CHAPTER 6 TEST BOREHOLE

6.1 Drilling Program

6.1.1 Outline of the Program

The test borehole drilling program has been planned based on the results of the 1st Field Survey (1999). An outline of drilling program, including location, depth planned and drilled, is listed below.

Location		Borehole No.		Aquifer		Borehole Depth	
No.	**Farm Name**	**JICA No.**	**WW No.**	**Target**	**Actual**	**Planned (m)**	**Drilled (m)**
J-1	Christiana	J-1N **(J-1A)**	39839	Nossob	**Auob**	240	256.00
J-2	Olifant water west	J-2A J-2N	39840 39841	Auob Nossob	Auob Nossob	85 155	130.51 209.00
J-3	Steynsrus	J-3K J-3A J-3N	39842 39843 39844	Kalahari Auob Nossob	Kalahari Auob Nossob	20 55 155	102.00 253.00 409.00
J-4	Okanyama (Aminuis)	J-4K J-4A J-4N	39845 39846 39847	Kalahari Auob Nossob	Kalahari Auob Nossob	100 285 395	53.20 204.00 356.00
J-5	Maritzville	J-5N	39848	Nossob	Nossob	260	187.00
J-6	Cobra	J-6K J-6A J-6N	39849 39850 39851	Kalahari Auob Nossob	Kalahari Auob Nossob	180 250 320	168.50 273.00 385.00
J-7	Jackalsdraai	J-7K J-7N	39852 39853	Kalahari Nossob	Kalahari Nossob	50 245	55.00 250.00
J-8	Tweerivier	J-8K J-8A J-8N	39854 39855 39856	Kalahari Auob Nossob	Kalahari Auob Nossob	110 225 325	129.00 250.00 346.00
J-9	Klein swart modder	J-9N **(J-9A)**	39857	Nossob	**Auob**	145	141.50
				Total depth :		**3,600**	**4,157.71**

The drilling works started on 10 April 2000 and was completed at the end of November 2000. Such works also include pumping test, borehole head construction and installation of water level recorder. The location of these boreholes and existing boreholes which water level recorders were installed are shown in Fig. 6.1-1(s.p.6-31).

A total depth of 4,157m was drilled. In most location, except locations of J-4, J-5 and J-9, the drilled depths are deeper than planned depth. The actual depths to the bottom of targeted aquifer are deeper than estimated, at most of location.

No Nossob Member was found at the locations of J-1 and J-9. These boreholes, therefore, were modified as Auob type boreholes.

6.1.2 Structure and Specification

1) Design Policy Based Upon the Results of the 1st Field Survey (1999).

One of the main purposes of test borehole is to gain hydrogeological information. Since there are three aquifers in the basin, structural designs have been made for the each aquifer independently. The other important purpose is to construct monitoring boreholes, for the further management of the groundwater basin. The test boreholes constructed under the project have been designed based on the following policies.

i) The borehole shall be drilled independently to each aquifer. The own structure, therefore, is needed for each type of borehole.

ii) The common materials on the each type of boreholes, however, shall be selected as much as possible, in order to avoid a wasteful procurement.

iii) In order to examine the hydrogeological character of each aquifer, the correct data such as water level, quality and yield shall be obtained from the borehole. Therefore, "full hole cementing method" had been applied to seal the non-target completely.

iv) Considering the limited availability of such test boreholes in the study area, the newly drilled boreholes by this program must be multipurpose. A sufficient diameter of the casing and screen pipe is needed, to be able to both of pumping and water level measurement.

v) The great majority of the existing boreholes in the study area were constructed without screen pipe installation. The main reasons of such structure are presumed as the sufficient hardness of the formation (Auob and Nossob), and economic viability. Considering the long-term use as monitoring borehole, however, any risk of the collapse of the hole wall must be avoided. The screen pipe, therefore, shall be installed for the any type of borehole.

vi) A good quality material shall be adopted for the major parts of the structure, in order to utilize the borehole for long term monitoring.

vii) The local material and standard must be chosen in preference, to make easy maintenance of the borehole. SABS (South African Bureau of Standard) standard shall be applied as a major part of the specification of the boreholes.

