain and advise for purpose of pumping test and major pumping test methods.

2. Contents

- Purpose of pumping test

'- Preliminary pumping test

- Step drawdown pumping test
- Constant rate pumping test
- Recovery test

3. Teaching Methods

(1) Explain purpose and various methods of pumping test using manual.

(2) Explain how to plan and conduct pumpingtest of:

Preliminary pumping test
step drawdown pumping test
constant rate pumping test
Recovery Test

4. Materials

14-1M1 DDCA's manual for Drilling Works
14-2M1 Drilling Chap. 9 P366-P367

8 PUMPING TEST (TA CODE 14)

8.1 PURPOSE AND METHODS OF PUMPING TEST (TA CODE 14-1)

8.1.1 Purpose of Pumping Test

The capacity of well shall be measured by the pumping test. The pumping test is carried out by installing electric submersible pump in a well.

The pumping test shall include the following components:

- Preliminary pumping test
- Step drawdown test
- Constant discharge rate test
- Recovery test

The purposes and methodology of each test are described below:

8.1.2 Preliminary Pumping Test

Preliminary Pumping Test is carried out to grasp the rough estimation of well yield. It is conducted generally for the period of 2 to 4 hours by varying the discharge rate. From the results of the preliminary pumping test, the schedule of the step draw down test is planned.

8.1.3 Step Drawdown Pumping Test

In Tanzania, the step drawdown test with three (3) to five (5) steps of two (2) hours is conducted. ***Figure 39*** shows an examples of t-dwl (time-dynamic water level) curve of the step drawdown test.

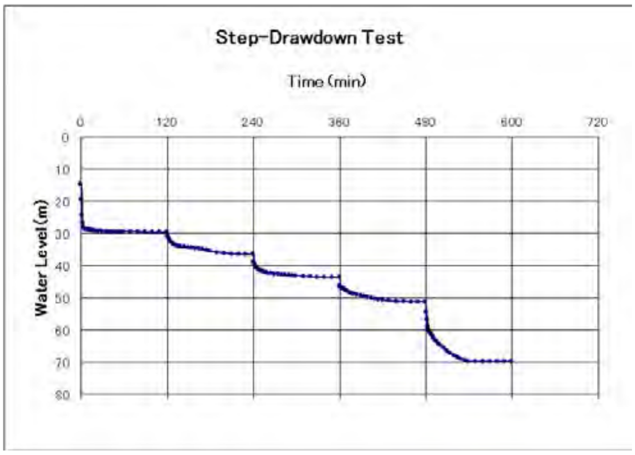


Figure 39 Example of Results of Step Drawdown Tests (t-dwl curve)

From the results of step drawdown test, the well loss can be calculated approximately by the following quotation:

$Swl=CQ^2$

Swl: well loss (m)

C: well loss constant, (h^2/m^5)

Q: discharge rate (m^3/h)

Well loss constant C indicates the resistance of well structure against water flow from the aquifer. If the screen or neighbouring aquifer is clogged, C will show the elevation.

Drillers can detect the clogging of screen by comparing current C and the past one, if they can obtained the past step drawdown test data.

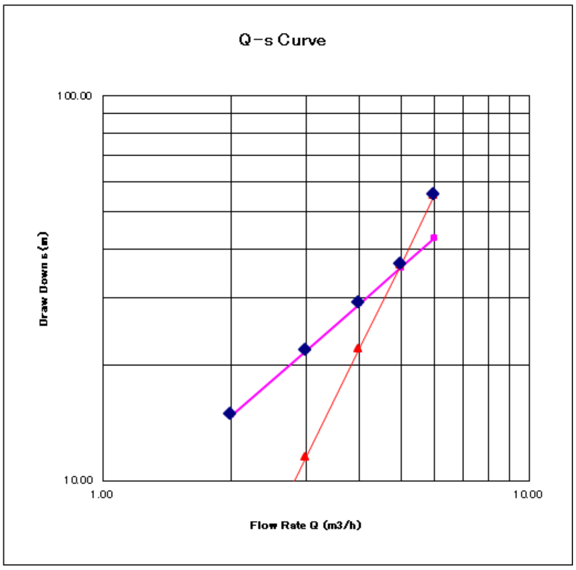


Figure 40 Example of Results of Step Drawdown Tests (Q-s curve)

Figure 40 shows the plotting of discharge rate and drawdown on Log-Log paper (Q-s curve). From this chart, the maximu discharge rate can be estimated. Because of transition from laminar flow to turbulent flow depending on the flow velocity, drawdown suddenly increases from certain value. This discharge rate of the transition is often used as maximum discharge rate. The excessive pumping over this maximum discharge rate may be the cause of the lowering of water level of a well.

The results of the step drawdown test is used for the decision of the discharge rate of the constant discharge rate test.

8.1.4 CONSTANT RATE PUMPING TEST

Figure 41 shows the example result of constant discharge rate test and the following recovery test.

The constant discharge rate test is often omitted for the purpose of well investigation. The major purpose of this test is, to verify if a well shows the same capacity as the analysed discharge rate from step drawdown test for longer pumping period.

In general, 24 to 48 hours pumping for piped water schemes and 8 to 12 hours for handpump well is applied for constant discharge rate. However, more pumping time may be applied for wells of large-scale water supply schemes.

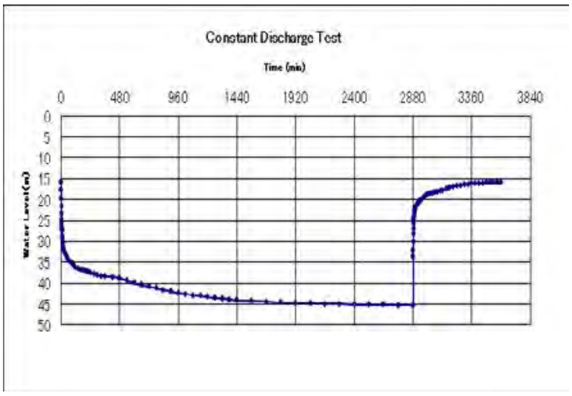


Figure 41 Example of Results of Step Drawdown Tests and Recovery Test (t-s

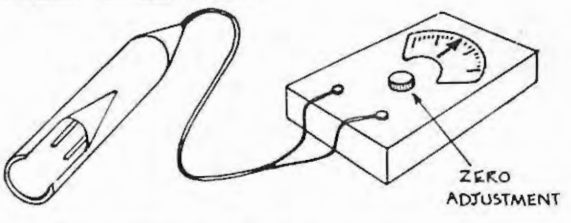
The hydraulic coefficients such as transmissivity, storage coefficients etc., can be analyzed from the results from the constant discharge rate test and recovery test.

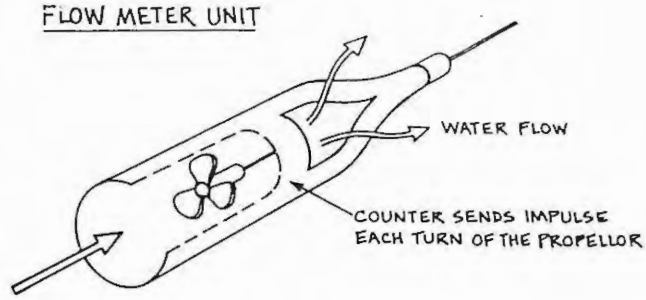
It is preferable to conduct constant discharge rate test even if it is for the well investigation.

8.1.5 RECOVERY TEST

The recovery test is continuously conducted immediately after the termination of the constant discharge rate test. ***Figure 41*** shows the examples of the plotting of time and dynamic water level (t-dwl curve) of a recovery test together with a constant discharge rate test. This test is to know how fast the dynamic water level is recovered to static water level. The recovered water level is an important factor to formulate the daily pump operation plan and also important to detect the deterioration of well.

Tests and measurements





Fluid flow measurement

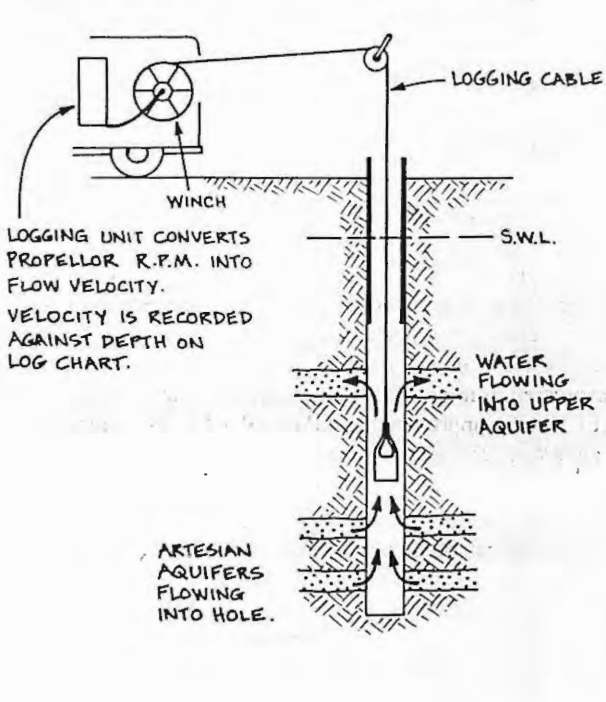
Measurement of flow up or down a bore hole is usually done using a **propeller type flow meter.**

Bore hole flow measurement is used to:

- detect and measure water flow between aquifers.
- define exactly which aquifers, or which parts of a wide aquifer, are yielding water.
- check whether well development procedures have been equally effective in all parts of the aquifer.

The source of **artesian flow** is checked by running the flowmeter. **Aquifer permeability or development** is checked using the flow meter down the hole while water is pumped or added at a known rate higher in the hole.

The drilling crew may be required to assist in handling the pumping equipment or in controlling the rate of flow.



Section 8 Test pumping water bores

- Reasons for test pumping
- Methods of measuring flow rates
- Test pumping procedures
- Testing low yield bores
- Testing high yield bores

Reasons for test pumping

From the driller's point of view, there are two main reasons for conducting a pumping test.

1. To check the drilling and bore construction practices used so that the driller can be sure that his methods are producing efficient wells.
2. To determine the optimum long term yield of a bore, and in particular, to find at what level the pump suction or intake should be set to maintain the optimum yield.

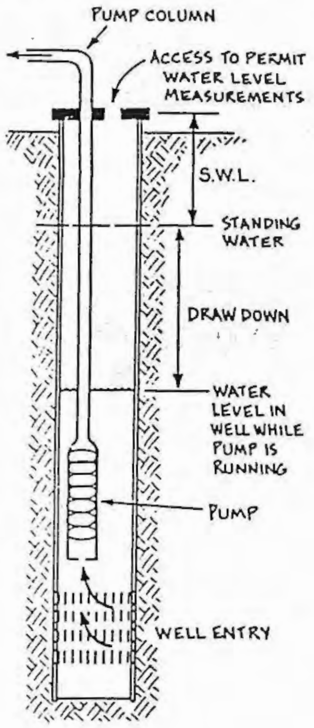
If the hole is to provide a secure long term supply, or if it has been drilled as part of a groundwater resource or aquifer appraisal program, additional pumping tests will be required. The extra tests will determine long term pumping rates and the interference between bores. Aquifer characteristics, including the safe yield of the reservoir, will be calculated.

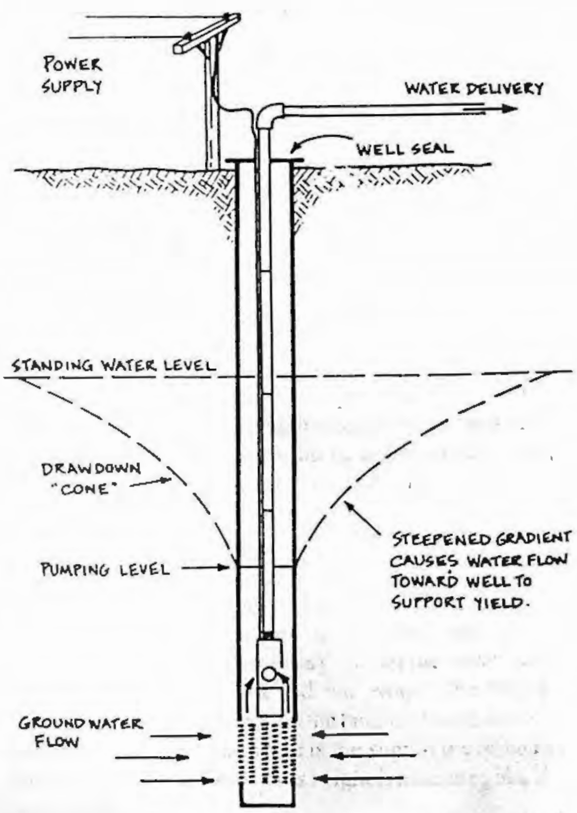
Bore efficiency is an expression of the performance of the actual bore in relation to the possible performance of the perfect well constructed at that site.

One term which is of importance to drillers is **drawdown.** When a bore is being pumped, the water level in the bore will be deeper than that of the standing water level (S.W.L.). The distance between the two is the drawdown.

The drawdown can be expected to increase as the pumping rate is increased. The relative efficiency of wells (constructed in the same aquifer) can thus be determined by comparing the drawdown at different pumping rates.

Thus, the drawdown is proportional to the pumping rate. The yield available from the well for each metre of drawdown is a useful guide to evaluate the well.





The yield (L/sec) per metre of drawdown is the specific capacity.

Specific capacity of a bore is used as a basis for stating its performance.

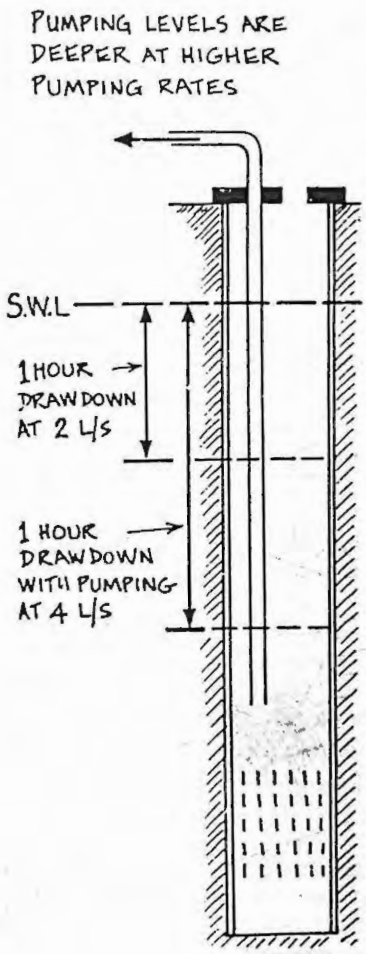
Specific Capacity = Yield ÷ Drawdown

Many of the developed groundwater reservoirs have been analysed and figures calculated for their hydraulic conductivity or transmissivity. This knowledge allows the theoretical specific capacity of wells tapping the aquifer, to be estimated.

A driller concerned about the efficiency of a well can compare the measured specific capacity with the theoretical figure calculated by Water Resources Authorities.

Over a period of time, a driller will build his own experience on figures that can be regarded as satisfactory Specific Capacities for the aquifers in the area where he works.

The L/sec per metre of drawdown is an easily calculated figure that helps the water well driller keep track, of his own achievements. It is rather like the way a vehicles performance can be rated by comparing its fuel consumption in litres per 100 kilometre (or miles per gallon).



Technical Area: 14 Pumping Test

Item: 14-2 Pumping test equipment

1: Objectives

To be able to explain and advise for necessary equipment to conduct pumping test.

2. Contents

- Submersible pump
- Control panel
- Riser pipe
- Pump head manihold
- Notch tank
- Water level indicator

3. Teaching Methods

(1) Explain the structure and components of pumping system using manual.

4. Materials

14-2M1 DDCA's Manual for Drilling Works

8.2 PUMPING TEST EQUIPMENT (TA CODE 14-2)

Figure 42 shows the standard setting of pumping test equipment. Major equipment necessary to conduct the pumping test is described below:

8.2.1 SUBMERSIBLE PUMP

Sumbmersible pump is the most important components of pumping test equipment. Various types and capacities of pumps are manufactured by many manufacturers. A pump consists of pump parts of multi-stage impellers and casings and submersible motors. The sumbmersible motor is of three phases power of 200 or 400 V or single phase of 200 V. They are classified by diameters of casings which they are to be applied. Each pump has a range of the total head and discharge rate. The pump is connected to the generator on the ground by submersible cables. Two-cores single cable is used for single phase pump. Three-cores single cable and three-cores double cables are respectively used for the starting methods of direct start and star-delta start for three phases pumps.

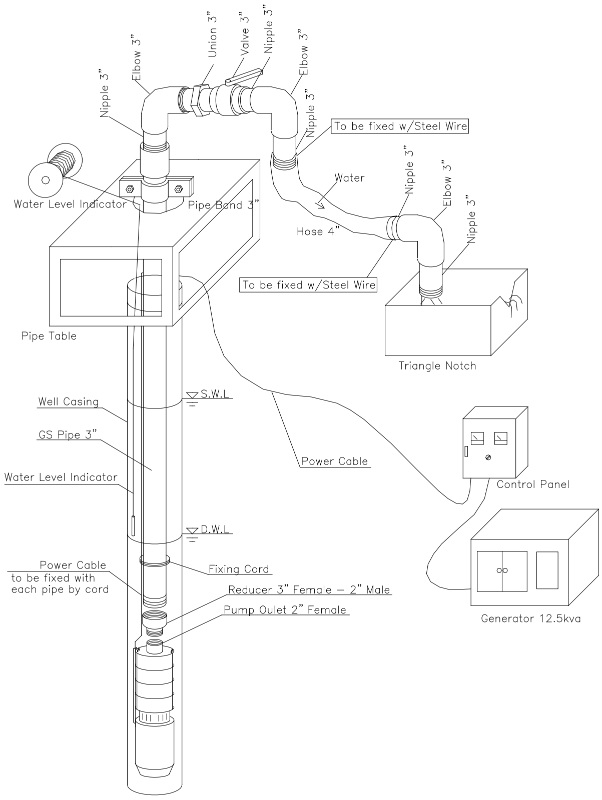


Figure 42 Standard Setting of Pumping Test Instruments

8.2.2 CONTROL PANEL

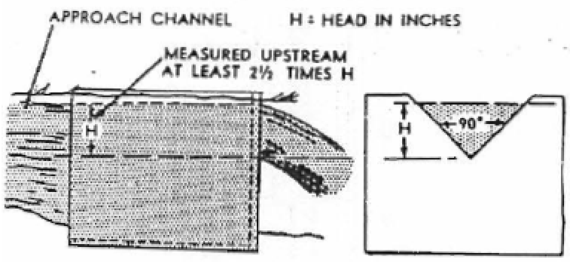
The control panel is an important instrument to control the pump. It is connected between the pump and the generator. It consists of the electrical circuit for on/off operation, safety cut/off for the over/under voltage and current, operation control by water level, pressure etc. The knowledge and skills of the operation and maintenance of the control panel is important for the drillers in charge of pumping test.

8.2.3 RISER PIPE

Riser pipes are threaded or franged pipes which conducts water from the pump to the ground or to the water tank. In general galvanized steel 1-1/2" to 6" pipes are used. For the permanent setting purpose, stainless riser pipes are used, too, as they are anticorrosive.

8.2.4 PUMP HEAD MANIHOLD

The pump head manihold consists of small pipes, elbows, reducers, valves, pressure gauges, air-release valve etc. This is important component to conduct proper control of the discharge rate for the test measurement.



Source: Australian Drilling Industry Training Committee Ltd

Figure 43 Structure of Notch Tank

8.2.5 NOTCH TANK

The discharge rate shall be correctly measured. For large discharge rate, the notch tank is used.

The discharge rate is calculated from the measured height of overflow from the weir(***Figure 43***). ***Table 34*** shows the conversion table from the measured height to the discharge rate.

Table 34 Conversion Table of Discharge Rate for 90 Deg. Notch Tank

Headabove Apex mm	L/sec	m³ day	gal/h	Headabove Apex mm	L/sec	m³ day	gal/h
000	00000	00000	00000	155	12.93	1117	10243
010	0.016	1.44	13	160	14.23	1229	11272
015	0.030	2.88	26	165	15.37	1328	12170
020	0.082	7.20	66	170	16.67	1431	13121
025	0.133	11.52	106	175	17.80	1538	14097
030	0.217	18.72	172	180	19.20	1650	15127
035	0.317	27.36	251	185	20.47	1768	16209
040	0.450	38.88	356	190	21.87	1889	17318
045	0.600	51.84	475	195	23.33	2016	18480
050	0.783	67.68	620	200	24.86	2148	19694
055	0.983	84.96	779	205	26.43	2284	20935
060	1.233	106.6	977	210	28.08	2426	22242
065	1.483	128.2	1175	215	29.77	2572	23572
070	1.800	155.5	1426	220	31.55	2726	24987
075	2.133	184.3	1689	225	33.38	2884	26439
080	2.216	217.4	1993	230	35.27	3047	27931
085	2.933	253.4	2323	235	37.22	3216	29426
090	3.367	290.9	2666	240	39.22	3388	31060
095	3.867	334.1	3062	245	41.30	3568	32710
100	4.383	378.7	3472	250	43.43	3752	34399
105	4.950	427.7	3920	255	45.20	3905	35798
110	5.583	482.4	4422	260	47.92	4140	37950
115	6.233	538.6	4937	265	50.25	4342	39798
120	6.933	599.0	5491	270	52.67	4550	41712
125	7.683	663.8	6085	275	55.11	4762	43652
130	8.467	731.5	6706	280	57.67	4982	45672
135	9.300	803.5	7366	285	60.27	5207	47731
140	10.18	879.8	8065	290	62.95	5438	49856
145	11.13	961.9	8818	295	65.70	5676	52034
150	12.17	1047	9596	300	68.52	5920	54265

A bucket is used for the measurement of small discharge rate. In this case, the usual confirmation of the volume of the bucket with the standard is important, so as not to prevent from the wrong measurement.

8.2.6 WATER LEVEL INDICATOR

The water level indicator consists of electric sensor which detect the water level by transmission of current through the water. The sensor is connected to the alarming device with buzzar or light by the two-cores cable with the depth measure. In order to conduct a smooth measurement, 1” PVC pipes are installed with the riser pipes to ensure the path of the sensor down to the water level.

Technical Area: 14 Pumping Test

Item: 14-3 Selection of Submersible Pump

1: Objectives
To be able to explain and advise for how to select suitable submersible pump according to capacity of well.

2. Contents
- Pump specifications
- Pump capacity curve
- Selection of submersible pump

3. Teaching Methods
(1) Explain specifications of submerible pump using catalog.
(2) Explain how to use pump capacity curve for the selection of the pump.

4. Materials
14-3M1 DDCA's Manual for Drilling Works

8.3 SELECTION OF SUBMERSIBLE PUMP (TA CODE 14-3)

8.3.1 PUMP SPECIFICATIONS

Drillers in charge of the pumping test shall be acquired the proper knowledge of the submersible pump for the selection of the suitable for each test. Principally, pump shall be selected according to the discharge rate and the total head. ***Table 35*** shows the specifications of the series of submersible pump of SP17 manufacture by GRUNDFOS. "17" of "SP17-10" means it is designed for pumping of 17 m^3/h of discharge rate. "10" is the number of stages of impeller. More number of stages produces hiegher pressure and needs more power. An option of ppower supply can be selected from voltages of 230 V or 400 V and from single phase or three phases. Diameter of the pump is important as well. The selected pump shall be of the diameter which can be smoothly installed into the casing pipes of the well, with the consideration of power cables.

8.3.2 PUMP CAPACITY CURVE AND SELECTION OF SUBMESIBLE PUMP

Figure 44 shows an example of the calculation of total head. In this example, the pump transmits the water of 10 m3/h up to the water tank of which the difference of the elevation down to the dynamic water level of the well is 82.5 m. In order to decide the total head of the submersible pump, head loss through the riser pipe and transmission pipe shall be calculated. The head loss of each diameter of the pipe can be calculated by using the pressure loss nomogram (See ***Figure 45***) According to the nomogram, unit head loss for each diameter of the pipes for 10 m^3/h are obtained as follows:

2" GS:	0.0350 m/m
2-1/2" GS:	0.0182 m/m
3" GS	0.0048 m/m

If 50 m of 2"GS is used, the head loss is calculated as 0.0350 m/m x 50 m = 1.75 m. For the type B in the example, 2" riser pipes and 3" transmission pipes are used. In this case the total head loss is calculated to be 6.89 m. The difference of the elevation between the dynamic water level and the tank is 82.5 m. Therefore the necessary pump head is calculated as 6.89 m + 82. 50 m = 89.39 m. Consequently the submersible pump with the discharge rate not less than 10 m^3/h and the total head not less than 89.39 m shall be selected.