2) Structure and Specification Adopted

Based on the aforesaid design policy, the structure and specification of the test boreholes were determined. The structure and specification described hereunder are the standard for the construction of each type of test borehole. The diameter, depth of drilling hole and size of casing and/or screen pipe, however, were altered in order to accept variety of drilling method and equipment, also depend on geological formation. The followings are the adopted structure and specification for the boreholes drilled.

(1) Test Borehole for Kalahari Aquifer (See, Fig.6.1-2)

The formation of Kalahari Aquifer is composed of unconsolidated to semi-consolidated sand, gravel and calcrete. The formation is an uppermost layer of the basin. Considering the expected depth and condition of the layer, single string structure was applied. The borehole shall be drilled up to the Rietmond Member. The major specifications determined are as follows.

Item		**Specification**
Structure	:	Single string, straight type borehole.
Setting of Pipes	:	Cement grout in casing pipe, gravel (1 to 3mm) packing in screen pipe
Hole Size	:	φ12-1/4” (311.2mm)
Casing Pipe	:	φ6”, SABS719, Grade B, Zinc galvanized steel
Screen Pipe	:	φ6” (168mm), SUS304 Stainless steel, Johnson type screen

(2) Test Borehole for Auob Aquifer (See, Fig.6.1-3)

The formation of Auob Aquifer is composed of fine to coarse grain size sandstone with minor intercalation of thin shale layer in local. The formation is, unconformable underlying the Kalahari Beds. Thus, sealing of the Kalahari Aquifer shall be required. Considering the necessity of the sealing of an overlying aquifer, double string structure was applied. The major specifications determined are as follows.

Item		Specification
Structure	:	Double string, two step telescope type
Setting of Pipes	:	Full hole cementing in casing pipe in the Pump House section Open hole in screen (and casing) pipe in the Screen Pipe House section
Hole Size	:	1) ϕ9-7/8" (250.8mm) in Pump House 2) ϕ7-7/8 (193.7mm) in Screen Pipe House
Casing Pipe	:	1) ϕ8 (216.3mm), SABS719, Grade B Zinc galvanized in Pump House 2) ϕ6", SABS719, Grade B, Zinc galvanized steel
Screen Pipe	:	ϕ6" (168mm), SUS304 Stainless steel, Johnson type screen

(3) Test Borehole for Nossob Aquifer (See, Fig. 6.1 -4)

The formation of Nossob Aquifer is composed of fine to medium grain size sandstone. Minor intercalation of thin siltstone to shale layer is observed at locally. The formation is lowermost layer of the groundwater basin. Thus, the sealing of the two aquifers of Kalahari and Auob shall be required. Double string structure was also applied for the aquifer. About drilling hole, therefore, two steps cementing method was adopted. The major specifications determined are as follows.

Item		Specification
Structure	:	Double string, three steps telescope type
Setting of Pipes	:	Full hole cementing in outer and inner casing pipe in the Pump House section Open hole in screen (and casing) pipe in the Screen Pipe House section
Hole Size	:	Pump House 1) ϕ12-1/4" (311.2mm) for outer casing pipe 2) ϕ9-7/8" (250.8mm) for inner casing pipe Screen Pipe House 3) 7-7/8 (193.7mm)
Casing Pipe	:	Pump House 1) ϕ10" (273mm), SABS719, Grade B Zinc galvanized steel for outer casing pipe 2) ϕ8 (216.3mm), SABS719, Grade B Zinc galvanized steel for inner casing pipe 2) ϕ6", SABS719, Grade B, Zinc galvanized steel
Screen Pipe	:	ϕ6" (168mm), SUS304 Stainless steel, Johnson type screen

* "Pump house" means a section of borehole having an enough diameter can be install the submersible pump.

** "Screen pipe house" means a section of borehole having a diameter can be install the screen pipes.

(4) Borehole Head Facilities

Water level recorders were installed on the each borehole. The instruments were supplied by JICA. In order to protect top ends of conductor and casing pipe, a borehole head block was constructed. The standard design of the borehole head block is shown in Fig. 6.1-5.

The water level recorders were installed on the borehole after the construction of the borehole head facilities. In the artesian boreholes of J-3N, J-6N and J-5N, however, an another design for the head facilities was applied. A pressure probe type of recorder was installed in upper chamber of the head facility.

A security fence was constructed around each individual test borehole. Figure 6.1-6 shows the design of the fence constructed.

6.1.3 Drilling Procedure

The test boreholes were drilled using the rotary drilling method using a direct mud circulation system. By such method, and to conform to the aforesaid structure, the following procedure and specification were applied for each type of borehole.

1) Test Boreholes for the Kalahari Aquifer (See, Fig.6.1-2)

Step No.	Work Description	Items and Specification applied
1	Drill a conductor hole on the surface to the required depth.	Hole size: 17-1/2" (444.5 mm)
2	Install a conductor pipe to the drilled depth.	Pipe size: 14" (355.6 mm OD)
3	Seal the annular space between the wall of a drilled bore and the conductor pipe by cementing.	
4	Resume drilling of the borehole to the required depth.	Bit size: 12-1/4" (311.2 mm)
5	Perform borehole geophysical logging through the drilled borehole.	Resistivity, SP, Temperature, Natural Gamma, Caliper and Neutron log.
6	Determine the position(s) of screen pipe through the instruction of the Engineer.	
7	Install casing pipe and screen pipe as determined.	Casing size : 6" (168 mm OD) Screen size : 6" (168 mm OD)

8	Make gravel packing for the annular space between the hole wall and screen pipe.	2mm to 4mm grain size
9	Perform the development of a borehole.	use air-lifting (surging or bailing from time to time may be necessary)
10	Make clay pack and cement grout packing for the annular space between the hole wall and casing pipe.	Up to the ground level
11	Perform the development of a borehole	By air-lifting (surging or bailing from time to time may be necessary)
12	Carry out the pumping test by submersible pump.	Step drawdown, constant discharge and time recovery test.
13	Construct the borehole head facilities and install the water level recorder.	

2) Test Borehole for Auob Aquifer (See, Fig.6.1-3)

Step No.	**Work Description**	**Specific Requirements**
1	Drill a conductor hole on the surface to the required depth	Hole size: 17-1/2" (444.5 mm)
2	Install a conductor pipe to the drilled depth.	Pipe size: 12" (318.5 mm OD)
3	Seal the annular space between the wall of a drilled bore and the conductor pipe by cementing.	
4	Resume drilling of the borehole to the required depth.	Bit size: Bit size : 9-7/8" (250.8 mm)
5	Perform borehole geophysical logging through the drilled borehole.	Resistivity, SP, Temperature, Natural Gamma, Caliper and Neutron log.
6	Install casing pipe to the drilled depth	Casing size : 8" (216.3 mm OD)
7	Make full hole cementing for the annular space between the hole wall and casing pipe	Inner-string method using float shoe
8	Resume drilling of the borehole to the required depth (up to top of the Mukorob Member)	Bit size: 7-7/8" (193.7 mm)
9	Perform borehole geophysical logging through the drilled borehole	Resistivity, SP, Temperature, Natural Gamma, Caliper and Neutron log.

10	Determine the position(s) of screen pipe through the instruction of the Engineer.	
11	Install casing and screens pipe as determined.	Casing size : 6" (168 mm OD) Screen size : 6" (168 mm OD)
12	Perform the development of a borehole	By air-lifting (surging or bailing from time to time may be necessary)
13	Carry out the pumping test by submersible pump.	Step drawdown, constant discharge and time recovery test.
14	Construct the borehole head facilities and install the water level recorder.	