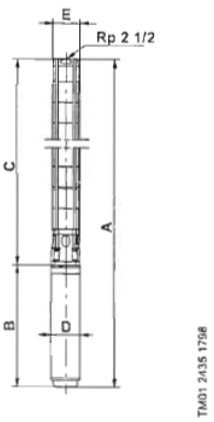
Figure 46 shows the pump capacity curve of SP17 series submersible pumps. The suitable pump can be selected by using the pump capacity curve according to the discharge rate and the total head. From these examinations, the submersible pump SP17-9 was selected.

Table 35 Specifications of Submersible Pump SP17 (Grundfos)

Technical data

Submersible pumps
SP 17

Dimensions and weights



SP 17-43 to SP 17-60 are mounted in sleeve for R 3 connection.

Pump type	Motor			Dimensions (mm)							Net weight [kg]	
	Type	Power [kW]	C	B		A		D	E*	E**		
				1x230V	3x230V 3x400V	1x230V	3x230V 3x400V				1x230V	3x230V 3x400V
SP 17-1	MS 402	0.55	314	291	241	605	555	95	131		13	11
SP 17-1 N (R)	MS 4000 R	0.75	314		398		712	95	131			17
SP 17-1 N (R)	MS 4000 R	2.2	314	573		887		95	131		26	
SP 17-2	MS 402	1.1	374	346	306	720	680	95	131		17	15
SP 17-2 N (R)	MS 4000 R	1.1	374		413		787	95	131			20
SP 17-2 N (R)	MS 4000 R	2.2	374	573		947		95	131		27	
SP 17-3	MS 402	2.2	435		346		781	95	131			19
SP 17-3 N (R)	MS 4000 R	2.2	435	573	453	1008	888	95	131		28	23
SP 17-4	MS 402	2.2	495		346		841	95	131			20
SP 17-4	MS 4000	2.2	495	573	453	1068	948	95	131		29	24
SP 17-5	MS 4000	3.0	556		494		1050	95	131			26
SP 17-6	MS 4000	4.0	616		574		1190	95	131			31
SP 17-7	MS 4000	4.0	677		574		1251	95	131			33
SP 17-8	MS 4000	5.5	737		674		1411	95	131			39
SP 17-9	MS 4000	5.5	798		674		1472	95	131			40
SP 17-10	MS 4000	5.5	858		674		1532	95	131			41
SP 17-11	MS 4000	7.5	919		773		1692	95	131			47
SP 17-12	MS 4000	7.5	979		773		1752	95	131			49
SP 17-13	MS 4000	7.5	1040		773		1813	95	131			50
SP 17-8	MS6	5.5	753		535		1288	143	142	142		50
SP 17-9	MS6	5.5	814		535		1349	143	142	142		51
SP 17-10	MS6	5.5	874		535		1409	143	142	142		53
SP 17-11	MS6	7.5	935		565		1500	143	142	142		55
SP 17-12	MS6	7.5	995		565		1560	143	142	142		56
SP 17-13	MS6	7.5	1056		565		1621	143	142	142		57
SP 17-14	MS6	9.2	1116		590		1706	143	142	142		64
SP 17-15	MS6	9.2	1177		590		1767	143	142	142		65
SP 17-16	MS6	9.2	1237		590		1827	143	142	142		66
SP 17-17	MS6	9.2	1298		590		1888	143	142	142		67
SP 17-18	MS6	11	1358		683		2041	143	142	142		72
SP 17-19	MS6	11	1419		683		2102	143	142	142		73
SP 17-20	MS6	11	1479		683		2162	143	142	142		74
SP 17-21	MS6	13	1540		708		2248	143	142	142		78
SP 17-22	MS6	13	1600		708		2308	143	142	142		79
SP 17-23	MS6	13	1661		708		2369	143	142	142		81
SP 17-24	MS6	13	1721		708		2429	143	142	142		82
SP 17-25	MS6	15	1782		738		2520	143	142	142		87
SP 17-26	MS6	15	1842		738		2580	143	142	142		88
SP 17-27	MS6	15	1903		738		2641	143	142	142		89
SP 17-28	MS6	18.5	1963		783		2746	143	142	142		96
SP 17-29	MS6	18.5	2024		783		2807	143	142	142		97
SP 17-30	MS6	18.5	2084		783		2867	143	142	142		99
SP 17-31	MS6	18.5	2145		783		2928	143	142	142		100
SP 17-32	MS6	18.5	2205		783		2988	143	142	142		101
SP 17-33	MS6	18.5	2266		783		3049	143	142	142		102
SP 17-34	MS6	22	2326		838		3164	143	142	142		109
SP 17-35	MS6	22	2387		838		3225	143	142	142		111
SP 17-36	MS6	22	2447		838		3285	143	142	142		112
SP 17-37	MS6	22	2508		838		3346	143	142	142		113
SP 17-38	MS6	22	2568		838		3406	143	142	142		114
SP 17-39	MS6	22	2629		838		3467	143	142	142		115
SP 17-40	MS6	22	2689		838		3527	143	142	142		117
SP 17-43	MS6	26	3118		903		4021	143	175	181		164
SP 17-45	MS6	26	3239		903		4142	143	175	181		167
SP 17-48	MS6	26	3420		903		4323	143	175	181		172
SP 17-51	MS6	30	3602		968		4570	143	175	181		185
SP 17-53	MS6	30	3723		968		4691	143	175	181		189
SP 17-55	MMS 6000	37	3844		1425		5269	144	175	181		239
SP 17-58	MMS 6000	37	4025		1425		5450	144	175	181		244
SP 17-60	MMS 6000	37	4146		1425		5571	144	175	181		248

* Maximum diameter of pump with one motor cable.

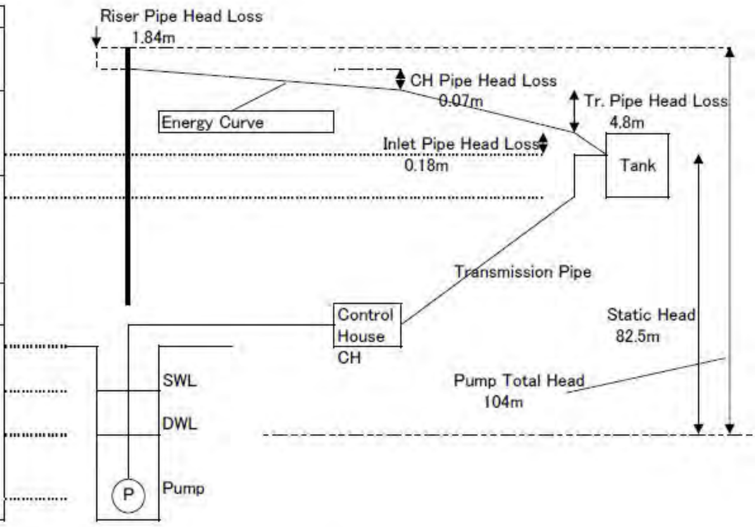
** Maximum diameter of pump with two motor cables.

The pump types above are also available in R and N-versions, see page 5 for further details.
Dimensions as above.

Other types of connection are possible by means of connecting pieces, see page 87.

GRUNDFOS

Elevation	Pipe Length
T. Head m (from Well GL)	
Inlet 40 m (from Well GL)	Inlet Pipe (Tank GL to Inlet) 10 m
Tank GL 30 m (from Well GL)	Transmission Pipe (Control House to Tank GL) 1000 m
Control House 0 m	Well – Control House 10 m
Well 0 m	Riser Pipe 52.5 m
SWL −14.64 m	
DWL −42.5 m	
Pump −52.5 m	



Head Loss Calculation

Type A	
Riser Pipe	
Pipe Type	2"GS
Pipe Dia.	52.48 mm
Velocity	1.28 m/sec
Hydro. Grad.	0.035 m/m
Pipe Length	52.5 m
Head Loss	1.84 m
Control House Pipe	
Pipe Type	2"GS
Pipe Dia.	52.48 mm
Velocity	1.28 m/sec
Hydro. Grad.	0.035 m/m
Pipe Length	10 m
Head Loss	0.35 m
Transmission Pipe	
Pipe Type	2"GS
Pipe Dia.	52.48 mm
Velocity	1.28 m/sec
Hydro. Grad.	0.035 m/m
Pipe Length	1000 m
Head Loss	35 m
Inlet Pipe	
Pipe Type	2-1/2"GS
Pipe Dia.	62.68 m
Velocity	0.9 m/sec
Hydro. Grad.	0.0182 m/m
Pipe Length	10 m
Head Loss	0.18 m

Total Head Loss	37.37 m
Elevation between Tank and DWL	82.5 m
Necessary Pump Head	119.87 m

Type B	
Riser Pipe	
Pipe Type	2"GS
Pipe Dia.	52.48 mm
Velocity	1.28 m/sec
Hydro. Grad.	0.035 m/m
Pipe Length	52.5 m
Head Loss	1.84 m
Control House Pipe	
Pipe Type	2"GS
Pipe Dia.	52.48 mm
Velocity	1.28 m/sec
Hydro. Grad.	0.0065 m/m
Pipe Length	10 m
Head Loss	0.07 m
Transmission Pipe	
Pipe Type	3"GS
Pipe Dia.	52.48 mm
Velocity	0.58 m/sec
Hydro. Grad.	0.0048 m/m
Pipe Length	1000 m
Head Loss	4.8 m
Inlet Pipe	
Pipe Type	2-1/2"GS
Pipe Dia.	62.68 m
Velocity	0.9 m/sec
Hydro. Grad.	0.0182 m/m
Pipe Length	10 m
Head Loss	0.18 m

Total Head Loss	6.89 m
Elevation between Tank and DWL	82.5 m
Necessary Pump Head	89.39 m

Velocity of Transmission Pipe shall be less than 0.6m/s

Total Head Loss shall be less than 20 m

Then,
Suitable Type is Type-B

Residual Head shall be not less than 5m

Provisional Pump Selection	
Pump Model	SP-17-10
Total Head	104 m
Necessary He:	89.39 m
Residual Head	14.61 m
Closing Head	112 m
Power	5.5 kw

Figure 44 Example of Calculation of Pump Total Head (Discharge Rate 10 m^3/h)

Pressure Loss Nomogram

Miscellaneous

Pressure Loss for Hot Galvanized Steel Pipes without Deposits

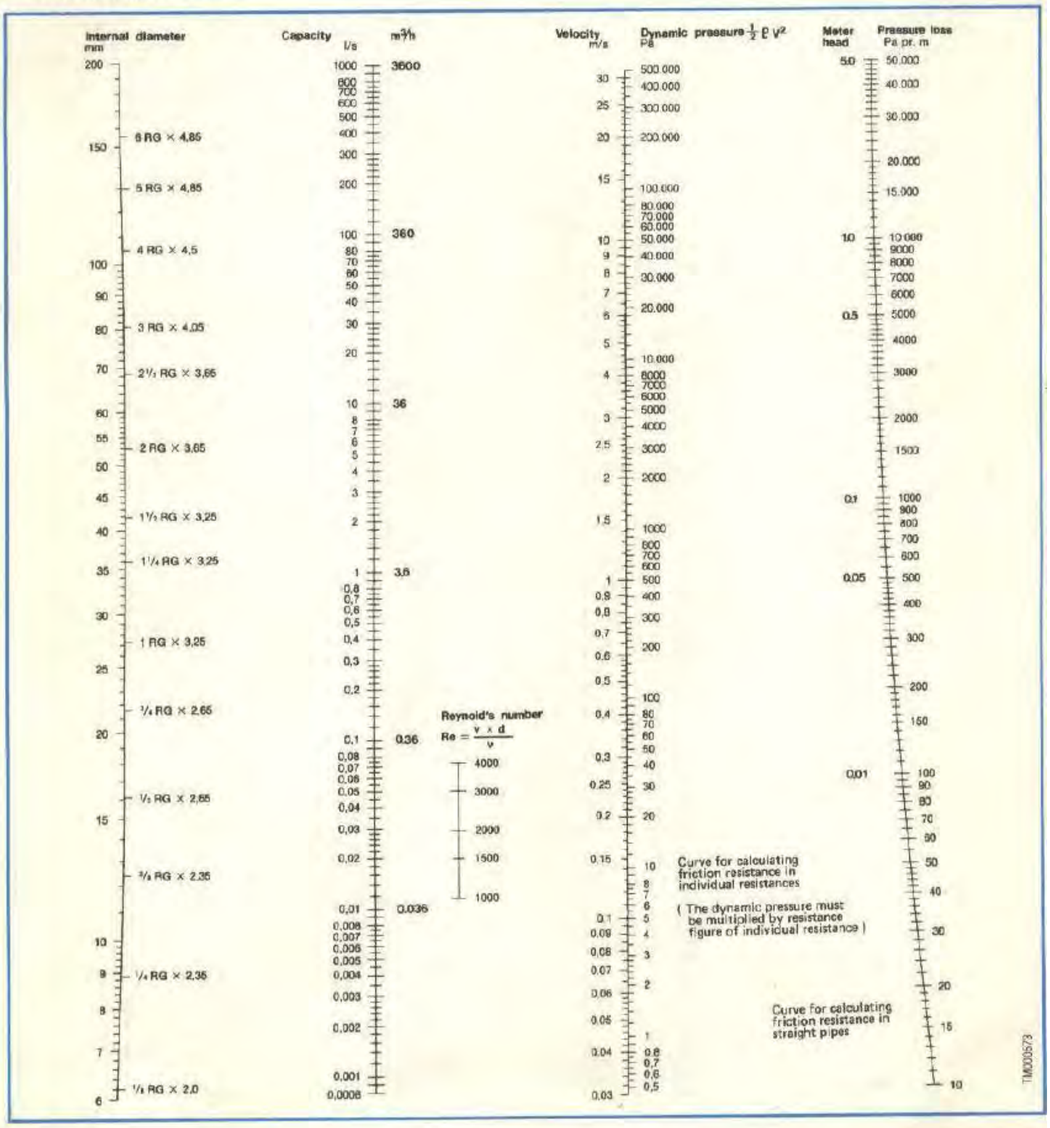
Water Temperature: 10°C

Application
Pipes for domestic water where no deposits are expected.

Temperature range
The nomogram is valid for water at 10°C. At 0°C the pressure loss error will be no more than +10% and at 55°C no more than −25%.

Basis
Colebrook's formula at a water temperature t=10°C and an absolute roughness k=0.15×10⁻³ m.

Diameters
On the right hand side of the diameter scale, the internal diameter of medium thick threaded pipes, steel 00, according to DS 540, 3rd edition, are stated.
According to this standard these diameters are indicated with the thread that can be cut in the pipe, plus the wall thickness in mm.



GRUNDFOS

Figure 145 Pressure Loss Nomogram for Galvanized Steel Pipe

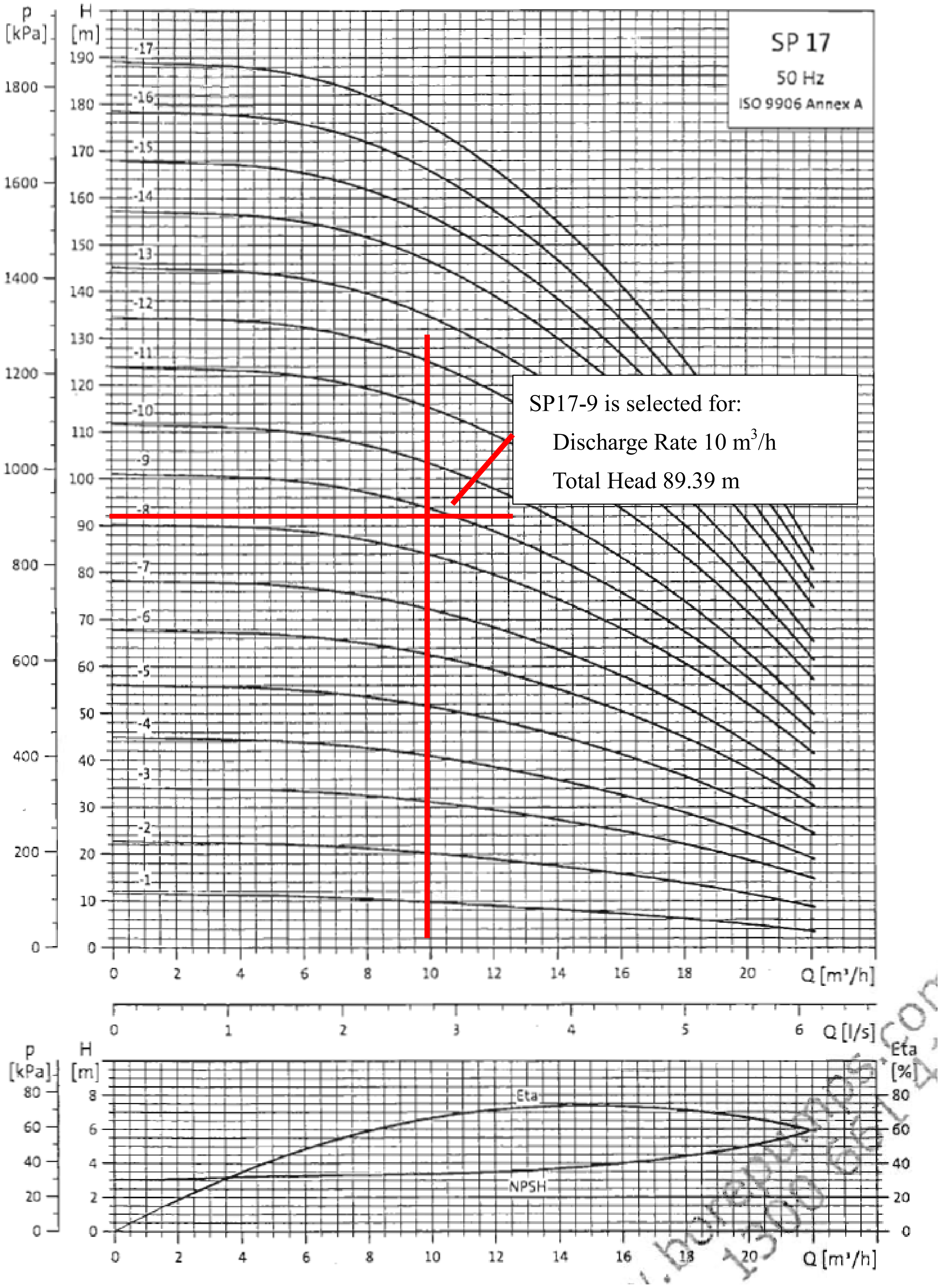


Figure 46 Pump Capacity Curve of SP17 Serieis (GRUNDFOS)

Technical Area: 14 Pumping Test
Item: 14-4 Interpretation of test results

1: Objectives

To be able to explain and advise for interpretation of step drawdown test and constant dicharge rate test and recovery test in order to determine well capacity and select proper pump.

2. Contents

- Record of pumping test
- Interpretation of step drawdown pumping test
- Interpretation of constant discharge rate puming test

3. Teaching Methods

(1) Explain non-equilibrium interpretation methods of pumping test using manual.
(2) Explain practical interpretation using exercise.

4. Materials

14-4M1 DDCA's manual for Drilling Works
14-4M2 Text Book of Hydrogeology and Well Hydraulics in the course of Well Management of JICA's technical cooperation project in Sudan

8.4 INTERPRETATION OF TEST RESULTS (TA CODE 14-4)

8.4.1 RECORD OF PUMPING TEST

DDCA normally conducts the constant discharge rate pumping test and the recovery test after the completion of the drilling works. The step drawdown tests are conducted when the client specially requests. ***Figure 48*** is the DDCA's record form for the constant discharge rate test and ***Figure 49*** is the one for the recovery test. A challenge related to the pumping test records of DDCA is that the summary of the pumping test including the preliminary pumping test, step drawdown pumping test, constant discharge rate pumping test and recovery test is not included in the record forms. This series of test shall be summarized as the example shown in ***Figure 47***.

Summary of Pumping Test

Borehole No.: CO 596/2008
Done By: DDCA

1. Contents:		
Preliminary Test	Yes	(Yes/No)
Step Drawdown Test	5	(numbers of steps)
Constant Discharge Rate Test	Yes	(Yes/No)
Recovery Test	Yes	(Yes/No)

2. Preliminary Test	
Date From	28-Oct-08
Date To	29-Oct-08
Duration (min)	360
Static Water Level (m)	11.21
Q (m3/h)	40.62
Q (L/min)	677
D.W.L (m)	15.28
s (m)	4.07

3. Step-Drawdown Test						
Date:	29-Oct-08		Date To	29-Oct-08		
Static Water Level (m) :			6.98			
Step	Duration (min)	Q (m3/h)	Q (L/min)	D.W.L (m)	s (m)	Q/s (m3/h/m)
1	120	10.09	168.17	11.68	4.70	2.15
2	120	20.63	343.83	14.94	7.96	2.59
3	120	29.33	488.83	15.70	8.72	3.36
4	120	40.62	677	16.58	9.60	4.23
5	120	49.50	825	17.52	10.54	4.70

4. Constant-Drawdonw Test	
Date From	30-Oct-08
Date To	01-Nov-08
Static Water Level (m)	8.85
Duration (min)	2880
Q (m3/h)	49.50
Q (L/min)	825
D.W.L (m)	21.40
Q/s (m3/h/m)	3.94
s (m)	12.55
Recovered D.W.L After 1hr(m)	12.70

Figure 47 Example of Form of Summary of Pumping Test

CONSTANT PUMPING TEST

Conducted for: 05:00 **Hours Done by:** DDCA
S.W.L at: 02 **meters** 57 **cm** **Yield:** 700 LPH **Drawdown** 45 **meters** 62 **cm**
Outflow measured with Tank Capacity of: 22 **liters.**

PUMP TEST METHOD

Air lift size...inches; Placed at depth of...............meters.
Pump Cylinder size............................inches; Placed at depth of...............meters.
Submersible pump size:....................Placed at depth of: 50 **meters** 00 **cm**

WATER LEVEL DRAWDOWN (B.G.L.)

Date	Time		DWL		Yield LPH	Date	Time		DWL		Yield LPH	Remarks (Water Appearance, Tes interrupted. Etc.
	hrs	min	m	cm			hrs	min	m	cm		
04.12.2008		00	02	57	-----			300	48	19		
		01	04	30	700							
		02	04	47	700							
		03	04	63	700							
		04	04	89	700							
		05	05	13	700							
		06	05	26	700							
		07	05	53	700							
		08	05	68	700							
		09	06	05	700							
		10	06	32	700							
		12	07	06	700							
		14	07	97	700							
		16	08	93	700							
		18	09	58	700							
		20	09	55	700							
		25	11	80	700							
		30	13	48	700							
		35	15	56	700							
		40	16	95	700							
		50	17	81	700							
		60	19	50	700							
		75	21	38	700							
		90	25	18	700							
		105	27	28	700							
		120	29	73	700							
		135	37	12	700							
		150	40	16	700							
		165	43	93	700							
		195	45	21	700							
		210	46	94	700							
		225	46	61	700							
		240	48	17	700							
		270	48	18	700							

Figure 48 DDCA's Record Form of Constant Discharge Rate Test

CONSTANT WATER LEVEL RECOVERY (B.G.L.)