3) Test Borehole for Nossob Aquifer (See, Fig. 6.1-4)

Step No.	Work Description	Specific Requirements
1	Drill a conductor hole on the surface to the required depth	Hole size: 20" (508 mm)
2	Install a conductor pipe to the drilled depth.	Pipe size: 16" (406.4 mm OD)
3	Seal the annular space between the wall of a drilled bore and the conductor pipe by cementing.	
4	Resume drilling of the borehole to the required depth. (up to top of the Rietmond Member)	Bit size: Bit size : 12-1/4" (311.2 mm)
5	Perform borehole geophysical logging through the drilled borehole.	Resistivity, SP, Temperature, Natural Gamma, Caliper and Neutron log.
6	Install casing pipe to the drilled depth	Casing size : 10" (273 mm OD)
7	Make full hole cementing for the annular space between the hole wall and casing pipe	Inner-string method using float shoe
8	Resume drilling of the borehole to the required depth. (up to top of the Mukorob Member)	Bit size : 9-7/8" (250.8 mm)
9	Perform borehole geophysical logging through the drilled borehole.	Resistivity, SP, Temperature, Natural Gamma, Caliper and Neutron log.
10	Install casing pipe to the drilled depth	Casing size : 8" (216.3 mm OD)
11	Make full hole cementing for the annular space between the hole wall and casing pipe	Inner-string method using float shoe

12	Resume drilling of the borehole to the required depth (up to top of the Dwyka Group)	Bit size: 7-7/8" (193.7 mm)
13	Perform borehole geophysical logging through the drilled borehole	Resistivity, SP, Temperature, Natural Gamma, Caliper and Neutron log.
14	Determine the position(s) of screen pipe through the instruction of the Engineer.	Will be informed by the Engineer
15	Install casing and screens pipe as determined.	Casing size : 6" (168 mm OD) Screen size : 6" (168 mm OD)
16	Perform the development of a borehole	By air-lifting (surging or bailing from time to time may be necessary)
17	Carry out the pumping test by submersible pump.	Step draw down test, constant discharge test and time recovery test.
18	Construct the borehole head facilities and install the water level recorder.	

6.1.4 Materials Used

All materials required for drilling and construction of the boreholes was selected to conform to the determined borehole structure and specifications. The followings are the major materials used for the borehole drilling and construction.

1) Conductor Pipe

The conductor pipes installed are high-grade carbon steel, black, conforming to the requirements of SABS1431. Pipes were supplied in standard lengths of 6 m. Grade B steel was supplied, so that the nominal wall thickness of the casing was more than 6 mm. Bevelled ends were specified for the both ends of each pipe.

2) Casing Pipe

The casing pipes installed are high-grade Zinc Galvanized (SABS763) steel, conforming to the requirements of SABS1431. The pipes were supplied in standard lengths of 6 m. Grade B steel was specified, so that, the nominal wall thickness of all casing is more than 6 mm. Bevelled ends were specified for the both ends of each pipe.

Following three kinds of casing pipe were provided.

	Outside Diameter	**Wall Thickness**	**Used for**
a)	6" (165mm)	6.0 mm	Screen Pipe House
b)	8" (219mm)	6.0 mm	Pump House
c)	10" (273mm)	6.0 mm	Pump House

3) Screen Pipe

The screen pipe selected for the boreholes are wedge wire (Johnson) type, conforming to the Zinc Galvanized carbon steel material with bevelled ends. The detailed specification for screen pipe shall be as follows:

Nominal size (inch)	:	6"
Screen diameter (mm)	:	168mm
Overall unit length (mm)	:	6,000
Slot size (mm)	:	1.0
Materials	:	SUS304, stainless steel
Opening ratio (%)	:	more than 20%
Joint	:	bevelled ends

4) Cement Grouting (for Full Hole Cementing)

Sulphur resistant cement of CEM II ENV 197 was applied as cement grouting. The cement slurry had a specific gravity within the range 1.74 to 1.8, and was made up with water that has a total dissolved solids (TDS) concentration of less than 1,200 mg/l and a sulphate concentration of less than 200 mg/l.

5) Concrete (for Head Works)

A mixture of Sulfur Resistant cement and aggregates was used for the head works concrete. This concrete mixing was made up of not less than five sacks of 50 kg each per cubic meter of finished concrete. The mix did not contain large amounts of fine materials. Fresh, potable water was used as mixing water. The aggregates used were durable and well graded in sizes ranging from sands to rock of less than 25mm.