Date	Time		Water level rose to:		Date	Time		Water level rose to:		Additional Notes
	hrs	min	m	cm		hrs	min	m	cm	
		00	48	19			300	37	24	
		01	48	08			330	37	02	
		02	47	75			360	36	16	
		03	47	48			390	35	03	
		04	47	19			420	32	17	
		05	46	65			450	26	14	
		06	46	18			480	18	13	
		07	45	90			540	16	72	
		08	45	60			600	10	17	
		09	43	98			660	07	94	
		10	43	52			720	06	41	
		12	43	38			780	05	03	
		14	43	27			840	04	71	
		16	43	18			900	04	12	
		18	43	07			960	04	01	
		20	42	88			1020	03	81	
		25	42	67			1080	03	66	
		30	42	44			1140	03	51	
		35	42	30			1200	03	50	
		40	42	21			1260	03	50	
		50	42	10						
		60	41	89						
		75	41	67						
		90	41	48						
		105	41	20						
		120	40	98						
		135	40	55						
		150	40	22						
		165	39	75						
		195	38	60						
		210	38	19						
		225	38	01						
		240	37	90						
		270	37	80						

REMARKS:

Figure 49 DDCA's Record Form of Recovery Test

8.4.2 INTERPRETATION OF PUMPING TEST RESULTS

There are various interpretation methos of pumping test. They are categorized in two major methods of non-equilibrium method and equilibrium method. The equilibrium methods are used to calculate the hydraulic coefficients of aquifer such as transmissivity, storage coefficient etc. These methods are based on Theis' formula. The non-equilibrium methods are used to calculate the well capacities and efficiency by calculating the parameters such as well loss and aquifer loss coefficient, specific capacity.

This section describes the simplified non-equilibrium method to determine the recommended discharge rate of the well to decide the pump capacity and position. This is one of practical interpretation methods for drillers. An example of the pumping test data and intrpreptation are given in ***Figure 50*** to ***Figure 53***. The data of well is as follows:

Completion Date		14-Oct-08
Well No.		CO 596/2008
Borehole No.		MKR-2-BH2
Pumping Test No.		PT-025
Village		Mwandege
Region		COAST
Contractor		DDCA
Static Water Level (m)		1.3
Blown Yield (m3/h)		4.2
Screen Position (m-m)		55.35-61.10, 69.68-72.54
Casing Depth (m)		76
Date of Step Drawdown Test	From	17-Oct-08
	To	18-Oct-08
Date of Constant Discharge Rate Test	From	19-Oct-08
	To	20-Oct-08

From the results of the step drawdown test, discharge rate, dynamic water level, drawdown and s/Q are summarized and Q-s curve is plotted as shown in ***Figure 52***. Then the recommended discharge rate is determined from the Q-s curve as to be 4.25 m^3/h with the consideration of safety factor of 0.85. Accordingly, dynamic water level is estimated to be 45.70 m. The pump setting depth can be determined from this dynamic water level and several meters for seasonal fluctuation. All the pumping test results, interpretation and pump setting plan are summarized as shown in ***Figure 53***.

1st Step				2nd Step				3rd Ster				4th Step				5th Step			
Time Since Pump Started (min)	Time of Each Step	Dynamic Water Level (m)	Discharge Rate Q (m3/h)	Time Since Pump Started (min)	Time of Each Step	Dynamic Water Level (m)	Discharge Rate Q (m3/h)	Time Since Pump Started (min)	Time of Each Step	Dynamic Water Level (m)	Discharge Rate Q (m3/h)	Time Since Pump Started (min)	Time of Each Step	Dynamic Water Level (m)	Discharge Rate Q (m3/h)	Time Since Pump Started (min)	Time of Each Step	Dynamic Water Level (m)	Discharge Rate Q (m3/h)
0	0	14.64																	
1	1	19.53	2	121	1	30.7	3	241	1	38.65	4	361	1	46.22	5	481	1	54.37	6
2	2	24.42		122	2	30.99		242	2	39.22		362	2	46.6		482	2	56.49	
3	3	26.61		123	3	31.37		243	3	39.75		363	3	46.72		483	3	58.55	
4	4	28.22		124	4	31.85		244	4	40.14		364	4	46.81		484	4	59.58	
5	5	28.47		125	5	32.35		245	5	40.5		365	5	46.95		485	5	60.06	
6	6	28.55		126	6	32.64		246	6	40.76		366	6	47.1		486	6	60.46	
7	7	28.61		127	7	32.85		247	7	41.02		367	7	47.23		487	7	60.84	
8	8	28.69		128	8	33.08		248	8	41.11		368	8	47.4		488	8	61.18	
9	9	28.75		129	9	33.25		249	9	41.3		369	9	47.51		489	9	61.52	
10	10	28.8		130	10	33.37		250	10	41.42		370	10	47.65		490	10	61.82	
12	12	28.88		132	12	33.58		252	12	41.62		372	12	47.93		492	12	62.38	
14	14	28.93		134	14	33.7		254	14	41.79		374	14	48.2		494	14	62.92	
16	16	29		136	16	33.82		256	16	41.89		376	16	48.45		496	16	63.42	
18	18	29.07		138	18	33.94		258	18	42.05		378	18	48.6		498	18	63.93	
20	20	29.12		140	20	33.98		260	20	42.2		380	20	48.73		500	20	64.43	
25	25	29.21		145	25	34.15		265	25	42.33		385	25	48.99		505	25	65.37	
30	30	29.27		150	30	34.35		270	30	42.44		390	30	49.24		510	30	66.27	
35	35	29.35		155	35	34.44		275	35	42.55		395	35	49.47		515	35	67.08	
40	40	29.4		160	40	34.57		280	40	42.67		400	40	49.7		520	40	67.78	
45	45	29.43		165	45	34.64		285	45	42.8		405	45	49.91		525	45	68.43	
50	50	29.44		170	50	34.8		290	50	42.9		410	50	50.1		530	50	68.98	
55	55	29.44		175	55	34.99		295	55	42.99		415	55	50.36		535	55	69.4	
60	60	29.45		180	60	35.47		300	60	43.07		420	60	50.51		540	60	69.68	
70	70	29.45		190	70	35.84		310	70	43.23		430	70	50.77		550	70	69.72	
80	80	29.47		200	80	36.09		320	80	43.4		440	80	50.99		560	80	69.75	
90	90	29.48		210	90	36.28		330	90	43.51		450	90	51.1		570	90	69.77	
100	100	29.48		220	100	36.4		340	100	43.6		460	100	51.14		580	100	69.78	
110	110	29.48		230	110	36.46		350	110	43.62		470	110	51.18		590	110	69.78	
120	120	29.48		240	120	36.46		360	120	43.62		480	120	51.18		600	120	69.78	

Figure 50　Example of Results of Step Drawdown Test

Constant Discharge Rate Test									Recovery Test					
Time Since Pump Started (min)	Dynamic Water Level (m)	Discharge Rate Q (m3/h)	Time Since Pump Started (min)	Dynamic Water Level (m)	Discharge Rate Q (m3/h)	Time Since Pump Started (min)	Dynamic Water Level (m)	Discharge Rate Q (m3/h)	Time Since Pump Started (min)	Time Since Pump stopped (min)	Dynamic Water Level (m)	Time Since Pump Started (min)	Time Since Pump stopped (min)	Dynamic Water Level (m)
0	15.72								2880	0	45.13			
1	17.68	5	100	35.46	5	1200	43.28	5	2881	1	33.61	2980	100	19.15
2	19.7		110	35.88		1260	43.48		2882	2	32.12	2990	110	19.03
3	21.44		120	36.1		1320	43.64		2883	3	29.95	3000	120	18.72
4	23.43		140	36.41		1380	43.89		2884	4	28.1	3020	140	18.52
5	24.53		160	36.7		1440	44		2885	5	26.83	3040	160	18.34
6	25.43		180	36.84		1560	44.21		2886	6	25.62	3060	180	18.18
7	26.24		200	36.95		1680	44.39		2887	7	24.88	3080	200	18.07
8	26.85		220	37.26		1800	44.5		2888	8	24.27	3100	220	17.95
9	27.23		240	37.45		1920	44.68		2889	9	23.75	3120	240	17.78
10	27.57		270	37.7		2040	44.85		2890	10	23.33	3150	270	17.42
12	28.67		300	38.04		2160	44.93		2892	12	22.86	3180	300	17.09
14	29.18		330	38.2		2280	44.99		2894	14	22.53	3210	330	16.82
16	30.29		360	38.32		2400	45.05		2896	16	22.28	3240	360	16.57
18	31.12		420	38.53		2520	45.1		2898	18	22.1	3270	390	16.57
20	31.6		480	38.75		2640	45.12		2900	20	21.88	3300	420	16.35
25	32.21		540	39.35		2760	45.13		2905	25	21.64	3330	450	16.35
30	32.7		600	39.95		2880	45.13		2910	30	21.24	3360	480	16.16
35	32.91		660	40.45					2915	35	21.01	3390	510	16.16
40	33.17		720	40.81					2920	40	20.95	3420	540	16.02
45	33.44		780	41.21					2925	45	20.7	3450	570	16.02
50	33.75		840	41.59					2930	50	20.51	3480	600	15.93
55	34.13		900	41.95					2935	55	20.38	3510	630	15.93
60	34.33		960	42.3					2940	60	20.23	3540	660	15.87
70	34.65		1020	42.56					2950	70	20.03	3570	690	15.87
80	34.91		1080	42.81					2960	80	19.72	3600	720	15.82
90	35.24		1140	43.06					2970	90	19.53	3660	780	15.82

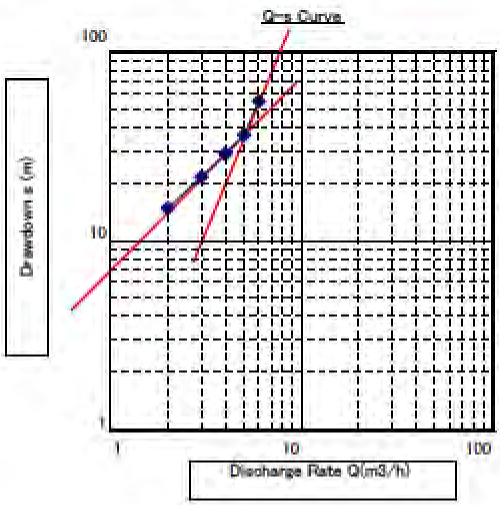
Figure 51　DDCA's Record Form of Recovery Test

Form No.: PT-002
Form Name: Analysis of Step Drawdown Test

Date: 17-Oct-08 – 18-Oct-08

Static Water Level (m):	14.64

Step	Duration (min)	Q (m3/h)	D.W.L (m)	s (m)	Q/s (m3/h/m)	s/Q (m/(m3/h))
1	120	2.00	29.48	14.84	0.13	7.42
2	120	3.00	36.46	21.82	0.14	7.27
3	120	4.00	43.62	28.98	0.14	7.25
4	120	5.00	51.18	36.54	0.14	7.31
5	120	6.00	69.78	55.14	0.11	9.19

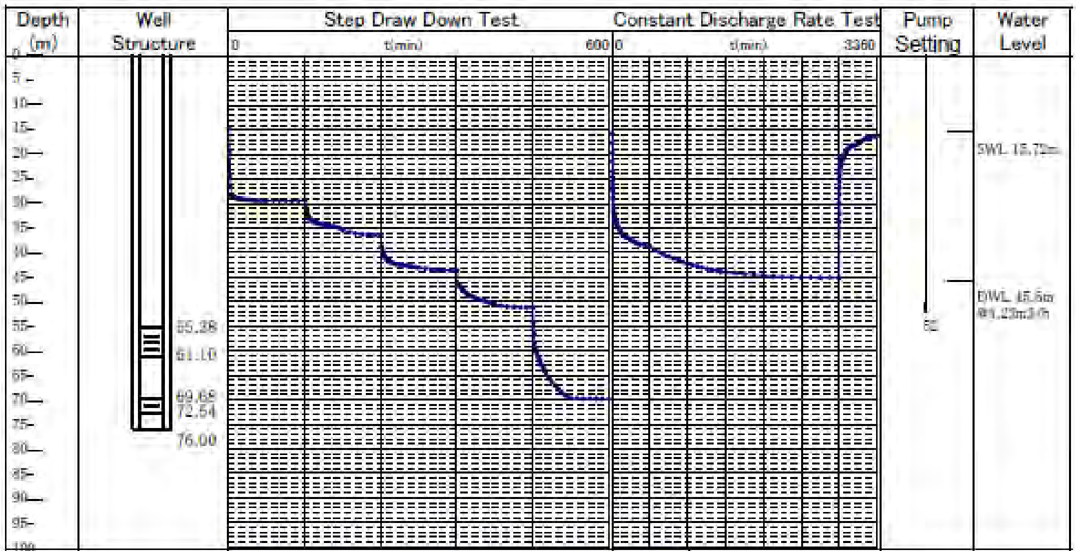


Analysed Max. Discharge Rate (m3/h)	5 (1)
@ s (m)	36.54 (2)
@D.W.L (m)	51.18 (3)
Safety Factor	0.85 (4)
Recommended Discharge Rate (m3/h)	
(1) x (4)	4.25 (5)
@ s (m)　(2) x (4)	31.06 (6)
@D.W.L (m (6) + SWL	45.70 (7)

Figure 52　Example of Interpretation of Step Drawdown Test

Form No.: PT-001
Form Name: Pumping Test Results

Well Information			
Completion Date	14-Oct-08	Static Water Level (m)	1.3
Well No.	CO 596/2008	Blown Yield (m3/h)	4.2
Borehole No.	MKR-2-BH2	Screen Position (m-m)	55.35-61.10, 69.68-72.54
Pumping Test No	PT-025		
Village	Mwandege		
Region	COAST		
Contractor	DDCA	Casing Depth (m)	76



14.64					15.72	SWL (m)
29.48	36.46	43.62	51.18	69.78	45.13	DWL (m)
2.00	3.00	4.00	5.00	6.00	5.00	Discharge Rate (m3/h)
14.54	21.62	28.98	36.54	55.14	29.41	s (m)
0.13	0.14	0.14	0.14	0.11	0.17	Q/s (m3/h/m)
7.43	7.27	7.25	7.31	9.19	5.08	s/Q (m/(m3/h))

Operational Discharge Rate: 4.23 m3/h, 7? L/min

Figure 53 Summary Report of Pumping Test Result and Pump Installation Plan

M14-4 M2

Sudan/ Japan Technical Cooperation
(JICA+PWCT)
Project For Human Resources Development
(Water Sector)

Well Management Training Course Plan
2nd. Session

Hydrogeology & Well Hydraulics

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Hydrogeologist

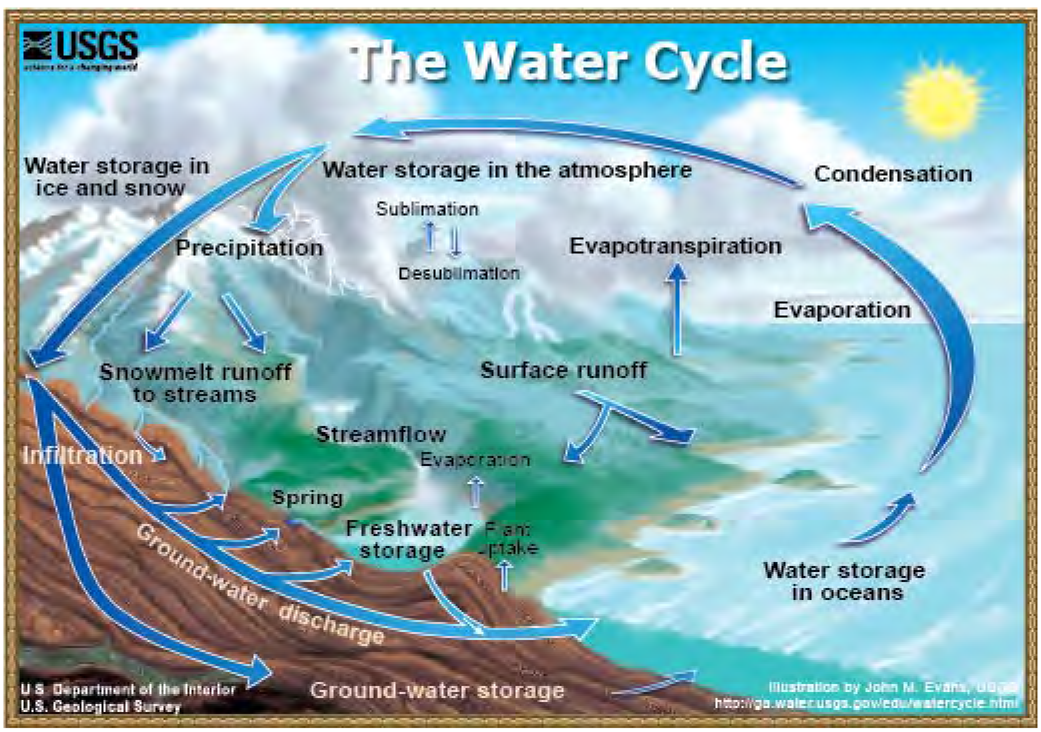
February 2010

1. HYDROGEOLOGY:

1.1. The Hydrologic Cycle:

Water Cycle or Hydrologic Cycle is the series of movements of water above, on, and below the surface of the earth. The water cycle consists of four distinct stages: storage, evaporation, precipitation, and runoff. Water may be stored temporarily in the ground; in oceans, lakes, and rivers; and in ice caps and glaciers. It evaporates from the earth's surface, condenses in clouds, falls back to the earth as precipitation (rain or snow), and eventually either runs into the seas or re-evaporates into the atmosphere. Almost all the water on the earth has passed through the water cycle countless times. Very little water has been created or lost over the past billion years

. Fig 1: The Hydrologic Cycle:

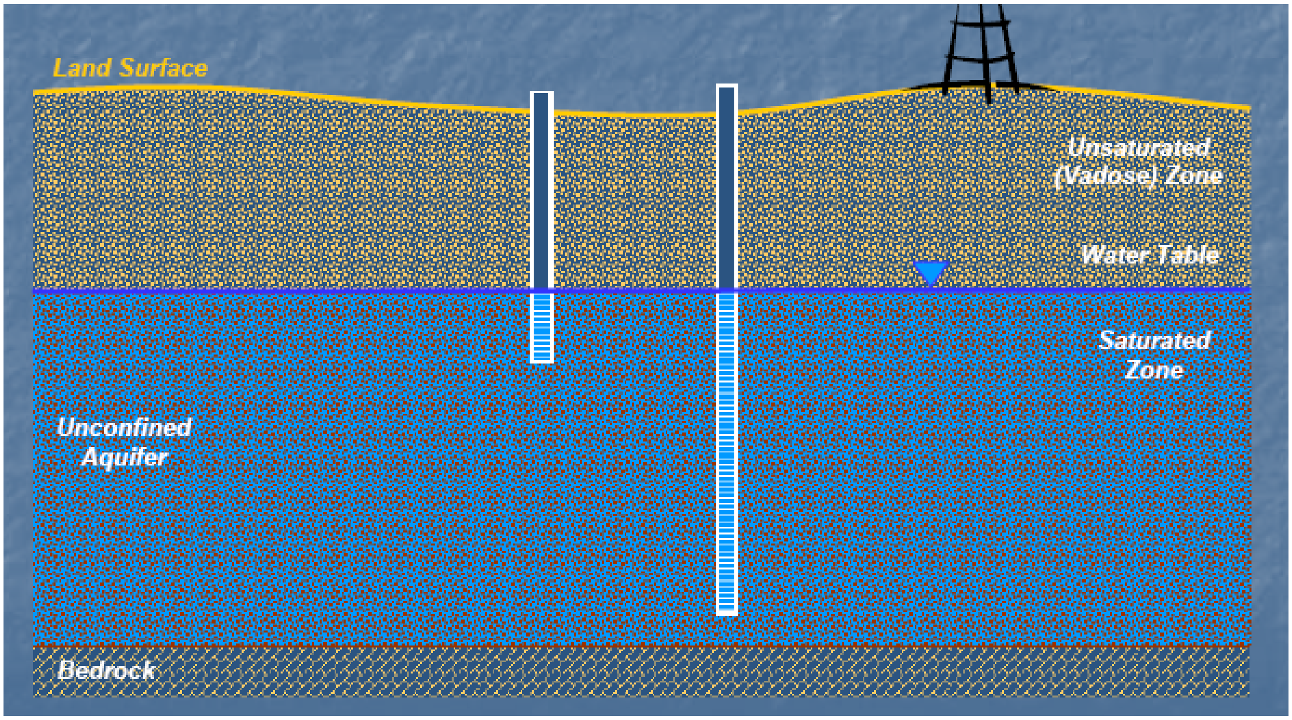


1.2. - AQUIFER TYPES:

1.2.1 - Unconfined Aquifers:

An unconfined aquifer is a permeable bed only partly filled with water and overlying a relatively impervious layer. Its upper boundary is formed by a free water table or phreatic level under atmospheric pressure. Water in a well penetrating an unconfined aquifer does not, in general, rise above the phreatic level. The water in an unconfined aquifer is called unconfined or phreatic water.

Fig 2: Unconfined (water table) Aquifer:

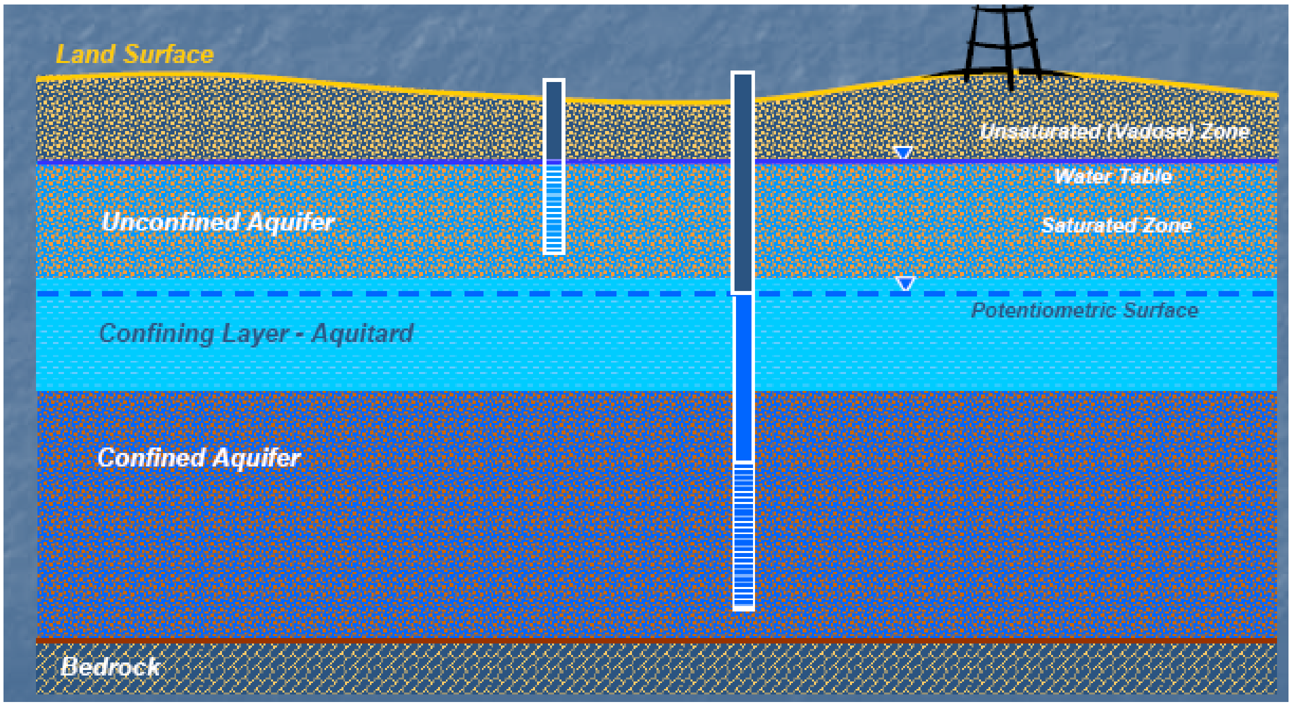


In fine-grained unconfined aquifers, gravity drainage of the pores is often not instantaneous; consequently the water is released only sometime after the lowering of the water level. Unconfined aquifers showing this phenomenon are called unconfined aquifers with delayed yield.

1.2.2. - Confined Aquifers:

A confined aquifer is a completely saturated aquifer whose upper and lower boundaries are impervious layers. Completely impervious layers rarely exist in nature and hence confined aquifers are less common than is often recognized.

Fig 3: Confined Aquifer:



In confined aquifers the pressure of the water is usually higher than that of the atmosphere and the water in wells stands above the top of the aquifer. The water in a confined aquifer is called confined or artesian water.

1.2.3. - Semi-confined Aquifers:

A semi-confined aquifer, also called leaky aquifer, is a completely saturated aquifer that is bounded above by a semi-pervious layer and below by a layer that is either impervious or semi-pervious. A semi-pervious layer is defined as a layer which has a low, though measureable, permeability. Lowering of the piezometric head in a leaky aquifer will generate a vertical flow of water from the semi-pervious layer into the pumped aquifer. Since the hydraulic conductivity of the covering layer is usually very small, the horizontal flow component in this layer can be neglected. For the detection of water movement in this type of aquifer, piezometers should be installed not only in the aquifer itself, but also in the upper semi-pervious layer and in the lower semi-pervious layer, if present. In general, the drawdown of the phreatic level in the semi-pervious layer is very small compared with the lowering of the piezometric level of the aquifer.

1.2.4. - Semi-unconfined Aquifers:

If the hydraulic conductivity of the fine-grained layer in a semi-confined aquifer is so great that the horizontal flow component in the covering layer cannot be ignored, then such an aquifer is intermediate between the traditional semi-confined aquifer and the unconfined aquifer and may be called a semi-unconfined aquifer.

2. HYDRAULIC PROPERTIES:

2.1. Transmissivity (T):

It is the product of the average hydraulic conductivity (or permeability) and the thickness of the aquifer. Consequently, transmissivity is the rate of flow under a hydraulic gradient equal to unity through a cross-section of unit width over the whole thickness of the aquifer. It is designated by the symbol kD or T. It has the dimensions of (L^3/TxL) or (L^2/T) and is, for example, expressed in (m^2/day).

2.2. Storage Coefficient and Specific Yield (S):

Both are defined as the volume of water released or stored per unit surface area of the aquifer per unit change in the component of head normal to the surface. They are designated by the symbol S and are dimensionless.

The storage coefficient refers only to the confined parts of an aquifer and depends on the elasticity of the aquifer material and the fluid. It has an order of magnitude of 10^{-4} to 10^{-6}.

The specific yield refers to the unconfined parts of an aquifer. In practice, it may be considered to equal the effective porosity or drainable pore space because in unconfined aquifers the effects of the elasticity of the aquifer material and fluid are generally negligible. It should be kept in mind that small pores do not contribute to the effective pore space because in small pores the retention forces are greater than the weight of the water. For sands the specific yield may be in the order of 0.1 to 0.2 (10% to 20%).

In American literature the terms storage coefficient and specific yield are often used synonymously.

2.3. Hydraulic Resistance (c):

Also called reciprocal leakage coefficient or resistance against vertical flow, is a property of semi-confined aquifers. It is the ratio of the saturated thickness of the semi-pervious layer (D′) and the hydraulic conductivity of the semi-pervious layer for vertical flow (k′), hence (D′/k′). It characterizes the resistance of the semi-pervious layer to upward or downward leakage. It is designated by the symbol (c) and has the reduced dimension of Time (it is expressed for example in days). It will be noted that if c = ∞ the aquifer is confined.

2.4. Leakage Factor (L):

The leakage factor L = $\sqrt{kDc}$ determines the distribution of leakage into the semi-confined aquifer. In other words, it determines the origin of water withdrawn from a well tapping the aquifer. High values of L indicate a great resistance of the semi-pervious strata to flow, as compared with the resistance of the aquifer itself. In that case the influence of leakage will be small. The factor L has the dimension of Length and it is, for example, expressed in meters.

2.5. Drainage Factor (B):

The drainage factor B = $\sqrt{(kD/\alpha Sy}$, which is encountered in unconfined aquifers with delayed yield can be compared with the leakage factor in semi-confined aquifers although it is defined in a different way. Large values of B indicate a fast drainage. The drainage factor has the dimension of Length (e.g. meters).

If B = ∞, the yield is instantaneous with the lowering of the water table and so the aquifer is unconfined without delayed yield.

4. METHODS OF ANALYZING PUMPING TEST DATA:

4.1 - DARCY'S LAW:

According to Darcy's Law, the rate of flow through a porous medium is proportional to the head loss, inversely proportional to the length of the flow path, and proportional to the coefficient k. The law can be expressed as follows:

$$Q = kiA, \text{ or, } Q/A = v = ki$$

Where:

Q = the flow rate (m^3/day),

k = a constant (m/day),

i = the hydraulic gradient, i.e. the loss of head h over the distance l,

A = the total cross-section perpendicular to the flow (m^2), and,

v = flow velocity (m/day).

The coefficient k in the Darcy's flow equation is a constant, depending on the properties of the porous medium and the fluid.

Since we deal here with water only, it is called the hydraulic conductivity or permeability. Since k is the amount of flow per unit cross-sectional area under the influence of a unit gradient, it has the dimensions of ($L^3/L^2 \times T$) or (L/T), but should not be confused with velocity.

In the following table some values of the hydraulic conductivity for various types of material are given (After Schoeller, 1962):

Table 3: order of magnitudes of hydraulic conductivities of some materials

Material	k in m^2/day
Clay	10^{-5} to 10^{-7}
Silt	10^{-1}
Fine sand	10^{-1} to 10
Coarse sand	10^{0} to $2x10^{2}$

Gravel	10^0 to 10^3 or more

The hydraulic gradient is a dimensionless factor. The piezometric head is the elevation of the water level in a piezometer with respect to a reference level, generally sea level. The piezometric head has the dimension of *Length* (L) and is expressed, for example, in meters. The piezometric surface is the imaginary surface through all the points to which the water rises in piezometers penetrating the aquifer.

The phreatic level or free water table in the soil is defined as the height at which the pressure of the groundwater equals that of the free atmosphere. Generally speaking, it is the level at which water stands in shallow boreholes and wells.

In this section the most important methods available for the evaluation of pumping test data are given. Since it is impossible to give a complete review of all the procedures, a selection has been made of formulas which can be commonly applied to actual field conditions. Little attention has been given to the mathematical derivation and proof of the formulas; it is their applications and limitations which are emphasized.

Before the application of the analysis methods, there are certain assumptions which has to be satisfied, these are:

- ✓ The aquifer has a seemingly infinite areal extent.
- ✓ The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the pumping test.
- ✓ Prior to pumping, the piezometric surface and/or phreatic are (nearly) horizontal over the area influenced by the pumping test.
- ✓ The aquifer is pumped at a constant discharge rate.
- ✓ The pumped well penetrates the entire thickness of the aquifer and thus receives water from the entire thickness of the aquifer by horizontal flow.

Although it would seem that the assumptions severely limit the application of the formulas, in reality this is not the case. Some of the assumptions are never met in nature, while others are only rarely observed such as the first one. Nevertheless the formulas are being applied with success and the calculated hydraulic characteristics have proved to be reliable for most purposes.

One assumption – that the aquifer is isotropic and homogeneous – is probably never met in nature. Nearly every aquifer contains variations in composition which cause its permeability to differ from place to place. For fully penetrating artesian wells the assumption of no stratification is not an important limitation. For unconfined aquifers the stratification is more important and should be taken into account in applying the formulas.

Another assumption – constant thickness of the aquifer – is not a serious matter because the thickness within the cone of depression generally does not change much. If, however, the aquifer thickness does change, it should be taken into account. So, slight deviations are not prohibitive to the application of the methods.

4.2. Pumping Test Interpretation:

There are two methods that are in common usage for calculating aquifer coefficients from time-drawdown data. Both approaches are graphical. The first involves curve matching on a log-log plot (the Theis method), and the second involves interpretation with a semi-log plot (the Jacob method).

Log-Log Type-Curve Matching:

1. Construct the type-curve (theoretical response) by plotting values of $W_{(u)}$ versus 1/u on a log-log paper.
2. Plot the measured time-drawdown field values (h_o-h, or s) versus t on a log-log paper of the same size and scale as the type-curve.
3. Superimpose the field curve on the type curve keeping the coordinate axes parallel. Adjust the curve until most of the observed data points fall on the type-curve.
4. Select an arbitrary match points and read off the paired values of $W_{(u)}$, 1/u, h_0-h (or s), and t at the match point.
5. Using these values together with the pumping rate Q and the radial distance r from pumped well to the observation well (piezometer), calculate T from the relationship:

$$T = QW_{(u)}/4\pi(h_0\text{-}h)$$

6. Calculate S from the relationship:

$$S = 4\ \pi Tt/r^2$$

The equations above are valid for any system of consistent units. It is equally valid to take the match point anywhere on the overlapping fields once they have been fixed in their correct relative positions. For ease of calculation, the match point is often taken at $W_{(u)} = 1.0$, $u = 1.0$.

Semi-Log Plots:

Theis Recovery Method:

After pumping is shut down, the water level will stop dropping and rise again to its original position. This is the so called recovery of the well. The rise of the water level can be measured as the residual drawdown s" which is the difference between the original water level before pumping and the water level measured at a certain moment t" since pumping stopped.

The data obtained during recovery permit the calculation of the transmissivity, thus giving a check on the results of the analysis of the data obtained during pumping. Moreover the recovery method has the advantage that the rate of recharge Q is constant and equal to the mean rate of discharge Q during pumping. This means that drawdown variations resulting from slight differences in the rate of discharge pumping do not occur during recovery.

The residual drawdown, s", during the recovery period is, according to Theis (1935), given by:

$$s'' = \frac{Q}{4\pi kD}(\ln\frac{4kDt}{r^2S} - \ln\frac{4kDt''}{r^2S''}$$

Where:

s" = residual drawdown in meters.

r = distance in meters from pumped well to observation well or, if the pumped well itself is considered, $r = r_w$ = effective radius of the pumped well.

S" = coefficient of storage during recovery, dimensionless.

S = coefficient of storage during pumping, dimensionless.

t = time in days since pumping started.

t" = time in days since pumping stopped.

Q = rate of recharge = rate of discharge in m^3/day.

Procedure:

When S and S" are constant and equal and $u = r^2S/4kDt$ is sufficiently small, the above equation can be written as:

$$s'' = \frac{2.30Q}{4\pi kD}\log\frac{t}{t''}$$

For a piezometer or for the pumped well, s" is plotted versus t/t" on single logarithmic (semi-log) paper (t/t" on logarithmic scale) and a straight line is fitted through the plotted points (Fig--). The slope of the line is equal to 2.3Q/4πkD. The value of $\Delta s''$, the residual drawdown difference per log cycle of t/t" can be read from the graph and substituted in the equation:

$$kD = \frac{2.3Q}{4\pi\Delta s''}$$

It should be noted that no value of S can be obtained with this method.

Table (4): Recovery data (r = 30 m, Q = 788m³/day):

t" (min)	t/ t"	s" (m)	t" (min)	t/ t"	s" (m)
0	∞	1.09	60	15	0.47
0.5	1661	1.01	90	10	0.40
1	831	0.97	120	7.9	0.36
2	416	0.91	150	6.5	0.32
3	278	0.89	180	5.6	0.30
5	166	0.85	240	4.4	0.26
10	84	0.76	300	3.8	0.23
20	42	0.65	450	2.8	0.18
30	29	0.58	600	2.4	0.15

JACOB's METHOD:

The Jacob method (Cooper and Jacob, 1946) is also based on the Theis formula; however, the conditions for its application are somewhat more restricted.

In the Theis formula, the exponential integral can be expanded in a convergent series so that the drawdown s may be written as:

$$s = \frac{Q}{4\pi kD}\left(-0.5772 - lnu + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} \ldots\right)$$

From $u = r^2S/4kDt$ it will be seen that u decreases as the time of pumping t increases. Accordingly, for large values of t and/or small values of r the terms beyond lnu in the series of the above equation become negligible. So, for small values of u (u<0.01), the drawdown can be expressed by the asymptote:

$$s = \frac{Q}{4\pi kD}\left(-0.5772 - ln\frac{r^2S}{4kDt}\right)$$

After rewriting and changing into decimal logarithms this equation reduces to:

$$s = \frac{2.30Q}{4\pi kD} log\frac{2.25kDt}{r^2S} \quad \text{……………. (J1)}$$

Therefore a plot of s versus the logarithm of t forms a straight line (Fig.---). The line is extended till it intercepts the time axis where s=0 so that the interception point has the coordinates s=0 and $t=t_0$.

Substitution of these values into equation (J1) gives:

$$0 = \frac{2.30Q}{4\pi kD} log \frac{2.25kDt_0}{r^2 S}$$

And because $2.30Q/4\pi D \neq 0$, it follows that $\frac{2.25kDt_0}{r^2 S} = 1$, or:

$$S = 2.25kDt_0/r^2 \text{.................... (J2)}$$

If $t/t_0 = 10$ and hence $\log t/t_0 = 1$, s can be replaced by Δs, i.e. by the drawdown difference per log cycle of time and it follows that:

$$kD = 2.3Q/4\pi\Delta s \text{................ (J3)}$$

It will be noted that $\Delta s = 2.3Q/4\pi kD$ is the expression for the slope of the straight line. This means that when a straight line is fitted through the plotted points, the value of t_0 is determined as well as Δs.

The following assumptions and conditions must be satisfied:

- ✓ The same conditions as for the Theis method.
- ✓ The values of u are small ($u < 0.01$), i.e. r is small and t is large.

The condition that u is small can be satisfied in confined aquifers for moderate distances from the pumped well within an hour or less, but for unconfined conditions it may take 12 hours or more of pumping.

Procedure:

- Plot the values of s versus the corresponding time t on single logarithmic paper (t on logarithmic scale) and draw a straight line through the plotted points.
- Extend the straight line till it intercepts the time axis where s = 0 and read the value of t_0.
- Determine the slope of the straight line, i.e. the drawdown difference Δs per log cycle of time.
- Substitute the values of Q and Δs into equation (J3) and solve for kD. With the known values of kD and t_0, calculate S from equation (J2).

Remarks:

- This procedure should be repeated for all available piezometers, i.e. for different values of r. There should be a close agreement between the calculated kD values as well as between those of S.
- When the values of kD and S are determined, they are introduced into the equation $u=r^2S/4kDt$ to check if u< 0.01, which is a condition for the applicability of the Jacob method.
- Before substitution into the equations, all numerical values should be ex pressed in the same set of units.

Table (5): Pumping test data (r = 3o m, Q = 788 m^3/day):

t (min)	s (m)		t (min)	s (m)
0	0		18	0.68
0.1	0.04		27	0.74
0.25	0.08		33	0.75
0.5	0.13		41	0.78
0.7	0.18		48	0.79
1.0	0.23		59	0.82
1.4	0.28		80	0.86
1.9	0.33		95	0.87

2.33	0.36		139	0.92
2.8	0.39		181	0.94
3.36	0.42		245	0.97
4.0	0.45		300	0.99
5.35	0.50		360	1.01
6.8	0.54		480	1.05
8.3	0.57		600	1.05
8.7	0.58		728	1.07
10	0.60		830	1.09
13.1	0.64			

Step-drawdown Test:

All conventional well hydraulics theory is based on the assumption that laminar flow conditions exist in the aquifer during pumping. If the flow is laminar, drawdown is directly proportional to the pumping rate. Under turbulent conditions, the linear relationship between drawdown and pumping rate no longer holds, and part of the drawdown is generally related to the pumping rate raised to some power greater than 1.0.

When turbulent flow occurs, the specific capacity will decline as the discharge rate is increased. When this happens, it is useful to have a means of computing the turbulent and laminar drawdown components in order to make proper judgement concerning the optimum pumping rate and pump-setting depth.

The step-drawdown test has been developed to examine the performance of wells having turbulent flow.

In this test the well is pumped at successively increasing pumping rates at equal time interval and the drawdown for each rate or step is recorded. Usually five to eight steps of 1 to 2 hours duration each is performed.

The data can then be used to determine the relative proportion of laminar and turbulent flow occurring at any pumping rate.

For a perfectly efficient well, drawdown in a confined aquifer (using gallon-minute-foot unit system) is given by:

$$s = \frac{264Q}{T} \log\left(\frac{0.3Tt}{r^2 S}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (E1)$$

This equation is also applicable to unconfined aquifers as long as the drawdown is small in relation to aquifer thickness.

Equation (E1) can be shortened to:

$$s = BQ \ldots\ldots\ldots\ldots\ldots\ldots. (E2)$$

Where:

$$B = \frac{264}{T} \log\left(\frac{0.3Tt}{r^2 S}\right) \ldots\ldots\ldots\ldots\ldots\ldots.. (E3)$$

For a specific well, the value of B is time dependant. However, B changes only slightly after a reasonable pumping duration and can thus be assumed to be constant.

When turbulent flow exists, Jacob suggests that the drawdown in a well can be more accurately expressed as a sum of first-order (laminar) component and a second-order (turbulent) component:

$$s = BQ + CQ^2 \ldots\ldots\ldots\ldots\ldots\ldots (\text{E4})$$

In the above equation, Jacob called the laminar term (BQ) the aquifer loss and the turbulent term (CQ^2) the well loss (head loss attributable to inefficiency).

Using equation (E4), Bierschenk (1964) presented a simple graphical method for determining B and C. Dividing equation (E4) by Q and rearranging terms yields:

$$\frac{s}{Q} = CQ + B \ldots\ldots\ldots\ldots\ldots. (E5)$$

This is a linear equation. If s/Q is plotted versus Q, the resultant is a straight line with a slope C and an intercept B.

Inverting the terms in equation (E5) shows how specific capacity declines as discharge increases (only with turbulent flow present):

$$\frac{Q}{s} = \frac{1}{CQ + B} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (E6)$$

Observing the change in drawdown and specific capacity with increased discharge provides information required to select optimum pumping rates.

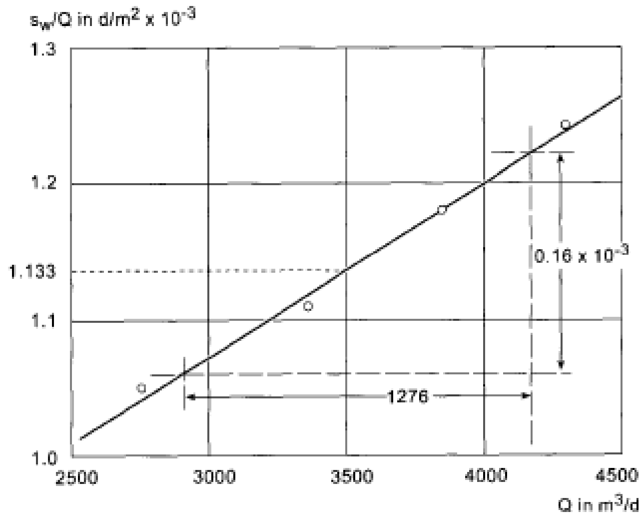
Table (6): Discharge and Drawdown data from typical Step-drawdown Test:

Q (gpm)	Q (m^3/day)	Drawdown-s- (ft)	Drawdown-s- (m)	s/Q
514	2801	13	4	0.0253
1066	5810	27	8.2	0.0253
1636	8916	43.4	13.2	0.0265
1885	10273	61.5	18.8	0.0326
2480	13516	82.5	25.2	0.0333
3066	16710	101.5	30.9	0.0331
3520	19184	120.5	36.7	0.0342

Procedure (see Fig 6):

- Plot the drawdown values of s versus the corresponding time t on semi-logarithmic paper (t on logarithmic scale).
- On linear paper, plot the values of s/Q versus the corresponding values Q.
- Fit a straight line through the plotted points;
- Determine the slope of the straight line Δ(s/Q)/ΔQ, which represents the value of C.
- Extend the straight line until it intercepts the Q = O axis. The *s/Q* value of the interception point represents the value of B.

Fig 6: Jacob Method Step-Test Analysis:



Exercise:

1- Using the data in table (5) and the Jacob method calculate the values of T and S.

2- From the recovery data of table (4), calculate the appropriate aquifer parameters.

3- Values of a step-drawdown test are given in table (6). Find the value of drawdown attributable to the well loss.

4- Complete table (7) and solve for T and S using the Theis type-curve method, the Jacob method, and the Recovery method. Evaluate the results given by the different methods.

Table (7): Pumping Test and Recovery data:

Time (min)	Depth to Water level (ft)	Drawdown (ft)	Recovery (ft)	Residual Drawdown (ft)	t/t"
0.167	251.6	1			
0.333	252.4	1.8			
0.5	252.1	1.5			
0.667	252.5	1.9			
0.833	253	2.2			
1	255.8	2.4			
2	259.9	5.2			
3	260.1	6.5			
4	261	7.9			
5	262.3	8.5			
6	263	9.3			
7	264.4	9.5			
8	264.8	10			
9	265.3	10.3			
10	265.9	11.7			
11	266.5	12.4			
12	267.2	13.8			
15	-	14.2			
20	-	14.7			
25	-	15.3			
30	-	15.9			
40	-	16.6			
60	-				
Pump Off					
60.167	263.9				
60.333	262.8				
60.5	262				
60.667	261.8				
60.833	261.4				
61	260.7				
61.5	260				
62	259.3				
63	257.1				
64	255.6				
65	254.4				
66	253.3				
67	252.9				
68	252.6				
69	252.4				
70	252.3				
72	252.2				
75	252				

References:

1. Fletcher G. Driscol, 1989, Groundwater and Wells, 2nd Edition, Johnson Filtration Systems Inc., USA.
2. G.P.Kruseman & N.A.De Ridder, Analysis and Evaluation of Pumping Test Data, ILRI, Bul. No. 11, 1983, 3rd edition.
3. USGS web-site.
4. William C. Walton, 1970, Groundwater Resources Evaluation, McGraw-Hill, Inc.

Technical Area: 15 Water Quality Analysis
Item: 15-1 Purpose of Water quality analysis

1: Objectives To be able to explain and advise for purpose of water quality analysis as a general knowledge.
2. Contents - Purpose of water quality analysis
3. Teaching Methods (1) Eplain purpose of water quality analysis using manual.
4. Materials 15-1M1 DDCA's manual for the Drilling Works

9 WATER QUALITY (TA CODE 15)

9.1 PURPOSE OF WATER QUALITY ANALYSIS (TA CODE 15-1)

9.1.1 IMPORTANCE OFSAFE WATER QUALITY

Access to safe drinking-water is important for health, basic human right and development at national, regional and local levels. In some areas, it has been found that investments in water supply can support a net economic benefit such as reductions in adverse health effects and health-care costs outweigh the costs of undertaking the interventions. It has also shown that the improvement of access to safe water confers benefits to the poor in particular, whether in rural or urban areas, and can be an effective part of poverty alleviation strategies.

According to above aspects, water quality analysis is required to be confirmed not only at drilling but also at rehabilitation.

9.1.2 WATER QUALITY PARAMETERS

Table 36 and lists suggesting water parameter to be analised in Tanzania, pollution sources and effects respectively. Categories of the tableare based on Tanzania Temporary Standards (TBS, 1974).

Table 36 Water Quality Parameters and each Pollition Sources and Effects

No.	Name of Constituent	Symbol	Pollution Source (Indicators)	Effects
Toxic				
1	Lead	Pb	Rust of lead pipes	Health effects
2	Arsenic	As	Geological condition	Health effects
3	Selenium	Se	Geological condition	Health effects
4	Chromium	Cr	Geological condition or effluents from industries	Health effects
5	Cyanide	Cn	Effluents from industries	Health effects
6	Cadmium	Cd	Effluents from industries	Health effects
7	Barium	Ba	Geological condition	Health effects
8	Mercury	Hg	Effluents from industries	Health effects
9	Silver	Ag	Geological condition	Not specified
Affecting Human Health				
1	Fluoride	F	Geological condition	Tooth decay and fluorosis
2	Nitrate	NO_3	Fertilizers, sewage, faeces or decaying organic matters	Cause of hemoglobinemia (blue babies) and support algae growth
3	Nitrite	NO_2	(Fertilizers, sewage, faeces or decaying organic matters)	Cause of hemoglobinemia (blue babies) and support algae growth
Organoleptic				
1	Color		Metals or organic matters	Appearance
2	Turbidity		Soil particles	Appearance
3	Taste		Geological condition, seawater, effluents from industries or algae growth	Taste
4	Odor		Sewage, effluents from industries or algae growth	Odour
Salinity and Hardness				
5	pH		Sewage, effluents from industries or algae growth	Attack metals (e. g. pipe rust)
6	Total Filterable Residue		Minerals from geological condition and dissolved matters	Taste and appearance
7	Total Hardness	$CaCO_3$	Geological condition	Taste and soap consuming

No.	Name of Constituent	Symbol	Pollution Source (Indicators)	Effects
8	Calcium	Ca	Geological condition	Not specified
9	Magnesium	Mg	Geological condition	Not specified
10	Magnesium + Sodium sulphate	Mg-Na_2	Sewage, effluents from industries or seawater	Na: taste
11	Sulphate	SO_4	Geological condition or effluents from industries	Taste and smell
12	Chloride	Cl	Sewage, effluents from industries, seawater or geological condition	Not specified
Less-toxic Metals				
13	Iron	Fe	Effluents from industries and mining / Pipe or pump rusting	Taste and appearance
14	Manganese	Mn	Geological condition	Taste and appearance
15	Copper	Cu	Rust of copper pipes	Taste
16	Zinc	Zn	Geological condition or pipes	Taste and appearance
Organic Pollution of Natural Origin				
17	BODs(5 days)	O_2	Organic matters	Cause of water born diseases and decaying water
18	PV (Oxygen abs. $KMnO_4$)	O_2	Organic matters	Cause of water born diseases and decaying water
19	Ammonium	NH_3	Faeces	Cause of water born diseases and disinfectant consuming
20	Total Nitrogen Exclusive Nitrate		Sewage or effluents from industries	Algae growth
Organic Pollution Introduced Artificially				
21	Surfactants ABS (Alkyl Benxyl Sulphonates)		Organic matters	Odour
22	Organic matter as carbon in chloroform extract)		Organic matters	Cause of water borne diseases
23	Phenolic substances as phenol		Effluents from industries	Health effects
Bacteriological				
1	Coliform count per 100ml at 37℃		Sewage	Cause of water borne diseases
2	E. coli count per 100ml at 44℃		Faeces	Cause of water borne diseases

Source: Guideline for Drinking-water quality (WHO, 2004) and Tanzania temporary standards (TBS, 1974)

Technical Area: 15 Water Quality Analysis
Item: 15-2 Item of water quality analysis

1: Objectives To be able to explain and advise for items analysed for groundwater and their effect on human health.
2. Contents - Item of water quality analysis
3. Teaching Methods (1) Explain items of water quality analysis using manual.
4. Materials 15-2M1 DDCA's manual for the Drilling Works

9.2 ITEM OF WATER QUALITY ANALYIS (TA CODE 15-2)

9.2.1 GUIDELINE/STANDARD OF WATER QUALITY

There are two types of guideline for drinking-watre in Tanzania; Guideline for Drinking-water Quality (WHO, 2004) and Tanzania temporary standards (TTS) (TBS, 1974). WHO guideline is for urban water suppies and large water supplies, and TTS is for domestic water supplies and small rural water supplries. Therefore, is is necessary to instruct which guideline/standard is adopt for water at drilled boreholes to customers and laboratories.

9.2.2 PARAMETERS OF WATER QUALITY ANALYSIS

Table 37 lists WHO guideline and TTS values, and drinking water quality should be less than the valuses in both Tables.

Table 37 Values of WHO Guideline and TTS

No.	Name of Constituent	Symbol	Units	WHO guideline	TTS
Toxic					
1	Lead	Pb	mg/l	0. 01	0. 01
2	Arsenic	As	mg/l	0. 01	0. 05
3	Selenium	Se	mg/l	0. 01	0. 05
4	Chromium	Cr	mg/l	0. 05	0. 05
5	Cyanide	Cn	mg/l	0. 07	0. 20
6	Cadmium	Cd	mg/l	0. 003	0. 05
7	Barium	Ba	mg/l	0. 7	1. 00
8	Mercury	Hg	mg/l	0. 001	0. 001
9	Silver	Ag	mg/l	Not mentioned	Not mentioned
Affecting Human Health					
1	Fluoride	F	mg/l	1. 5	1. 5 - 4. 0
2	Nitrate	NO_3	mg/l	50	10 – 75
3	Nitrite	NO_2	mg/l	3	Not mentioned
Organoleptic					
1	Color		mg/l	15 TCU	15 - 50
2	Turbidity		mg/l	5 NTU	5 - 25
3	Taste		-	Not objectionable	Not objectionable
4	Odor		-	Not objectionable	Not objectionable
Salinity and Hardness					
5	pH			6. 5-8. 5/9. 5	6. 5 – 9. 2
6	Total Filterable Residue		mg/l	1500	2000
7	Total Hardness	$CaCO_3$	mg/l	Not mentioned	600
8	Calcium	Ca	mg/l	200	Not mentioned
9	Magnesium	Mg	mg/l	150	Not mentioned
10	Magnesium + Sodium sulphate	$Mg\text{-}Na_2$	mg/l	-	Not mentioned
11	Sulphate	SO_4	mg/l	400	600
12	Chloride	Cl	mg/l	600	800
Less-toxic Metals					
13	Iron	Fe	mg/l	1	1
14	Manganese	Mn	mg/l	0. 4	1. 5
15	Copper	Cu	mg/l	2	3. 0
16	Zinc	Zn	mg/l	15	15
Organic Pollution of Natural Origin					
17	BODs(5 days)	O_2	mg/l	6. 0	6. 0
18	PV (Oxygen abs. $KMnO_4$)	O_2	mg/l	10	20
19	Ammonium	NH_3	mg/l	0. 5	Not mentioned
20	Total Nitrogen Exclusive Nitrate		mg/l	0. 1	1
Organic Pollution Introduced Artificially					
21	Surfactants ABS		mg/l	1	2

<table>
<tr><th>No.</th><th>Name of Constituent</th><th>Symbol</th><th>Units</th><th colspan="2">WHO guideline</th><th>TTS</th></tr>
<tr><td></td><td>(Alkyl Benxyl Sulphonates)</td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>22</td><td>Organic matter as carbon in chloroform extract)</td><td></td><td>mg/l</td><td colspan="2">0. 2</td><td>0. 5</td></tr>
<tr><td>23</td><td>Phenolic substances as phenol</td><td></td><td>mg/l</td><td colspan="2">0. 001</td><td>0. 002</td></tr>
<tr><td colspan="7">Bactriological</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Coliform count per 100ml at 37℃</td><td rowspan="2">-</td><td rowspan="2">-</td><td>Acceptable</td><td>Allowable</td><td rowspan="2">1-3</td></tr>
<tr><td>-</td><td>1-3</td></tr>
<tr><td>2</td><td>E. coli count per 100ml at 44℃</td><td>-</td><td>-</td><td colspan="2">Nil</td><td>Nil</td></tr>
</table>

Source: Guideline for Drinking-water quality (WHO, 2004) and Tanzania temporary standards (TBS, 1974)

9.2.3 TIMING OF WATER ANALYSIS

Water is analysed after pumping tests (after water become likely clean) and rehabilitations. Moreover, regular water analysis is needed for both rural water supply and urban water supply in order to ensure safe drinking-water in boreholes. Therefore, DDCA should advise to customers to analyse water regularly. ***Table 38*** and ***Table 39*** respectively show frequency of sampling for rural water supply and urban water supply.

Table 38 Frequency of Sampling for Rural Water Supply

Type of Source/Population served	Up to 1,000	Up to 2,000	Up to 5,000
Borehole deeper than 8m	6 months	4 months	3 months

Source: National Environmental Standards Compendium (TBS, 2003)

Table 39 Frequency of Sampling for Urban Water Supply

<table>
<tr><th>Population served</th><th>Max interval between successive samples</th><th>Minimum number of samples to be taken from whole distribution</th></tr>
<tr><td>Less than 20,000</td><td>1 month</td><td rowspan="3">1 sample / 5,000 people / month</td></tr>
<tr><td>20,000 – 50,000</td><td>2 weeks</td></tr>
<tr><td>50,000 – 100,000</td><td>4 days</td></tr>
<tr><td>More than 100,000</td><td>1 day</td><td>1 sample / 10,000 people / month</td></tr>
</table>

Source: Design Manual for Water Supply and Wastewater Disposal (MoWI, 2009)

9.2.4 SAMPLING AND TRANSPORTATION METHODS

Sampling is a very important process in order to get the true value of water quality. Therefore, following processes are required for sampling.

- To clean the working
- To wash hands
- To avoid dust and draughts in the working area
- To use clean and dry containers washed by proper methods
  - those rinced by distilled water for general parameters
  - those sterilized by ethanol etc. for bacteriological parameters
  - those washed by solution of hydrochloric acid and rinced by distilled water for heavy metals
- To rinse containers three times by water sample if they are wet by a different water sample
- To sterilize an intake of a tap or a pump by ethanol or fire in order to sterilize and to prevent

biological contamination

- To avoid touching any part of the container dishes and sampler
- To keep samples cold
- To transfer samples within 24 hours to a laboratory

9.2.5 OTHER NOTIFICATION

The followings are also important for water analysis implemented at sites.

- To adequately calibulate equipment before analysis such as pH meter and conductivity mether
- To turn off equipment if they are not utilized for a while.

Drilling and Dam Construction Agency (DDCA)
Japan International Cooperation Agency (JICA)

DDCAP

Technical Support Plan for the Drilliers in DDCA

Version 1

January 2013

Groundwater Development and Management Capacity Development (DDCAP) Project

Contents

Tables

Figures

Appendix

1 BACKGROUND

Ministry of Water (MoW) has been implementing Water Sector Development Programme (WSDP), in order to realize the National Water Sector Development Strategy (NWSDS). A target of WSDP is that water supply and sanitation facilities in rural areas are provided 90% and 75% respectively by 2025. In likewise, it is that water supply and sewerage system is completely installed in urban areas, and an average of water supply in whole country becomes 93% by 2025.

A plan of a number of water supply facilities to be constructed by the rural water supply component of the WSDP is 79,754, in order to provide safe water to approximately 34.5 million un-served populations. The water source of 91% out of the planned facilities is expected from the groundwater. Therefore, it is estimated that the drilling 1,200 wells annually are required for achievement of the target. Although private sector are the main actor for groundwater development of the rural water supply component of the WSDP, their current capacity of drilling wells annually is reported as approximately 600. In other words, their capacities such as technical abilities and resources have a great gap compared with the demand written in the above.

In order to address this challenge, MoW formulated a “Strategy for Strengthening Water Well Driling Industry in Tanzania” in 2006, and mandated the capacity development of private drilling companies to DDCA (Drilling and Dam Construction Agency) by launch their new services such as a hiring of drilling equipment and technical instructions.

In response to the request of the Government of Tanzania for the technical cooperation to DDCA, the Government of Japan agreed on Minutes of Meeting (M/M) and Record of Discussions (R/D) between the MoW, DDCA and Japan International Cooperation Agency (JICA) in December 15th 2011. Based on this background, the Groundwater Development and Management Capacity Development Project (DDCAP) was started on March 2013. A purpose of the project is to “enhance the DDCA’s capacity to support the water well drilling industry” by strengthening of DDCA’s techniques for groundwater development and their capacity of technology transfer toward private drilling companies, and by establishment of an equipment hiring system in DDCA.

The following outputs are planned in order to achieve the overall target and the project purpose written in the above.

Output 1: DDCA’s ability to impart techniques and skills regarding water well drilling to private drilling sector is enhanced.

Output 2: The capacity of DDCA in groundwater development, which is required to provide technical instructions, is enhanced.

Output 3: A system to hire drilling equipment and machinery is established.

This Technical Support Plan for the Drillers in DDCA (hereinafter referred to as “TSP”) was prepared in order to provide technical instructions and guidance related to well drilling and rehabilitation & fishing techniques for the senior drillers of DDCA. The manuals for both Well Drilling and Rehabilitation & Fising Techniques were prepard in separate volumes, in order to deliver the training. These documents are the one of the products of the activites of【2-2】and【2-3】related to the output 2 above, and stipulated in PDM (Project Design Matrix) of the Project, which intends to develop the DDCA’s drillers capacity of groundwater development, which is required to provide technical instructions to the drillers of private companies.

The technical instructions and guidance for the senior drillers in DDCA will be carried out entire project period. Accrdingly, the document both TSP and Manuals will be updated and/or modified by reflecting the results of the training.

2 OUTLINE OF TECHNICAL SUPPORT PLAN

2.1 PURPOSE OF THE PLAN

The purpose of the Technical Support Plan (TSP) is to enhance the capacity of well drillings, well rehabilitation and tool fishing for the senior drillers in DDCA. The technical areas necessary to be enhanced at DDCA were identified by the Project. The technical instruction and guidance to the DDCA should be provided based on the TSP.

2.2 TARGET GROUP OF THE PLAN

As of 2012, 74 drillers belong to the Drilling Project Operation Department and the Technical Support Department. Drillers were classified by Drilling Project Department into four technical level of S, A, B and C. The number of drillers classified into S and A was 35 (senior drillers), while the number of those who were classified to B and C was 39 (middle drillers). The target of the activity on enhancement of the DDCA's capacity related to output 2 is these 35 senior drillers.

2.3 TECHNICAL AREAS NECESSARY TO BE ENHANCED AT DDCA

Eight technical areas necessary to be enhanced were identified as a result of the baseline survey on DDCA. The areas necessary to be enhanced consist of drilling tools and equipment, drilling control, borehole logging, gravel packing, development, backfilling/surface cementing, pumping test and water quality analysis.

2.4 NEW TECHNICAL AREAS TO BE NEEDED AT DDCA

Two new technical areas to be needed were identified as a result of the baseline survey on DDCA. These areas consist of well rehabilitation and tool fishing.

2.5 METHOD OF TECHNICAL TRAINING AND GUIDANCE

Three methods are taken for the training and guidance as follows:

- **Learning with manuals**

The manuals for each technical area to be enhanced were prepared by the Project. Senior drillers can learn necessary knowledge and skills by using these manuals. A seminar on utilization of the manual is planed to be held in March 2013, for 35 senior drillers.

- **Practical training at the headquarters of DDCA**

Practical trainings at the headquarters of DDCA using DDCA's equipment and tools are planned. These trainings include "Drilling Tools and Equipment", "Borehole Logging", "Pumping Test" and "Fishing Tools Making".

- **On-site Technical Training and Guidance on Technical Instructions by Instructors**

DDCA will certify 12 technical instructors by March 2013. They are in charge of technical instructions to drillers of private drilling companies who hire the drilling equipment from DDCA. At the same time, they will conduct internal training to other DDCA's drillers at drilling sites. The teaching guidance which was prepared by the Project can be utilized for technical instructions to both private drillers and DDCA's drillers. The technical training and guidance to technical instructors by JICA experts related to on-site technical instructions is planed.

3 ORGANIZATION AND INSTITUTION OF DDCA

3.1 ORGANIZATION SETTINGS OF DDCA

DDCA was established under the Executive Agency Act enacted in 1997 by the Government of Tanzania and came into operation in 1999. It was consolidated by the former Drilling Section under the Water Resource Department and the Dam Construction Section under the Construction

Department in the Ministry of Water (MoW). Since then, DDCA was mandated by MoW to undertake the drilling and dam construction works.

Headquarter of DDCA is located in Dar es Salaam. The organization is consisted of four departments, which are Internal Auditing, Drilling Project, Earthworks Project, Technical Support and Business Support Department. ***Figure 1*** shows the organizational structure of DDCA. Each department is consisted of several sections. There are 12 sections in total under the four departments. Each department is operated by a manager who is a head of department.

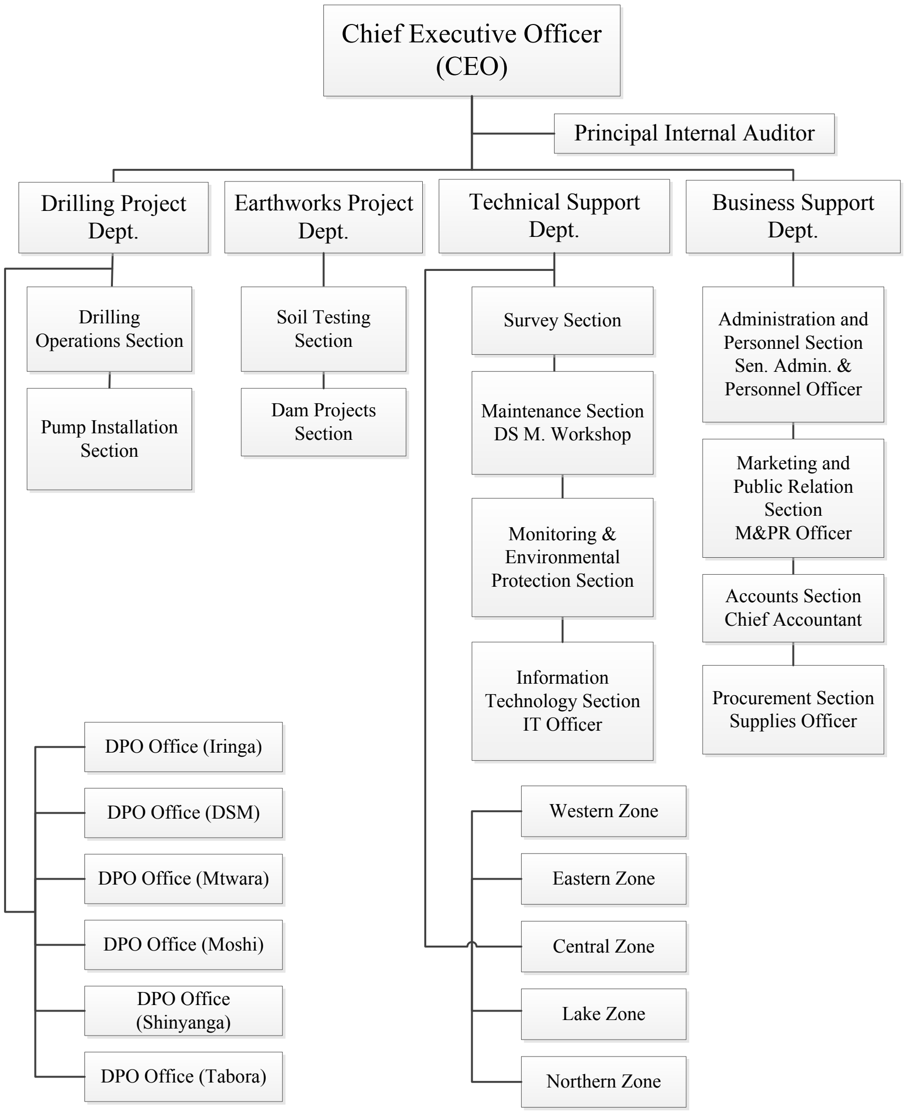


Figure 1 DDCA Organizational Structure

3.2 PERSONNEL SETTING IN DRILLING PROJECT DEPARTMENT AND TECHNICAL SUPPORT DEPARTMENT

Apart from the headquarters, there are six Drilling Project Offices (DPOs) located under the Drilling Department for supervising the drilling works and providing the assistance on the procurement of equipment and materials in case drilling works are conducted in the upcountry. Under the Technical Support Department, there are five zonal offices for supervising the DPOs and promoting the business activities of DDCA.

The staffs involved in the drilling work are almost from the Drilling Project Department and Technical Support Department. Most of those staffs were graduated from Water Development and Management Institute (WDMI). They obtained the certificate or diploma in drilling or other areas.

As above mentioned, in the Drilling Project Department, out of 99, 84 staffs are employed in permanent basis and 15 are employed in contract basis, while 28 are permanent and 34 are contract basis in the Technical Support Department out of 62.

Table 1 shows the number of staffs by position following to the regulation of PO-PSM[1]. Also the number of the staffs from the Technical Support Department who were given the same position with the Drilling Project Department is shown. In many cases, the position of the new staffs are started with the lowest one of Assistant Technician, and orderly promoted to the Technician II, Technician I, Senior Technician and Principal Technician. According to the PO-PSM, the chance of promotion is given in every three to five years. Experience and educational level of the staffs shall be considered for the promotion as the evaluation criteria (PO-PSM, 2002)[2].

Table 1 Number of Staffs in Drilling Project Department DDCA by Position of PO-PSM

Position of PO-PSM	Drilling Project Dep.	Technical Support Dep.
Assistant Technician	40	8
Technician II	14	4
Technician I	4	0
Senior Technician	18	0
Principal Technician	23	0
Total	99	12

The duties are assigned to each staff based on their knowledge, skills and experiences held. ***Table 2*** shows the number of staffs by duty in Drilling Project Department and the Technical Support Department.

Table 2 Number of Staffs by duty in Drilling Project Department DDCA and Technical Support Department

Duty	Drillin Project Dep.	Technical Support Dep.
Manager	1	1
Zonal Manager	4	0
Drilling Project Officer	4	0
Driller	2	0
Rig in Charge	16	0
Assistant Rig in Charge	9	1
Operator	20	1
Assistant Driller	15	1
Mechanics	9	7
Flushing	2	0
Pumping Test	9	0
Electronics	0	3
Plant Operator	1	2
Drawing	1	1
Stock keeper	1	0
Surveyor	2	13
Autoelectrorician	1	1
Drawing	0	1
Office Attendant	0	1
Panel Beating & Spray	0	2
Quarryman	0	5
Hydrogeologist	0	2
Environment	0	1
IT Computer	0	1
Transport & Logistics	0	2
Driver	2	17
Pump Installation	1	2
Total	99	62

1 The position of the PO-PSM is given to the staffs employed by DDCA themselves since the working condition of the PO-PSM is applied for them.

2 Scheme of Service, PO-PSM, Tanzania, 2002

16 drilling teams are organized by rig. A team is composed of Rig in Charge, Assistant Rig in Charge, Operator and Assistant Driller. Sometimes, the person in charge of Mechanics is included into the member of the team. Also some members of the team come from the Technical Support Department. On the other hand, the staffs in charge of well development and pumping test, who are from the Drilling Department, conduct a specific works of well development and pumping test for the well drilled in Dar es Salaam, while the team itself does them in case the drilling work was conducted outside of Dar es Salaam.

For the staffs in the Drilling Project Department, 68 in total including the member of the drilling team and others are normally involved in the drilling work in the site, while only 5 staffs in the Technical Support Department take in charge of it. 73 staffs in total in both departments responsible for the drilling works are defined as "Driller" in the Project.

3.3 QUALIFICATION POSSESSED BY DDCA STAFFS

Currently DDCA has 226 staffs in total. The details of those staffs are shown in ***Table 3***. According to ***Table 3***, the number of the certificate holders is largest, followed by the diploma holders. Certificates were uniquely given by the institutions according to the NVA or NTA qualified by VETA or NACTE. The areas qualified in the certificate include drilling, mechanics, electronics, driving, and computer. For the diploma holders, the areas qualified include drilling, marketing and mechanics. Many staffs possess the certificate and diploma in drilling area. Normally, the duties are given to the staffs according to the specialized area qualified in the certificates. For the staffs who completed Form VI and Standard VII, many of them are assigned as driver, drilling worker and quarryman for the gravel.

Table 3 Number of Staffs by Qualification

Quarification	Masters	Degree	Diploma	Technician	Certificate	Form IV	Standard VII	Total
No.	10	13	31	6	146	1	19	226

(Source: The Project Team prepared according to the staff list provided by DDCA)

4 STRUCTURE OF DRILLING WORKS IN DDCA

4.1 DRIILING RIGS OWNED BY DDCA

Currently, DDCA owns 15 operational rigs consisting, which are 4 cable tools and 11 rotary (9 large and 2 small). ***Table 4*** shows model, type, year of purchase and capacity (diameter and depth) of 15 operational rigs of DDCA.

Table 4 Operational Drilling Rigs of DDCA

No.	Rig No.	Model	Rig Type	Year of Purchase	Drilling Diameter	Max. Drilling Depth (m)
1	1	PERCUSSION	Cable/Tool	1930	6"-10"	150
2	16	PERCUSSION		1965	6"-10"	180
3	17	PERCUSSION		1961	6"-12"	200
4	60	PILCON		1984	6"-8"	80
5	42	SCHRAMM	Rotary (Large)	1974	6"-12"	300
6	44	SCHRAMM		1974	6"-12"	300
7	46	SCHRAMM		1974	6"-12"	300
8	49	SCHRAMM		1974	6"-12"	300
9	50	SCHRAMM		1974	6"-12"	300
10	78	KOKEN		1997	6"-12"	200
11	81	SANKYO		2004	6"-12"	300
12	82	BPVL		2007	6"-12"	150
13	83	BPVL		2007	6"-12"	150
14	77	PAT	Rotary (Small)	1997	5"-8"	80
15	80	PAT		2004	5"-8"	100

4.2 ORGANIZATION OF DRILLING TEAM

As shown in ***Table 4***, DDCA has 15 drilling teams for each rig under the Drilling Project Department. Normally, a team consists of four to five members of one rig in charge, one assistant rig in charge, two to three operators and drilling workers. Since cable and tool rigs are rarely used, three staffs share four rigs and other necessary staffs are temporaily employed for the necessary.

Apart from the 15 drilling teams, DDCA has two pumping test teams in Dar es Salaam and one team in Sumbawanga (Rukwa region). Normally, a team consists of four members of one pumping test in charge, one assistant pumping test in charge and two pumping test assistant for each team. Only drilling team of KOKEN rig (Rig No. 15) is furnished with the pumping test equipment. Accordingly, there are four pumping test teams in total in DDCA.

Also, DDCA has one flushing team in Dar es Salaam, which conducts well development works. The flushing team transports the air compressor by their truck, and develops wells by air lifting. In upcountry, development is mainly conducted with air compressor for DTH drilling, as most of well are drilled by DTH drilling method,. In Dar es Salaam and Coast area, where mud drilling is major method, air compressor for the development shall be brought to the site since there air compressor is not used for mud drilling. In these areas, the flushing team conducts the development work at each drilling site.

4.3 STANDARD SPECIFICATION OF THE WELLS

More than 80 percent of wells drilled by DDCA are ordered by private customers. They are used for drinking water, industry, irrigation etc. The water demand and the diameter of casing and screen pipes differ by the uses of well. This is because the maximum yield of pump to be installed differs in accordance with the diameter of casing and screen pipes. ***Table 5***, shows that the more discharge rate is required, the larger diameter of casing and screen pipes are needed.

Table 5 Maximum yield by diameter of casing screen pipe

Casing Diameter	Applicable Pump	Maximum Discharge Rate (m^3/h)	Use
4"or 5"	Handpump	0.7	Rural water supply, private households etc
	Submersible Pump	15.0	
6"	Submersible Pump	40.0	Rural water supply, small scale urban water supply, industrial water etc
8"	Submersible Pump	70.0	Large scale urban water supply, irrigation, industrial water etc
10"	Submersible Pump	120.0	

Apart from the drilling depth, well specifications such as the type and diameter of casing and screen pipes etc. are to be determined prior to the drilling work. As the result of the baseline survey, the specifications of the wells of DDCA were identified as described in the followings.

- **Type of Casing**

DDCA employs the PVC (polyvinyl chloride) casing and screen pipes. Steel casing and screen pipes were used until the end of 1990s. Subsequently, the usage of PVC casing and screen pipes got increased. Currently, PVC casing and screen pipes are employed for almost all drilling works. Compared to the steel casing and screen pipes, those of PVC has advantages such as resistance to oxidation, good workability because of their light weights and so on. On the other hand, they are easily damaged by physical impact. Moreover, the maximum installation depth is around 250 m, because of limitation of strength, though it does not matter in Tanzania since most of wells are of not more than 200 m in depth. Consequently, steel or stainless steel casing and screen pipes are rarely being used in Tanzania.

- **Water Consumption of Well and Diameter of Casing and Screen Pipes**

Table 6 shows the number of wells drilled by DDCA in 2011/2012 average drilling depth by casing diameter. 23 wells without casing were judged unsuccessful before the installation of the casing and screen pipes. The wells with 4" and 5" casing diameter occupies 64 percent to total, which is a highest demand. This shows that many clients of DDCA have demand of wells for small scale water facilities with hand pump or small submersible pump. Regarding hand pump wells, 5” casing and screen pipes instead of 4” are mainly used nowadays for the purposes of the prevention of well trouble and the future extension to submersible pump. The 4” casing wells drilled in 2011/2012 were drilled under the special requirement in the Project for Rural Water Supply in Mwanza and Mara regions funded by Japanese Government. The number of wells with 6” casing and screen pipes occupies 26 percent to the total number. This is the most general diameter for the wells for piped schemes in rural water supply and industrial usage. The wells with 8” casing and screen pipes contributes just small number, i.e. only one percent to the total. This type of well is rarely demanded except when very large discharge rate is required.

The average depths are 81 m for the diameter of 4” or 5”, 99 m for 6” and 124 m for 8”.. As the diameter becomes larger, the deeper drilling and larger capacity rigs are needed.

Table 6 Number of Wells Drilled in 2011/2012 and Average Depth by Casing Diameter

Casing Diameter	Number of Wells	Percentage (%)	Average Depth (m)
4”	9	3	81
5”	163	61	
6”	70	26	99
8”	4	1	124
Without casing	23	9	94
Total	269	100	85

Note) : Compilation from the drilling record in 2011/2012

- **Drilling Diameter**

Generally, mud drilling method is applied for soft sedimentary rock while DTH drilling method is applied for hard basement rock. Even if the casing and screen pipes of same diameter are used, the drilling diameter differs in accordance with drilling methods and geological conditions. The drilling diameter is selected so that sufficient annular space between the hole and casing and screen pipes is secured. Insufficient annular space will cause the trouble on casing and screen installation and gravel packing. Not less than 13 mm in one side is necessary for DTH drilling, while not less than 50 mm in one side is needed for mud drilling.

Mud is not used for DTH drilling because the strata are consolidated. Therefore small annular space is enough for installation of casing and screen pipes and gravel packing. However, more space is needed for mud drilling since sand and clay in the mud disturb of the gravel packing. DDCA uses the drilling diameter shown in ***Table 7*** in accordance with the drilling method and diameter of casing and screen pipe.

Table 7 Diameter of casing and screen pipes and drilling diameter by drilling method

Drilling Method	Casing, Casing Screen Pipe Diameter	Drilling Diameter
DTH	4” or 5”	6-1/2”
	6”	8”
	6” or 8”	10” – 12”
Mud	4” or 5”	8”
	6”	9-7/8” – 10”
	6” or 8” PVC	10” or 12”

5 CONTENTS OF DRILLING WORKS AND ISSUES ON TECHNICAL INSTRUCTIONS

Contents of drilling works, technical level of DDCA’s drillers in each technical areas and issues on technical instructions were identified through the field survey and interview to DDCA. ***Figure 2*** shows the process of drilling works of DDCA. Though there are slight differences of drilling method and diameter in the wells of DDCA, the process of drilling works is almost same.

However, the large rig and higher technical level are needed for the drilling of larger diameter and deeper wells. Identified drilling process and issues on technical instruction are described as follows.

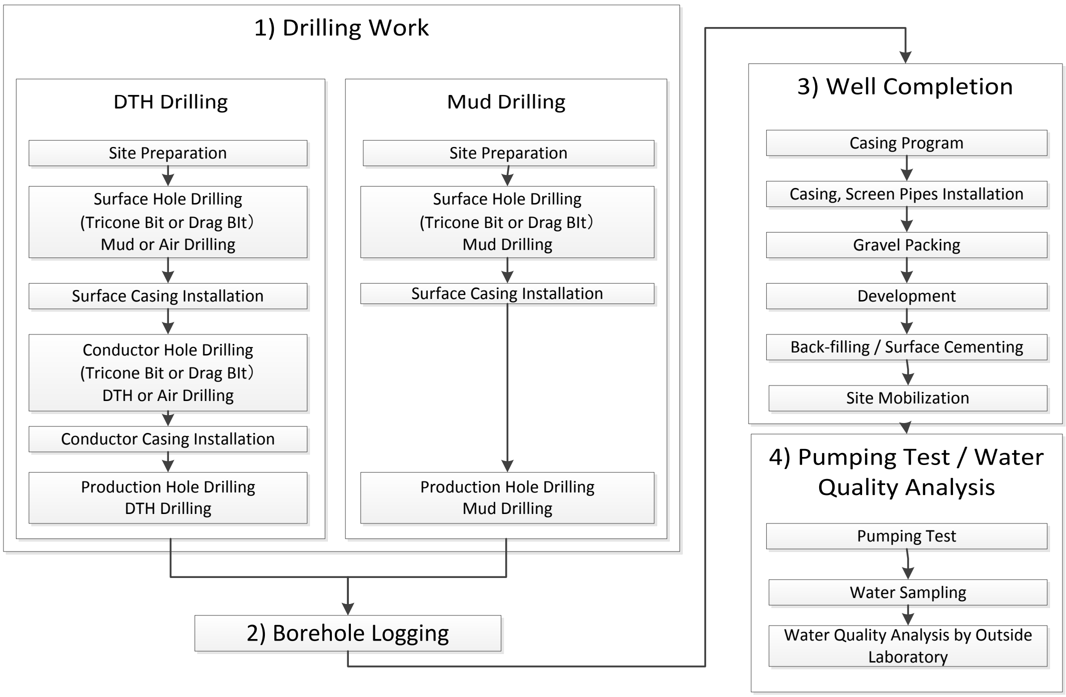


Figure 2 Process of drilling works

5.1 DRILLING WORK

The drilling work process includes the site preparation and the drilling machine carrying-in, the drilling up to required depth. Before the completion of the drilling, well is cleaned in order to prepare for the borehole logging and the casing and screen installation. The drilling process differs by drilling methods of mud and DTH drilling. The details of the drilling works for both DTH and mud drilling are described below.

- **Site Preparation**

  The site preparation includes the reconnaissance of the site, the drilling machine setting, the removal of the stones, trees or plants, the leveling and repairing of access road for machines.

- **Surface Hole Drilling and Surface Casing Installation**

  Unconsolidated surface formation are drilled down to depth of 3 to 10 m for both DTH and mud drilling. Normally, the drilling of surface hole is done by mud drilling by using tricone bit or blade bit. In case the surface is dry and not collapsible, air drilling is employed by using an air compressor for DTH drilling. DDCA uses steel or PVC surface casing of 3 to 4 m length.

- **Conductor Hole Drilling and Conductor Casing Installation**

  In basement rock area where the DTH drilling is applied, shallow strata of 10 to 50 m in depth from the surface are unconsolidated and collapsible. Therefore they are not supposed to be drilled by DTH. This unconsolidated layer needs to be protected from the collapse during the drilling of production hole. The protection shall be done by installation of the conductor casing soon after the drilling down to hard basement rock. Accordingly, the standard DTH drilling includes three stages i.e. drilling of surface hole, conductor hole and production hole.

  The conductor hole drilling is conducted by mud or air drilling with using tricone or blade bit in the same manner as the surface hole drilling. The conductor casing is steel casing with the screwed connections so that it can be pulled out from the hole after drilling. The casing pulled out is reused for other boreholes. In case of mud drilling, the bore wall can be protected by the mud from the collapse. Accordingly, two stages drilling consisting of the drilling of surface and production holes without drilling of conductor hole.

- **Drilling of Production Hole**

  The production hole of DTH drilling wells is drilled by DTH drilling and those of mud drilling is by mud drilling. During the drilling, cuttings are collected in every 2 m and kept as geological samples. The result of analysis of the geological samples, the driller's record of lost circulation and the penetration rate are important information on determination of the screen positions. Aquifer positions are easily identified since the water spouts out with air during DTH drilling in aquifers. In case of mud drilling, careful observation and records of the change of geological layer, penetration rate, mud viscosity and so on are important for the determination of the identification of aquifer positions. After reaching the target depth and confirmation of the existence of aquifers, the well is cleaned by mud to prepare for the next procedures of the borehole logging, and the installation of casing and screen pipes.

Technical level of Drilling Works and Issues on Technical Instruction

DDCA's drillers were confirmed to have basic techniques to conduct drilling works by using drilling equipment. Whereas, the following issues on efficiency of the work were observed

- Regarding the site preparation, it was observed that the equipment was put in place without leveling the ground. The leveling is necessary for keeping the equipment and machinery stable.
- The solid separation was observed to be ineffective due to too short drain canal and its slope. This may cause the low penetration and the rapid wearing of the drilling equipment. The meaning of mud control shall be properly understood by drillers so that the mud control is to be done in appropriate manner.
- There was no check list prepared for the equipment and materials to be brought into the site. It helps to prevent from suspending the work due to running out of the equipment and materials.
- The capacity of the drilling equipment (maximum lifting load of rig, discharge rate and pressure of mud pump, unit weight of drilling pipe etc) was not comprehended properly. Also sometimes the weight indicator or pressure gauge was not being used during the drilling works.
- Neither Marsh funnel (viscosimeter) nor mud balance was used for mud control.

Most of drillers were observed to rely on their past experience rather than measured figure such as machinery capacity and value of discharge and pressure. Accordingly, it takes a time to transfer the knowledge and technique to other drillers. This is regarded as an issue on provision of technical instructions.

5.2 BOREHOLE LOGGING

Currently, DDCA uses one logging machine made in Japan. The measuring items include spontaneous potential (SP), short and long resistivity and natural radioactivity (gamma rays). Borehole logging is an important process for determination of the proper screen positions in consideration of the geological record, penetration rate, water level and record of lost circulation. However, borehole logging is conducted only for drilled wells of which the contract conditions require it.

Technical level of borehole logging and issues on technical instruction

Currently DDCA has one technician who are in charge of the borehole logging. He was confirmed to be competent for borehole logging work and interpretation of the result. An issue on data management observed is that the borehole logging technician does not have enough knowledge on how to transfer the data into the computer and how to make a logging chart. Accordingly, the borehole logging results were not properly stored by DDCA.

DDCA realizes the importance of the logging. They intend to implement the borehole logging for as many wells as possible. In order to respond the increasing demand, DDCA regards it necessary to allocate drillers who know the operation of the borehole logging instrument to each drilling team. Also it is necessary for drillers to acquire the usage of a logging machine which is remained unused since purchased in 2012. The issue on technical instruction is that there are few drillers who have already know about the usage. Accordingly, transference of the experience and knowledge on logging to drillers is required.

5.3 WELL COMPLETION

Well completion is the process to complete a well including the determination of casing programme, installation of casing and screen pipes, gravel packing, well cleaning, backfilling/surface cementing and site demobilization. The details of each work are shown as below.

- **Casing Programme**

  The position of the screen shall be determined by the comprehensive interpretation based on the cuttings, geological record prepared by driller, the change of penetration rate, record of lost circulation of mud or air and result of borehole logging. In case the screen is not installed in the correct position, the water yield corresponding to the aquifer capacity would not be expected. Therefore, the screen positions shall be carefully determined. Furthermore, after the well cleaning, the quick determination is needed since the condition of the hole is getting worse over time.

- **Installation of Casing and Screen Pipes**

  According to the casing programme, the screen needs to be installed at the appropriate position. Before installation, numbering shall be done for all casing and screen pipe arranged in a line on site. In the installation, the depth often become less than planned due to the overhung layer in the hole and deposit in the bottom of hole. In such a case, it is necessary for casing and screen pipe to be pulled out and reinstalled after flushing. Accordingly, the flushing before installation and over drilling is important (to drill deeper than planned so as to secure the space for deposit).

- **Gravel Packing**

  In gravel packing, DDCA sieves granite into the size of 3 to 4 mm and uses it as gravel. Appropriate gravel packing work as well as the positioning of the screen is needed to intake the water as much expected yield as the well capacity has. Under certain geological condition, more gravel are required even if the wells were drilled by same diameter bit since drilling hole size can be expanded more than bit diameter. In case the driller is not aware of this, the gravel could not be completely packed into the planned depth. It causes well trouble such as sand rush. In gravel packing, amount of gravel is multiplied by safety rate calculated in consideration of the geological condition. It is important that the depth of gravel packing is confirmed by physical measurement.

- **Development**

  After installation of casing, screen pipe and gravel, pumping is required in order to remove out the cuttings and mud water into the layer. DDCA conduct the development work by air lift with using the air compressor. In case of the development work for the well drilled by DTH drilling normally only one day might be taken to complete development with using air lift.

- **Backfilling/Surface Cementing**

  The physical measurement of the gravel depth packed is important after the gravel packing. The gravel shall be increased in case the depth of gravel becomes deeper due to the removal of particles in development and pumping test.

  The backfilling is to fill the annular space between hole and casing screen with materials such as cuttings. It is supposed to be done after pumping test to conduct gravel packing. In case it takes a long time to start the development after the gravel packing, estimated amount of gravel to be added in backfilling due to the falling depth.

- **Site Demobilization**

  The site demobilization includes taking out of all equipment and machinery, clean-up of site, leveling of ground and backfilling of mud pond.

Technical Level of Well development and Issues on Technical Instruction

It was confirmed that after drilling DDCA conducts the installation of the casing and screen pipe, gravel packing, development with air lift, backfilling, cementing and site demobilization without any problem. The points to be considered were observed as below.

- The amount of gravel is determined by not calculation but experience. The work would be happened to suspend due to the shortage of gravel.
- Regarding the air lift, usually single pipe is used in air lift and double pipe is rarely used. Air lift by single pipe can damage the casing. Accordingly, drillers are required to acquire the work process of air lift by double pipe and the selection standard of air lift.

The issues on technical instruction is to make them enhance the calculation on installation depth of casing and screen pipe, and method of development by air lift in order to provide the instruction for others.

5.4 PUMPING TEST AND WATER ANALYSIS

- **Pumping Test**

  DDCA conducts the pumping test to investigate the well capacity. Normally constant pumping test and recovery test are being done except when the client requires the step test. The pumping test is conducted by the pumping test team, whose work is specialized in pumping test. However, DDCA intends that all drillers shall acquire the work process of pumping test.

- **Water Quality Analysis**

  Water quality analysis is conducted by the outside laboratories. The sample for the analysis is collected after completion of the pumping test. The role of technical instructor regarding the water quality analysis is to preserve properly the collected water.

Technical level of Pumping Test and Water Quality Analysis, and Issues on Technical Instruction

The pumping test is done by the pumping test team. Only a few drillers have knowledge of pumping test. It is necessary for drillers to impart the technique and knowledge on pumping test. Regarding the water quality analysis, only those who have experienced the pumping test know about it. The drillers are required to acquire the knowledge on sampling and basic water quality items.

5.5 WELL REHABILITATION

Well rehabilitation is not included into the drilling process. The work aims to make the well recover its function when the deterioration of water quality is found in operating well, and the well is got unused due to the accident inside the well such as drop of pump. DDCA take on the well rehabilitation work every year though the annual number of contract is just around 20. The work of well rehabilitation includes flushing and fishing. For the well which the water deterioration was found, well flushing with air lift or submersible pump shall be done. In case of the drop of pump and lifting pipe, fishing tools are made by drillers to take them out from the hole. Technique on fishing for well rehabilitation is the same like picking up the falling objects during drilling work.

Technical Level of Well Rehabilitation and Issues on Technical Instruction

Currently, well rehabilitation is not major works for DDCA. However, the techniques on taking measure of sand rush and falling pump are indispensable for drillers and there are demand to such techniques from private companies. It was confirmed that at least DDCA drillers have technique on flushing and fishing through drilling works. As issues on the technical instruction, the techniques are not shared and standardized in DDCA. Therefore the manuals on well rehabilitation would be useful for imparting and sharing the technique.

6 EVALUATION OF TECHNICAL LEVEL OF DDCA'S DRILLERS

It was confirmed, through the baseline survey on DDCA, that the drillers of DDCA have basic technique on the drilling. However not all drillers have the techniques on further drilling work such as logging and pumping test. The technical instructor to private sector shall acquire the entire process of the drilling works. Moreover, for the technical area identified the shortage of basic knowledge, the drillers shall be enhanced intensively. In addition to the baseline survey on the drilling work in DDCA, more details on the technical area necessary to be enhanced are needed. Therefore, the competence test to the drillers was conducted in November 2012 in order to measure the technical level of drillers.

6.1 PURPOSE OF THE COMPETENCE TEST

The purpose of the competence test is as follows.

- To identify areas necessary to be enhanced and new technical areas at DDCA for the technical instruction to the private sector,
- To identify the technical level of each driller and utilize these basic information for selecting the candidate of technical instructor.

6.2 TARGET GROUP OF THE COMPETENCE TEST

There are 74 drillers in DDCA. Out of 74, 68 belong to the Drilling Project Department and 6 are from Technical Support Department. They are members of the either drilling team or pumping test team which is involved in drilling works. The target drillers are classified to the four levels of S, A, B and C in order to select the candidates of technical instructors to the private drilling companies. The drillers classified to level S is defined that they have experienced and acquired high drilling knowledge and technique and they are in position to provide the instruction to others. Regarding level A, they are competent in doing the drilling work as a supervisor. The drillers classified to level B have a relevant experience to do the work according to the instruction from the supervisor, while those who are level C have a skill to do the supporting work according to the instruction from supervisor. This classification is determined by the evaluation of supervision of the Drilling Project Department through observation of their daily work performance and the achievement of the work. The number of the drillers and those who have taken the competence test by classification is shown in ***Table 8***.

The drillers who classified to S and A level are senior drillers, who shall be a candidate of the technical instructor. The activities enhancing the capacity of DDCA are targeted for senior drillers. Though the middle drillers, who classified to B and C, are not targeted in this Project, they would be senior driller in the near future as the result of capacity development through the daily work. The competence test was conducted to both senior and middle drillers in total 66 drillers in order to identify the entire technical level of drillers. Out of 66 drillers, 35 are senior and 39 are middle drillers. The number of senior and middle drillers who taken the competence test were 29 and 37, respectively. Some drillers missed to take a test since they were involved in their own task and some others have already positioned providing the instruction.

Table 8 Classification of Drillers

Technical Level	All Drillers			Competence Test Respondents			Reference
	DPD	TSD	Sub total	DPD	TSD	Sub total	
S	9	0	9	5	0	5	1)
A	25	1	26	23	1	24	2)
B	18	3	21	17	3	20	3)
C	16	2	18	16	1	17	4)
Sub total S, A	34	1	35	28	1	29	5) =1) + 2)
Sub total B, C	34	5	39	33	4	37	6) = 3) + 4)
Total	68	6	74	61	5	66	7) =5) + 6)

Note : Technical level S. and A are classified to senior driller while B and C are classified to middle driller
DPD: Drilling Project Department, TSD: Technical Support Department

6.3 CONTENTS OF COMPETENCE TEST

15 technical areas shown in ***Table 9*** were covered in the competence test. Each technical area is consisted of several items and each item has several questions. ***Table 9*** shows the number of item and question. In total 68 questions were asked in the questionnaire.

Table 9 Contents of the Competence Test

No.	Technical Area	No.	Technical Area
1	Site Mobilization	9	Back-Filling & Surface Cementing
2	Drilling Tools and Equipment	10	Site Demobilization
3	Drilling Drawbacks	11	Well Investigation
4	Drilling Control	12	Tool Fishing
5	Borehole Logging	13	Well Rehabilitatation
6	Casing Program / Installation	14	Pumping Test
7	Gravel Packing	15	Water Quality Analysis
8	Well Development		

7 IDENTIFICATION OF TECHNICAL AREAS NECESSARY TO BE ENHANCED AND NEW TECHNICAL AREAS TO BE NEEDED

7.1 METHOD OF MARKINGS AND RESULT OF TEST

Table 10 shows the accuracy rate by each item for whole respondents. The marking was set as 100 percent in case all questions of each item were answered correctly. Then, the accuracy rate was calculated according to the score attained by each respondent. The accuracy rate shown in ***Table 10*** is the average accuracy rate by item for all respondents. The accuracy rate by area was given by calculating the average accuracy rate of items under each area.

Regarding the accuracy rate of senior drillers by area, areas of logging, gravel packing, pumping test and water quality analysis were resulted in below 30 percent which is lowest in whole area. The reason assumed is that the drillers who have experienced logging, pumping test and water quality analysis are just a few. Also through the baseline survey it was anticipated that there are many drillers who are not competent in calculation of the gravel. The average rate of whole area was 44.6 percent. Accordingly, the area and item of accuracy rate attained to less than 45 percent was the standard for determination of the area necessary to be enhanced or newly acquired.

Table 10　Accuracy rate by area and item

Technical Area / Item	Accurracy Rate			Numbers of Question
	Senior Drillers	Middle Drillers	All Drillers	
1 Site Mobilization	**85.5%**	**82.6%**	**80.0%**	**3**
1-1　On-site Drilling Machine Setting-Out	85.5%	82.6%	80.0%	3
2 Drilling Tools and Equipment	**35.5%**	**28.0%**	**22.2%**	**4**
2-1　Selection of drilling bit and drilling method	30.1%	23.6%	18.6%	4
2-2　Bit rotation speed control	39.5%	30.5%	23.4%	4
2-3　Weight of drilling tools and weight on bit control	36.9%	30.0%	24.7%	3
3 Drilling Drawbacks	**58.7%**	**50.9%**	**44.5%**	**2**
3-1　Countermeasures against lost circulation (mud and air)	52.5%	45.3%	39.6%	2
3-2　Countermeasures against borehole collaption	70.0%	61.3%	54.1%	3
3-3　Countermeasures against jamming of drilling tools	53.5%	46.0%	39.9%	4
4 Drilling Control	**38.4%**	**34.3%**	**31.1%**	**1**
4-1　Air control of compressor for DTH drilling	72.3%	65.0%	59.5%	1
4-2　Mud control	26.1%	23.8%	22.0%	3
4-3　Proper mud flow velocity	44.1%	40.0%	36.5%	3
4-4　Control of mud pump operation	20.4%	20.8%	21.2%	3
4-5　Mud control for drilling of clay layer	29.0%	21.8%	16.2%	2
5 Borehole Logging	**26.9%**	**23.9%**	**21.4%**	**1**
5-1　Borehole logging instruments	21.7%	19.7%	18.0%	1
5-2　Interpretation of borehole logging results	32.2%	28.0%	24.9%	2
6 Casing Program / Installation	**45.3%**	**43.3%**	**41.4%**	**1**
6-1　Casing Program / Casing Installation	39.0%	35.0%	31.5%	1
6-2　Role of centralizer	51.7%	51.5%	51.3%	2
7 Gravel Packing	**23.7%**	**17.9%**	**13.5%**	**1**
7-1　Calculation of annular volume	12.2%	6.0%	1.4%	1
7-2　Calculation of gravel volume	13.9%	11.3%	9.4%	1
7-3　Determination of gravel size	45.0%	36.5%	29.7%	1
8 Well Development	**43.8%**	**39.1%**	**35.5%**	**1**
8-1　Well cleaning after drilling	35.9%	30.6%	26.5%	1
8-2　Single-tube method air-lifting	58.6%	54.5%	51.3%	1
8-3　Double-tube method air-lifting	36.8%	32.3%	28.8%	1
9 Back-Filling & Surface Cementing	**44.7%**	**42.0%**	**39.9%**	**1**
9-1　Back-filling	55.0%	45.5%	37.9%	1
9-2　Surface cementing	34.3%	38.5%	42.0%	1
10 Site Demobilization	**69.8%**	**63.3%**	**58.1%**	**1**
10-1　Precautions upon site demobilization	69.8%	63.3%	58.1%	1
11 Well Investigation	**73.4%**	**65.3%**	**58.8%**	**1**
11-1　Necessary information of well rehabilitation plan	73.4%	65.3%	58.8%	1
12 Tool Fishing	**41.4%**	**39.2%**	**37.4%**	**1**
12-1　Tool fishing plan	36.8%	36.0%	35.1%	1
12-2　Fishing tools	46.0%	42.3%	39.6%	1
13 Well Rehabilitatation	**34.8%**	**34.4%**	**34.0%**	**1**
13-1　Deterioration of casing	46.6%	48.5%	50.0%	1
13-2　Cause of rust-colored water	5.4%	5.5%	5.5%	1
13-3　Cause of sand production	41.5%	39.5%	37.9%	1
13-4　Methods of removal of sand sedimentation	24.1%	32.0%	37.9%	1
13-5　Methods of casing cleaning	29.2%	28.0%	27.1%	1
13-6　Usage of borehole camera	62.1%	53.0%	45.8%	1
14 Pumping Test	**27.6%**	**26.4%**	**25.5%**	**1**
14-1　Purpose of Pumping Test	35.8%	31.3%	28.0%	1

Technical Area / Item	Accurracy Rate			Numbers of Question
	Senior Drillers	Middle Drillers	All Drillers	
14-2 Selection of Submersible Pump	17.4%	18.0%	18.9%	1
14-3 Test Method	20.8%	26.0%	29.7%	1
14-4 Interpretation of test results	36.5%	30.2%	25.4%	4
15 Water Quality Analysis	**18.9%**	**22.8%**	**25.7%**	**1**
15-1 Purpose of Water quality analysis	17.1%	27.5%	35.2%	1
15-2 Item of water quality analysis	20.7%	18.0%	16.1%	1

Table 11 shows the distribution of the number of senior drillers by accuracy rate for all areas, drilling related areas and areas necessary to be enhanced (accuracy rate below 45 %). The number attained the accuracy rate more than 45 percent was 16 senior drillers for whole area (46 %), 20 for drilling related area (57 %), 3 for area to be enhanced (9 %). The result shows that the technical level of drilling related area involved in daily work was high, whereas the level of the other area was not. That is to say few drillers have acquired the basic knowledge for except drilling area. It is important for DDCA to enhance their capacity by increasing the number of drillers who acquired the basic knowledge on the area necessary to be enhanced.

The selection of the candidate of technical instructor shall be done comprehensively in consideration of not only the technical level identified by the competence test but also the evaluation of the daily performance from the drilling managers and supervisors, and also the plan of personnel allocation as well. The score of the drilling related area in the competence test is expected to be attained more than 45 percent. Enhancement for the knowledge shorten is possible to be covered during the training of instructors to be conducted for the activity of output 1. The specific activity of the training shall be included into the Private Sector Capacity Development Supporting Plan.

Table 11 Distribution of number of senior drillers by accuracy rate

Accuracy Ratet	Distribution of No. of drillers			Accuracy Ratet	Distribution of No. of drillers		
	All Area	Drilling Related Area	Area Necessary to be Enhanced		All Area	Drilling Related Area	Area Necessary to be Enhanced
Below 5%	0	0	1	40%	2	2	5
10%	1	1	0	45%	6	5	7
15%	0	0	0	50%	7	5	3
20%	0	0	1	55%	4	3	0
25%	1	0	3	60%	5	6	0
30%	0	1	4	65%	0	6	0
35%	3	0	5				
No. of drillers attaining more than 45 %					16	20	3
Ratio to all senior drillers (35 drillers)					46%	57%	9%

7.2 TEST RESULT BY TECHNICAL AREA

Table 12 shows the accuracy rate by technical area. The average rate for the whole area and drilling related area is shown at the bottom of the table. The average of senior drillers for all areas is 44.6 percent and 49.5 percent for drilling related area of which their level of understanding is high. Compared between senior and middle drillers for whole area and drilling related area, the accuracy rate of senior drillers is higher than that of middle drillers. This result is corresponding to the evaluation of the Drilling Project Department.

Table 12 Test result by technical area

No.	Technical Area	Accuracy Rate			Remarks
		Senior Drillers	Middle Drillers	All Drillers	
1	Site Mobilization	85.5%	80.0%	82.6%	Drilling Related Area
2	**Drilling Tools and Equipment**	**35.5%**	22.2%	28.0%	Drilling Related Area
3	Drilling Drawbacks	58.7%	44.5%	50.9%	Drilling Related Area
4	**Drilling Control**	**38.4%**	31.1%	34.3%	Drilling Related Area
5	**Borehole Logging**	**26.9%**	21.4%	23.9%	Other Area
6	Casing Program / Installation	45.3%	41.4%	43.3%	Drilling Related Area
7	**Gravel Packing**	**23.7%**	13.5%	17.9%	Drilling Related Area
8	**Well Development**	**43.8%**	35.5%	39.1%	Drilling Related Area
9	**Back-Filling & Surface Cementing**	**44.7%**	39.9%	42.0%	Drilling Related Area
10	Site Demobilization	69.8%	58.1%	63.3%	Drilling Related Area
11	Well Investigation	73.4%	58.8%	65.3%	Other Area
12	**Tool Fishing**	**41.4%**	37.4%	39.2%	Other Area
13	**Well Rehabilitation**	**34.8%**	34.0%	34.4%	Other Area
14	**Pumping Test**	**27.6%**	25.5%	26.4%	Other Area
15	**Water Quality Analysis**	**18.9%**	25.7%	22.8%	Other Area
Average of All Areas		44.6%	37.9%	40.9%	Other Area
Average of Drilling Related Areas		49.5%	40.7%	44.6%	Other Area

(shaded box): Areas attained below 45% by senior drillers

The current situation on the drilling level of senior drillers observed from ***Table 11*** and ***Table 12*** is summarized as below.

- **Drilling Work**

The drilling work includes site setting, drilling, installation of surface and middle casing, and casing after drilling and development before installation of the screen pipe, of which these areas are shown in 1 to 4 of ***Table 12.*** These areas are the major daily task for drillers. However, the score of the area on drilling tools and equipment, and supervision of the drilling was lower than the standard. Therefore, the knowledge of this area should be acquired. The score for the knowledge on drilling method, bit selection, tools weight and bit injection pressure, and drilling operation management including mud control, mud pump operation and drilling of clay layer was attained by low accuracy rate. It means that at least drillers conduct the drilling work with using the knowledge acquired by experience. However, the issue would come to the technical instruction providing the knowledge on the drilling work management such as tools weight and bit injection pressure. The utilization of the instruction manuals would helpful for the technical instructor to enhance them such knowledge.

- **Borehole Logging**

The average accuracy rate of borehole logging was 26.9 percent. Since many senior drillers have just experienced the supporting work for logging, they would have insufficient experience and knowledge. Accordingly, it is important for the as many as drillers to be given the opportunities of logging work and acquire it by using the technical manual.

- **Casing Programme**

The accuracy rate was 45.3 percent. The conclusion was that they have basic experience and knowledge.

- **Gravel Packing**

The accuracy rate was low, which attained to 23.7 percent. The questions included the calculation of vacancy volume and gravel. In drilling site, the drillers do not have a theoretical calculation of gravel, but determine it depending on their experience. Regarding the calculation of the vacancy volume and gravel, if the supporting data book is provided and carried by each driller to the site, the drillers would mitigate the task of calculation. The data book is supposed to include the specification of the drilling tools and volume table.

- **Development**

The activity for the enhancement of the capacity is necessary since the accuracy rate was 43.8 percent, which was slight low. The question was asking about the method of development such as air lift, bailing and surging. The reason attained by low accuracy rate was assumed that the names of method were not familiar to them. In the provision of technical instruction, uniformed terms should be used. Also the accuracy rate to the question asking about the air lift was low, especially for the air lift with double pipe. Normally, DDCA uses the air lift with single pipe. It is necessary for the technical instructor to acquire and give the instructions of the knowledge on air lift with double pipe as an option.

- **Backfilling/Surface Cementing**

The accuracy rate was 44.7 percent. Backfilling and surface cementing are important area in terms of protecting the surface water flowing into the well and also preserving the aquifer. The technical instructor shall provide the advice on appropriate method.

- **Site demobilization**

The drillers seem to have basic knowledge about the site demobilization according to the accuracy rate of 69.8 percent. For site mobilization, there are no complex works needed for the specific skill. At least the drillers shall possess the perception on the site recovery and environmental conservation. The appropriate method of demobilization is to be facilitated to the private drilling companies.

- **Well Investigation**

The well investigation includes the items such as well depth, screen position and pump type in order to conduct the well rehabilitation. The understanding was relatively high since the accuracy rate was 74.4 percent.

- **Fishing**

The accuracy rate was 41.4 percent which was higher than expected, though the fishing for the well rehabilitation had been an area of which DDCA desired to make the drillers enhance. The fact was that the technique applied for fishing was not shared and unplanned among the drillers. It is useful to prepare the universal manual for the technical instruction on fishing in order to share the technique. The uniformity of the term is necessary in preparation of the manual.

- **Well Rehabilitation**

The accuracy rate was 34.8 percent, which was higher than expected, though DDCA had observed itself that well rehabilitation is the area necessary to be enhanced. On the other hand, the accuracy rate for the question on the cause of rust coloured water was 5.4 percent, which was quite low. The knowledge on the deterioration of the casing is needed for the diagnosis of well. It is helpful for them to enhance the knowledge on it from the technical manual.

- **Pumping Test**

The accuracy rate was 27.8 percent, which was low as expected. This is because the pumping test was only conducted by the pumping test team. For the enhancement of DDCA, the knowledge of the pumping test should be acquired with using the technical manual, and the opportunity the pumping test work is supposed to be given to as many as senior drillers if possible.

- **Water Quality Analysis**

The pumping test team is responsible for the sampling of water quality analysis. As same as the pumping test, the accuracy rate was low, which was only attained to 18.9 percent. Actually, the knowledge on detail methodology of the water quality analysis is not necessary for drillers.

However, at least basic knowledge on analysing items and the points to consider in sampling shall be obtained for technical instructor. Transference of the knowledge with using the manual could be effective for the enhancement of this knowledge.

8 TECHNICAL SUPPORT PLAN FOR WELL DRILLING

8.1 IDENTIFIED TECHNICAL AREAS

Among the technical areas which DDCA is conducting, it seems that the basic knowledge and experience are not yet acquired by whole senior drillers. The eight areas of drilling tools and equipment, drilling operation management, logging, gravel packing, well development, backfilling and surface cementing, pumping test and water quality analysis are concluded as the technical areas necessary to be enhanced. For water quality analysis, as the technical instructor, they are supposed to have certain knowledge as a series of the groundwater development process, though there are not so much things to be acquired by them.

8.2 METHOD OF TECHNICAL TRAINING AND GUIDANCE

The technical areas necessary to be enhanced were identified through the baseline survey and competence test. Moreover, the technical level of senior drillers related to such area was also identified. The methods for enhancement of the capacity of each technical area are described below.

- **Drilling tools and equipment**

The accuracy rate of this area was attained by 35.5 percent, which is below the standard. The comprehensive knowledge such as specification and selection method of tools and equipment, and type of bit shall be acquired for the technical instructor. The manual to be prepared in the project, utilization of the manual, and provision of the guidance on site at workshop of DDCA's headquarter shall be useful for the enhancement of such capacity.

- **Drilling control**

The accuracy rate of this area was resulted in 38.4 percent, which is below the standard. The area includes the knowledge necessary to drilling work such as bit weight during drilling, air volume, mud control, specification of temporary casing. For the technical instructor, the knowledge on drilling mechanism such as mud function and appropriate velocity shall be needed. The manual to be prepared in the project and technical guidance would be useful for the enhancement of such knowledge.

- **Borehole logging**

Normally the borehole logging is conducted by the staff in charge of borehole logging. Accordingly, there are few senior drillers who acquired the technique of borehole logging. The accuracy rate in the competence test was 26.9 percent, which shows lower level than others. The acquirement of mechanism and interpretation of the borehole logging with using the manuals, and usage of logging tools on site shall be effective for enhancement of the technique of logging.

- **Gravel packing**

The capacity level of gravel packing was quite low according to the competence test resulted in 23.7 percent of accuracy rate. This is because most of drillers determine the amount of gravel by experience not theoretical calculation. The list of calculation form of gravel and volume of the hole shall be attached in the manual in order to simplify the calculation work on site. The utilization of such tools shall be provided in the seminar.

- **Development**

The accuracy rate of the development was attained by 43.8 percent, which is below the standard. The rate to the question asking about the airlift with single pipe was attained by 58.6 percent, which is high. When it comes to the airlift with double pipe, it was attained by 35.9 percent, which is low. The knowledge on the bailing and swapping as well as airlift with single pipe and double pipe shall be acquired for enhancement of the development work in order to make it possible to provide the appropriate instruction on the development. The utilization of the manual would be helpful.

- **Back-Filing / Surface Cementing**

Techniques of back-filling / surface cementing are not complicated. However, improper workmanship in this area may bring contamination of well by the inflow of surface water. Therefore, it is important for drillers to acquire proper techniques of the back-filling / surface cementing. Regarding surface cementing, drillers shall understand the proper mixing ratio of water and cement in order to ensure the strength of cement slurry. Annexing a list of mixing ratio to manuals helps easier on-site calculation. Learning with manual is an effective measure to acquire such knowledge.

- **Pumping Test**

Pumping test works are conducted by independent pumping test teams. Consequently, only few drillers have basic knowledge in this area. Accuracy rate in competence test was 27.6 %, which was considerably low. In order to conduct technical instructions, the knowledge of interpretation methods to evaluate well capacity is necessary, in addition to that of practical works regarding pumping test equipment, installation methods, measuring methods etc. On-site guidance is an effective measure for practical works. Learning with manual is effective for interpretation methods.

- **Water Quality Analysis**

DDCA's task regarding water quality analysis is water sampling during pumping test. As well as pumping test, only few drillers have basic knowledge in this area. Accuracy rate in competence test was 18.9 %, which was the least score among all areas. Detailed analysis methods are not necessarily learnt by drillers. The knowledge of proper water sampling procedures and general information of analysis items are sufficient for technical instructions. Learning with manual is an effective measure.

Table 13 shows measures for technical enhancement in each technical area.

Table 13 Technical Enhancement Measures for each Technical Area

Technical Area	Learning with Manual	Practical Training at the headquarters of DDCA	On-site Technicl Instruction by Instructor
Drilling Tools and Equipment	✔	✔	✔
Drilling Control	✔		✔
Borehole Logging	✔	✔	✔
Gravel Packing	✔		✔
Well Development	✔		✔
Back-Filling & Surface Cementing	✔		✔
Pumping Test	✔	✔	✔
Water Quality Analysis	✔		✔

8.3 TECHNICAL SUPPORT PLAN FOR WELL DRILLING

8.3.1 PREPARATION OF MANUAL

The manual was prepared with focused on the eight technical areas necessary to be enhanced. The manual includes the procedure of the work for each technical area, the work of listing up the specification of drilling equipment and materials, and data and drilling mechanism necessary for the technical instruction. Also in the manual, the general document on drilling technique and catalog of drilling material maker were attached or referred. The contents and structure are described in the fowling section.

8.3.2 TECHNICAL SEMINAR

The technical seminar shall be conducted for senor drillers to enhance their capacity. The seminar includes on the utilization of the manual and technical guidance on site regarding drilling tools, equipment, borehole logging and pumping test. The target of the seminar shall be 35 of all senior drillers. There is an option to conduct it by splitting them into two teams, which is consisted of 16 per each.

(1) Seminar on utilization of the manual

The seminar on the manual shall be conducted in Dar es Salaam in March 2012. The purpose is to make the drillers acquire the contents of the manual and utilization of the manual during the drilling work. The seminar including on fishing manual is planned to take one day.

(2) Technical training and guidance on drilling tools, specification of the equipment and borehole logging

The technical training and guidance on drilling tools, specification of equipment and borehole logging shall be done for 2 days in June 2013 by dividing 2 groups. The existing well owned by DDCA would be utilized for the technical guidance on the borehole logging. Also the equipment and materials of DDCA's headquarter would be utilized for the technical guidance on drilling tools and equipment. The clean-up of the existing well is required for DDCA in prior to the guidance.

(3) Technical training and guidance on pumping test

The technical training and guidance on pumping test shall be done for 2 days in September 2013. One day shall be allocated for the technical guidance utilizing the existing well of DDCA, and in 2^{nd} day the seminar shall be held at a certain venue. As same as the guidance on borehole logging, the clean-up of the existing well is required for DDCA in prior to the guidance.

8.3.3 On-site Technical Training and Guidance to Technical Instructors

In July 2013, JICA Expert conducts an on-site technical training and guidance to 12 certified technical instructors during their activities of instructions to other drillers at drilling sites. This guidance is made at four drilling sites of which two of DDCA's site and other two of sites for hiring equipment. At each site three technical instructors receive the guidance during two days. After this guidance, the internal technical instruction activities are principally conducted by DDCA's self. However, during the Project, JICA Experts provide technical supports at drilling sites and/or in DDCA's office, according to DDCA's requests.

8.3.4 Review of Internal Technical Instructions in DDCA

Continuous revision of manuals and instruction methods for technical enhancement of DDCA is required. In this purpose, a technical instruction review meeting is held by the drilling project operation department once a year. In this meeting, the technical improvement of senior drillers and the plan of revision of manual and instruction methods are examined.

8.4 Composition of Manuals for Well Drilling

Table 14 shows composition of manuals for enhancement of drilling techniques. Technical areas and items in ***Table 14*** correspond to those in the teaching guidance. Prepared manuals are used as materials for the teaching guidance as well.

Table 14 Composition for Manuals for Drilling Techniques

Technical Area /Item	Objective
2 Drilling Tools and Equipment	
2-1 Selection of drilling bit and drilling method	To learn differences between drilling methods and how to select them according to geological conditions.
2-2 Rotary Bits	To learn type, structure and use of rotary bits for mud drilling.
2-3 DTH and DTH Bit	To learn type, structure and use of DTH and DTH bits for DTH drilling.
2-4 Rig Accessory	To learn necessary contents and specifications of rig accessory such as drill pipe, drill collar etc.
2-5 Casing Tools	To learn specifications of steel casing pipes to be used as surface and conductor casing.
2-6 Drilling Equipment	To learn specifications of major drilling equipment such as drilling rig, mud pump, compressor, supporting truck etc.
2-7 Drilling Calculation	To learn necessary calculation for drilling work such as unit conversion,

Technical Area /Item	Objective
	calculation of discharge rate, annular volume etc.
2-8 Weight of drilling tools	To learn unit weight and total of drilling tools weight which shall be balanced with rig capacity during drilling.
2-9 Rotary bit rotation speed and weight on bit	To learn suitable bit rotation speed and weight on bit so as to use them effectively and safely during mud drilling.
2-10 DTH Bit rotation speed and weight on bit	To learn suitable DTH bit rotation speed and weight on bit so as to use them effectively and safely during DTH drilling.
4 Drilling Control	
4-1 Mud control	To learn rolls of mud fluid to conduct effective drilling and how to keep condition of mud.
4-2 Mud Pump Operation	To learn how to operate mud pump for effective use.
4-3 Casing for mud drilling	To learn specifications of surface and conductor casings and procedure to install and remove them.
4-4 Drilling operation for mud drilling	To learn how to control various parameter of drilling and procedures of each work such as pipe connection, cleaning hole etc.
4-5 Bit control and repairing for mud drilling	To learn how to control and repair bits for effective use.
4-6 Air control for DTH drilling	To learn rolls of air and how to control pressure and delivery for effective DTH drilling.
4-7 Air compressor operation	To learn how to operate air compressor for effective use.
4-8 Casing for DTH drilling	To learn specifications of surface and conductor casings and procedure to install and remove them.
4-9 Drilling operation for DTH drilling	To learn how to control various parameter of drilling and procedures of each work such as pipe connection, cleaning hole etc.
4-10 Bit control and repairing for DTH drilling	To learn how to control and repair DTH bits for effective use.
5 Borehole Logging	
5-1 Borehole logging instruments	To learn principles, measuring items and operation procedures of borehole logging.
5-2 Interpretation of borehole logging results	To learn how to determine screen position from borehole logging results.
7 Gravel Packing	
7-1 Determination of gravel size	To learn how to determine gravel size suitable to well structure and aquifer formation.
7-2 Calculation of gravel volume	To learn how to calculate gravel volume for the proper preparation on site.
7-3 Gravel packing	To learn gravel packing procedures and precautions to prevent from failure of packing.
8 Well Development	
8-1 Well cleaning after drilling	To learn several well cleaning methods to be selected according to well conditions, such as bailing, swabbing, air-lifting etc.
8-2 Single-tube method air-lifting	To learn single-tube method air-lifting which is popular method.
8-3 Double-tube method air-lifting	To learn double-tube method air-lifting which is more safe methods than single-tube one.
9 Back-Filling & Surface Cementing	
9-1 Back-filling	To learn procedures of back-filling.
9-2 Surface cementing	To learn how to calculate mixing of cement and water and how to place it.
14 Pumping Test	
14-1 Purpose and methods of Pumping Test	To learn purpose of pumping test and major pumping test methods.
14-2 Pumping test equipment	To learn necessary equipment to conduct pumping test.
14-3 Selection of Submersible Pump	To learn how to select suitable submersible pump according to capacity of well.
14-4 Interpretation of test results	To learn interpretation of step drawdown test and constant dicharge rate test and recovery test in order to determine well capacity and select proper pump.
15 Water Quality Analysis	
15-1 Purpose of Water quality analysis	To learn purpose of water quality analysis as a general knowledge.
15-2 Item of water quality analysis	To learn items analysed for groundwater and their effect on human health.

9 TECHNICAL SUPPORT PLAN FOR WELL REHABILITATION AND TOOL FISHING

9.1 IDENTIFIED TECHNICAL AREA

Two areas of fishing and well rehabilitation are concluded as the new technical area to be needed. Currently, these areas are not major technical area which DDCA is working on. However, the technical instructor shall be competent in these areas since the demand would be increased in the future. Also the accuracy rate was resulted below the standard.

9.2 METHOD OF TECHNICAL TRAINING AND GUIDANCE

The new technical areas to be needed were identified through the baseline survey and competence test. Moreover, the technical level of senior drillers related to such area was also identified. The methods for enhancement of the capacity of each technical area are described below.

- **Tool Fishing**

Accuracy rate of competence test was 41.4 %, which was slightly lower than the standard value. Currently, tool fishing and well rehabilitation is not major works of DDCA. Accordingly, techniques in these areas have not been unified. The familiarization of unified techniques to drillers by the formulation of manuals is an effective support measure. A practical training of guidance of types, uses and making methods of fishing tools in DDCA's headquarters is effective, as well.

- **Well Rehabilitation**

The accuracy rate in this area was 34.8 % which was lower than the standard value. In order for proper technical instructions of well troubles, drillers are required to acquire the knowledge of causes of well deterioration, sand removal methods, casing cleaning methods etc. Learning with manual is an effective measure.

Table 15 shows measures for technical enhancement in each technical area.

Table 15 Technical Enhancement Measures for each Technical Area

Technical Area	Learning with Manual	Practical Training at the headquarters of DDCA	On-site Technicl Instruction by Instructor
Tool Fishing	✔	✔	✔
Well Rehabilitation	✔		✔

9.3 TECHNICAL SUPPORT PLAN FOR WELL REHABILITATION AND TOOL FISHING

9.3.1 PREPARATION OF MANUALS

Manuals for well rehabilitation and tool fishing were prepared in the Project. These manuals contain the necessary knowledge and data such as work procedures, specifications sheet of equipment and materials etc. General technical books of drilling, catalogues of manufacturers of equipment and materials are utilized by annexing or indicating the name and the reference part of each material. Contents and composition of the manuals are described in the next section.

9.3.2 TECHNICAL SEMINAR

Seminars on use of technical manuals and a seminar for practical training of tool fishing shall be provided. The target group is 35 senior drillers. However, if it is necessary, the seminar may be conducted for two groups divided into half, according to the contents of seminar.

(1) Seminar on Utilization of the Manual

This lecture-style seminar is held in in the seminar venue in Dar es Salaam in March. The objective is to facilitate senior drillers to master the contents of manuals and the use of manuals during drilling works. The period of the seminar is one day, together with the seminar of technical manuals for drilling.

(2) Technical Training and Guidance of Fishing Tool Making

This seminar is conducted in two days in July 2013 in the headquarters of DDCA. In the first day a practical training of making fishing tools from steel product is conducted. In the second day, a lecture is given in a seminar venue in Dar es Salaam. DDCA is required to prepare for necessary steel materials, welding materials and tools.

9.4 COMPOSITION OF MANUALS FOR WELL REHABILITATION AND TOOL FISHING

Table 16 shows composition of manuals of well rehabilitation and tool fishing. Technical areas and items in ***Table 16*** correspond to those in the teaching guidance. Prepared manuals are used as materials for the teaching guidance as well.

Table 16 Composition of Manuals for Well Rehabilitation and Tool Fishing

Technical Area /Item	Objective
12 Tool Fishing	
12-1 Tool fishing plan	To learn necessary contents of tool fishing including down-hole investigation and work plan.
12-2 Fishing tools	To learn type of several fishing tools and their use.
13 Well Rehabilitation	
13-1 Phenomena and causes of well deterioration	To learn several type of well deterioration such as incrustation on screen, sand production etc. and their causes.
13-2 Methods of well rehabilitation	To learn several methods of well rehabilitation such as mechanical and chemical cleaning, sedimentation removal etc.
13-3 Usage of well camera	To learn usage of well camera to observe inside conditions of well.

10 IMPLEMENTED TECHNICAL TRAINING AND GUIDANCE

This chapter summarizes the activities related to the technical training and guidance for DDCA which was taken in the 1st year of the Project. The major target group of these activities was DDCA's drillers and the actual technical enhancement for them was implemented. Furthermore, these activities aimed at the base construction of another three years' activities of technical training of guidance for DDCA.

10.1 PRACTICAL TECHNICAL TRAINING AT DRILLING SITES (AUGUST TO SEPTEMBER 2012)

JICA expert team conducted the field survey at drilling sites from August to September 2012. The objective of the survey was to grasp contents of drilling works of DDCA and the technical level of drillers. In case certain challenges on drilling works are found during the survey, the experts conducted technical training and guidance to drillers at each site regarding these challenges. Challenges observed at each site, contents of guidance and considerations for the activities of technical training and guidance of the Project are summarized below.

- **Coast region Mitamba – Mud Drilling Site**

  Challenges : Mud pits were too small and they were too closely located. Thus, the mud circulation system was not effective on its solid contents separation function. Due to this situation, recirculation of solid contents in mud was decreasing drilling progress.

  Contents of Guidance: It was found that drillers did not sufficiently understand the mechanism of cutting removal function of mud circulation system. Due to the insufficient mud density or velocity, drill cutting retain at the borehole bottom. Retained cuttings are re-drilled and disturb the drilling progress. The expert explained such mechanism of drilling. Furthermore, the importance of proper solid separation system for the prevention of the re-circulation of cuttings was explained, as well.

- **Coast region Misugusugu - Mud Drilling Site**

  Challenges: Discharge rate of mud pump was not measured. Accordingly, mud was leaking from pump, because of misjudgment of replacement timing of piston and seals. In addition, pump pressure was not checked with pressure gauge. This may cause an overlooking of the decrease of discharge rate due to the elevation of pressure.

  Contents of Guidance: The expert instructed the importance of regular measurement of discharge rate in order for the effective cutting removal by mud circulation. The mechanism of variation of discharge rate due to the pressure increase according to drilling diameter and depth was also instructed. Through the above guidance, the importance of comprehension of mud circulation system for the prevention of drilling drawbacks was emphasized.

- **Mwanza region Maliza - DTH Drilling Site**

  Challenges: The drilling team was taking long time to remove the sedimentation from the borehole bottom during DTH drilling.

Contents of Guidance: The guidance of sand removal methods such as mixing water into compressed air, the use of foam agent, etc. were conducted. Other methods such as bailing, reverse circulation were explained as well.

Consideration: Some of these methods are already used by DDCA's drillers. However, DDCA does not have any unified manual for them. It is an effective measure of technical enhancement to familiarize these methods to drillers by formulating unified manuals.

- **Dar es Salaam region Kibamba - Mud Drilling Site**

Challenges: Drill cuttings deposited in mud pits were suctioned by the pump and re-circulated.

Contents of Guidance: As well as the site in Mitamba mentioned-above, drillers' comprehension of functions of mud circulation system was not sufficient. Therefore, the expert instructed the importance of cutting separation and the prevention of re-circulation. He explained that such insufficient comprehension of drilling mechanism would cause the ineffectiveness of the works, as well.

- **Dar es Salaam region Bunju A - Mud Drilling Site**

Challenges: An interruption of drilling work occurred, due to the necessity of transport of additional screen pipes as some of them had been found to be damaged.

Contents of Guidance: The estimation methods of quantities of casing and screen pipes for the site preparation were instructed. The necessity of securing supplementary quantities was explained, as well.

Consideration: As DDCA does not have a manual of procedures of drilling materials preparation, each driller conducts this work in their own way. It is important to include in the manual the procedures of drilling material preparation and quantity check in order to familiarize unified procedures to drillers.

- **Dar es Salaam region Msakuzi - Mud Drilling Site**

Challenges: The spare parts had not been kept at site when the breakdown of hydraulic parts occurred.

Contents of Guidance: The expert instructed the importance of keeping spare parts of which frequent replacement is predicted, in order for the prevention of the interruption of the works. Furthermore, he also explained that the continuing operation of hydraulic system without repairing some of the parts would cause the further breakdown.

Consideration: The daily maintenance manual for hiring equipment was prepared in the course of activities related to Output 3. Even for the equipment used by DDCA, it is important to use this manual for the proper implementation of daily maintenance.

- **Dar es Salaam region Vikuruti - Mud Drilling Site**

Challenges: The drilling team was taking long time to cope with the lost circulation during mud drilling.

Contents of Guidance: Countermeasures against lost circulation such as placing of strong mud, mixing of blocker materials like sawdust were instructed. Furthermore, the importance of the control of mud density and viscosity and the regular measurement of discharge rate and returning rate of mud was explained.

Consideration: In addition to lost circulation, drilling drawbacks such as bore wall collapse, jamming of drilling tools are important technical areas to all drillers. Though senior drillers in DDCA have the basic knowledge about them, unified techniques shall be familiarized to each driller.

- **Dar es Salaam region Sinza - Mud Drilling Site**

Challenges: The diameter of drag bit was found to be smaller than the standard size, due to the friction wear.

Contents of Guidance: JICA expert explained the following obstacles on drilling works caused by diminished bit:

- When the diminished bit is replaced with a new bit, reaming with this new bit is necessary before reaching the drilled depth,
- By pushing the new bit into small sized hole, bit may be stacked,
- Gravel packing work may be disturbed due to insufficient annular space,

Furthermore, he explained the importance of bit control and proper bit repairing.

Consideration: Too long use of bit for the purpose to economization of labor of bit replacement and repairing is not advisable. It may bring about obstacles and ineffectiveness on drilling works. It is important to familiarize the proper procedures of bit control to drillers.

- **Dar es Salaam region Kijichi – Pumping Test Site**

Challenges: The pumping test started before the water had become perfectly clear by air-lifting. In addition, the volume of measuring bucket had not been confirmed with the measurement standard.

Contents of Guidance: The expert instructed the importance of complete the air-lifting with perfectly clean and sand free water. In case of starting pumping test before the perfect well cleaning, an incorrect measurement of pumping test is suspected, due to the change of aquifer conditions during the test. Furthermore, there is a concern of smaller water yield against the expected one, as the cleaning effect by pumping is normally smaller than that of air-lifting.

The importance of the confirmation of bucket volume with a standard was instructed. The pumping test is important to determine the specifications of pump for water supply. Incorrect measurement may bring about the shortage of water supply and/or the breakdown of pump under improper operating conditions after the construction of water supply facilities.

- **Lindi region Kingurungundwa DTH Drilling Site**

Challenges: The drillers did not grasp the correct lifting capacity of rig nor weight of drill pipes. Furthermore, they did not check the weight on bit with weight indicator.

Contents of Guidance: The expert instructed the importance of keeping proper weight on bit with the knowledge of the weight of drill pipes and drill collars, and lifting capacity of rig.

Consideration: With an excess of weight, there is concern over hole deviation and/or damages on drilling tools. Therefore, it is important to keep proper weight by understanding the weight of drilling tools according to the drilling depth. Regarding the lifting capacity of rig, it is important to understand the room of capacity against the tools weight in order to conduct drilling work without causing tool jamming. Learning such drilling dynamics is important for drillers in order to conduct effective works and technical instructions.

10.2 WORKSHOP RELATED TO ENHANCEMENT OF DRILLING ORGANIZATION (SEPTEMBER 2012)

A workshop related to enhancement of drilling organization was held on 12th September 2012. The participants contained 31 persons in total, of which nine counterparts of the project, 14 drillers of DDCA, three maintenance staffs of the maintenance section of DDCA and five staffs of JICA Expert Team. In the workshop, an interim analysis result of baseline survey on drilling equipment and organization of DDCA was reported. Furthermore, policies of enhancement of drilling organization were discussed. The unification of techniques by formulating manuals and the evaluation system of the technical level of drillers were confirmed to be necessary.

In this workshop, as part of technical support for DDCA's drillers, a seminar of well rehabilitation was held. Currently well rehabilitation is not major works of DDCA. Consequently, DDCA does not have unified techniques for it. However, as well as tool fishing, this technical area was identified as areas necessary to be newly acquired from the result of the baseline survey. The lectured contents in the workshop were "causes of well deterioration", "importance of well operation history", "well deterioration by incrustation", "well deterioration by iron bacteria", "well deterioration by corrosion" and "well rehabilitation methods".

10.3 TECHNICAL SEMINAR OF BOREHOLE LOGGING (NOVEMBER 2012)

A technical seminar of borehole logging for a trainee of borehole logging technician was held on 14th and 15th November, 2012. Contents of the seminar are described as below:

Objective: As of 2012, only one borehole technician belongs to DDCA. Because he has other tasks of hydrogeological survey and drilling supervision, sometimes it is difficult to correspond to the requirement of borehole logging at once. In this reason, DDCA selected one staff as a trainee and is currently facilitating him to be second borehole technician. Another purpose of the seminar was strengthening the supporting organization for technical enhancement of borehole logging techniques, by increasing the number of borehole logging technicians.

Contents of Seminar: In the first day, a practical training of borehole logging instruments was carried out at actual drilling site at Msoga village in Bagamoyo district. In the second day, guidance for the interpretation and data management was made, using the manuals for each subject prepared in the Project.

As the seminar was held on actual drilling site, the exact time and day were determined just before the seminar. In this reason, participation of senior drillers was excluded in spite of initial plan, because of the difficulty in fixing their schedule. Another seminar of borehole logging is planned for senior drillers. In the next time, prior determination of date and time is needed, by securing a borehole for training in or near DDCA's headquarters.

11 TRAINING SCHEDULE

Figure 3 shows the training schedule which consists of technical training and guidance related to Output2 and training of technical instructors related to Output2. ***Table 17*** shows the demarkation of the preparation and allowances between the Project and DDCA, necessary for these technical training and guidance.

Table 17 Demarkation on Necessary Preparation and Allowances for Technical Training and Guidance

Item	Practical Training at the headquarters of DDCA	Technical Seminar in Venu in Dar es Salaam	On-site Technical Training and Guidance for Technical Instructors
Venue	DDCA	Project	drilling site of private drilling company of DDCA
Daily or travel allowance for participants, coordinators and DDCA's lecturers	DDCA	DDCA	DDCA
Lecturer of WDMI for seminar on utilization of the manual (in case necessary)	-	Project	-
Copy of seminar materials	Project	Project	Project
Preparation of necessary tools, equipment, securing of existing wells	DDCA (Cleaning of existing well, preparation of borehole logging equipment, pumping test equipment, materials for fishing tools and welding rods etc.)	-	-

Activity		Remarks	Lecturer / In Charge	Schedule (2013 – 2016)
Output 1	Finalization of Teaching Guidance			
	Instructors' Seminar / Certification	1 day / time	DDCA: Mr. Songea, Mr. Makaso Expert: Mr. Saito	▲ For 12 Instructors (1 day); ▲ Necessary numbers for supplementation (1 day); ▲ Necessary numbers for supplementation
	On-site Guidance for Technical Instructors		DDCA: Mr. Makaso Expert: Mr. Hida, Mr. Saito	▲ 3 Instructors x 2 sites = 6 prs.
	Technical Instruction Review		Drilling Department	▲ ▲ ▲
Output 2	Finalization of Manuals		DDCA: Mr. Songea, Mr. Makaso Expert: Mr. Saito	
	Technical Seminar			
	Seminor of Technical Manuals	1 day / time	DDCA: Mr. Songea, Mr. Makaso Expert: Mr. Saito	▲ 35 Senior Drillers; ▲ 35 Senior Drillers
	Practical Training (at DDCA'S headquarters)			
	Guidance of Drilling Tools and Equipment	Explanation of Equipment 0.5 day + Lecture 0.5 day	DDCA: Mr. Songea, Mr. Makaso Expert: Mr. Saito	▲
	Practical Training of Borehole Logging	Practical Training 0.5 day + Lecture 0.5 day	DDCA: Mr. Kulwa, Mr. Makaso Expert: Mr. Sumida, Mr. Saito	▲ 35 Senior Drillers x 2 days
	Practical Training of Making Fishing Tools	Practical Training 1 day + Lecture 1 day	DDCA: Mr. Songea, Mr. Makaso Expert: Mr. Saito, Mr. Hida	▲ 35 Senior Drillers x 2 days
	Practical Training of Pumping Test	Practical Training 1 day + Lecture 1 day	DDCA: Mr. Makaso, Mr. Prosper Expert: Mr. Saito	▲ 35 Senior Driller x 2 day
	On-site Guidance for Technical Instructors		DDCA: Mr. Makaso Expert: Mr. Hida, Mr. Saito	▲ 3 Instructors x 2 sites = 6 prs.
	Technical Instruction Review			▲ ▲ ▲
	On-site Technical Instruction by DDCA			
	On-site Technical Instruction Plan (Determination of Instructors in Charge, Recipient Drillng Teams, Schedule)		DDCA: Mr. Songea	▲ ▲ ▲
	Implementation of On-site Technical Instruction (8 sites /year)		DDCA: Mr. Songea	

JICA Expert Team

Position	Name
Chief Advisor / Groundwater Development Expert	Yuichi Hata
Deputy Chief Advisor / Drilling Expert	Masakazu Saito
Field Technique Training Expert	Yoshimi Hida
Operation Management / Organizational and Institutional Development Expert	Mikiko Azuma
Training Planner / Private Sectors Development Expert	Chiaki Tamekawa
Machinery and Equipment Maintenance Expert	Koji Uzawa
Geophysicist / Well Database Specialist	Tatsuya Sumida
Wells and Groundwater Resources Management Expert	Aya Kadokami

: Activities which require the preparation of equipment and machineries to be hired

Figure 3 Training Schedule

Appendix : List of Senior Drillers with Technical Rank

No.	E-No	Ansr-No	Name of Employee	Position	Duty	Rig No.	Model	Station	Mode of Employment	Certificate	Department	Technical Rank
1	D-02	R-35	Adam Salehe Rashid	Assistant Technician	Rig in charge	44	Schram	DSM	Permanent	Certificate in Drilling Grade I	DPD	A
2	D-05		Anderson Kanza Masoka	Principal Technician	Rig in charge	83	BPVL	DSM	Permanent	Diploma in Drilling	DPD	S
3	D-08	R-60	Benny Mpikita Makaso	Assistant Technician	Operator	81	Sankyo	DSM	Permanent	Certificate in Drilling Grade I	DPD	A
4	D-10		Charles Fadhil Mbaga	Principal Technician	Rig in charge	82	BPVL	DSM	Permanent	Certificate in Drilling	DPD	S
5	D-16	R-27	Donald Ishengoma Dominic	Technician II	Operator	44	Schram	DSM	Permanent	Certificate in Drilling Grade II	DPD	A
6	D-18	R-58	Elias Samwel Meena	Assistant Technician	Operator	46	Schram	DSM	Permanent	Certificate in Drilling Grade I	DPD	S
7	D-25	R-13	Gerald Benezeth Biyengo	Senior Technician	Pumping Test			DSM	Permanent	Certificate in Drilling	DPD	A
8	D-27		Godfrey Shemu Mahalanha	Assistant Technician	Rig in charge	17	Purcussion	DSM	Permanent	Certificate in Drilling Grade I	DPD	A
9	D-29	R-43	Gordan Philipo Haule	Technician II	Operator	70		DSM	Permanent	Certificate in Drilling	DPD	A
10	D-31	R-09	Haji Rashid Mkungile	Technician II	Operator	82	BPVL	DSM	Contract	Certificate in Drilling Grade II	DPD	A
11	D-42	R-42	Isaya Henry Majaliwa	Assistant Technician	Ass. Rig in charge	80	PAT301TP	DSM	Permanent	Certificate in Drilling Grade I	DPD	A
12	D-44	R-12	Yakobo Thadei Henjewele	Technician I	Rig in charge	9	Purcussion	DSM	Permanent	Certificate in Drilling	DPD	A
13	D-47	R-10	John Busi	Assistant Technician	Ass. Rig in charge	49	Schram	DSM	Contract	Certificate in Drilling Grade III	DPD	S
14	D-48	R-08	John Isdori Marimu	Senior Technician	Operator	83	BPVL	DSM	Permanent	Certificate in Mechanics	DPD	A
15	D-52	R-15	Juma Anafi Mlowola	Principal Technician	Operator	42	Schram	DSM	Permanent	Certificate in Drilling	DPD	S
16	D-56		Kasika Ndembo Kasika	Senior Technician	Rig in charge	16	Purcussion	DSM	Permanent	Certificate in Drilling	DPD	A
17	D-58	R-65	Linus Michael Siriwa	Assistant Technician	Operator	78	Koken	DSM	Permanent	Certificate in Drilling Grade I	DPD	A
18	D-62	R-11	Mabula Richard Minzi	Assistant Technician	Operator	42	Schram	DSM	Permanent	Certificate in Drilling Grade I	DPD	A
19	D-64	R-56	Masanja Bundala Jeremia	Assistant Technician	Rig in charge	46	Schram	DSM	Permanent	Certificate in Drilling Grade II	DPD	A
20	D-65	R-49	Maulid B. Seleman	Assistant Technician	Flushing			DSM	Contract	Certificate in Drilling Grade III	DPD	A
21	D-68	R-24	Melkion Joachim Mhagama	Senior Technician	Rig in charge	44	Schram	DSM	Permanent	Certificate in Drilling	DPD	A
22	D-69	R-03	Meshack Marcus Nyenza	Assistant Technician	Operator	80	PAT301TP	DSM	Permanent	Certificate in Drilling Grade I	DPD	A

No.	E-No	Ansr-No	Name of Employee	Position	Duty	Rig No.	Model	Station	Mode of Employment	Certificate	Department	Technical Rank
23	D-71	R-25	Minzi Nangi Mabula	Principal Technician	Operator	44	Schram	DSM	Permanent	Certificate in Drilling	DPD	A
24	D-72		Munzari Kassim Tindi	Assistant Technician	Rig in charge	78	Koken	DSM	Permanent	Certificate in Drilling Grade II	DPD	S
25	D-73	R-46	Mussa Elzei Makaso	Technician II	Rig in charge	80	PAT301TP	DSM	Permanent	Certificate in Drilling Grade I	DPD	A
26	D-76	R-18	Obayi Suphiani Kitosi	Technician I	Rig in charge	77	PAT301A	DSM	Permanent	Certificate in Drilling	DPD	A
27	D-79	R-62	Paulo Mswata	Technician II	Ass. Rig in charge	78	Koken	DSM	Contract	Dipl. Hydrogeology & Water Well Drilling	DPD	S
28	D-82	R-14	Prosper Mwemezi Lutailwa	Technician I	Pumping Test			DSM	Permanent	Certificate in Drilling	DPD	A
29	D-91	R-41	Saidi Ramadhani Mwaulungu	Assistant Technician	Ass. Rig in charge	50	Schram	DSM	Permanent	Certificate in Drilling Grade I	DPD	A
30	D-95	R-20	Simon Manyonga	Technician II	Ass. Rig in charge	81	Sankyo	DSM	Contract	Dipl. Hydrogeology & Water Well Drilling	DPD	S
31	D-97	R-32	Stephen Newton Halinga	Assistant Technician	Rig in charge	49	Schram	DSM	Permanent	Certificate in Drilling Grade II	DPD	A
32	D-98	R-47	Thomas Lazaro Masheyo	Assistant Technician	Rig in charge	42	Schram	DSM	Permanent	Certificate in Drilling Grade II	DPD	A
33	D-100		Tito Michael Mtanda	Principal Technician	Rig in charge	81	Sankyo	DSM	Permanent	Certificate in Drilling	DPD	S
34	D-144	R-01	Kabuche Peter Mafwere	Technician (Plant)	Ass. Rig in charge	83	BPVL	DSM	Permanent	Adv. Driver's Certificate Course Grade I	TSD	A
35	D-160	R-45	Omary Halili Shabani	Technician II	Operator	83	BPVL	DSM	Permanent	Certificate in Drilling Grade I	DPD	A

DPD: Drilling Project Department, TSD: Technical Support Department