6) Drilling Mud and Chemicals

Following drilling mud and chemicals were used, based on the geological formation and drilling conditions.

CAP 21	: CAP 21 is a partially hydrolysed tri-polymer emulsion, and was used to the stabilize reactive clay and the shale formation. The specific gravity of CAP 21 is 1.05 g/cm^3.
EZEEMIX	: EZEEMIX is partially hydrolysed polyacrylamide and polyacrylate copolymer emulsion, was used to stabilize reactive clay and shale formation. The specific gravity of CAP 21 is 1.05 g/cm^3.
PAC-R	: PAC-R is a high molecular weight polyanionic cellulose. It was used for filtration control and supplementary viscosity in most water based drilling fluids.
Extra-GEL/ Bentonite	: Extra-GEL/Bentonite viscosifier is a high yielding bentonite, specially processed to promote ease of mixing and superior mud mixing in fresh water. Specific gravity of Extra-GEL/Bentonite is 2.5 to 2.6 g/cm^3.

7) Development Chemical

Following development chemicals were used based on the geological formation and drilling conditions.

STPP	: STPP is sodium polyphosphate, and was used as a disperse to clean aquifers during borehole development.
ROTAFORM CONCENTRATE	: ROTAFORM CONCENTRATE is a highly concentrated biodegradable blend of anionic surfactants and stabilizing agents.

8) Centralizers

Steep hinged type centralizers which can be clamped onto the casing pipes, was used only for the Kalahari boreholes.

9) Casing Cementing Shoes

The cement float shoe, with aluminum non-return valve were selected for the cementing shoe of full hole cementing operation.

10) Gravel Pack

Only fresh quartz gravel was used as the gravel pack material of Kalahari boreholes. No crushed stone was used. The grain size of the gravel was 1.4 mm to 3.0 mm.

6.1.5 Drilling method

1) Drilling

The rotary drilling method with a direct mud circulation system was applied as principal method for the drilling. Drilling have been made basically in the diameters indicated in aforesaid section of Construction Procedure above.

2) Drilling Fluid

The drilling fluid had the following properties; 1) a maximum specific gravity of 1.20, 2) a maximum of 40 sec. (500cc/500cc) of marsh funnel viscosity and 3) a maximum of 2 mm in 30 minutes of mud cake have been used for the normal drilling operation. The sand content was kept within a maximum of 3% after filtering by 200-mesh sieve. The chemicals, used during drilling, was non-toxic and fully biodegradable.

3) Gravel Packing and Cement Grout (Kalahari Borehole)

For the Kalahari boreholes, the gravel pack was made, in the annular space between the hole wall and the screen pipe. The grain size of the gravel was 1.4mm – 3.0mm. The annular space between the casing pipes and the drilled hole wall was sealed with clay (max. 3 m thickness) and with cement from above the clay packing to ground level. .

4) Full Hole Cementing (Auob and Nossob Boreholes)

On the boreholes for the Auob and Nossob Aquifers, the overlaying formation was sealed off to examine the proper hydrogeological character of the targeted aquifer. Therefore, full hole cementing was made in the annular space between the hole wall and casing pipes, and/or the annular space between the two casing pipes, at the pump house section of the drilled borehole. The methods of the full hole cementing shall be basically applied either “Inner-string Method”

5) Borehole logging

The measurement must be conducted by a mechanically lowered electrode, sensor and probe. The cable speed, therefore, was set properly and regulated to obtain proper records. The all measurements were made only in uncased borehole filled with drilling fluid. Borehole logging have been performed for six parameters of 1) Natural Gamma, 2) Spontaneous Potential, 3) Neutron, 4) Resistivity, 5) Temperature and 6) Caliper in the whole depth of borehole immediately after the completion of the each stage of drilling. Before the commencement of logging, the viscosity, the electrical conductivity, apparent resistivity and the temperature of the filtered drilling fluid and the water used in the drilling fluid was measured.

6) Installation of Casings and Screens

After interpretation of borehole logging results, data regarding lost circulation zones and the drilling log, the lengths and positioning of screens and blank sections of casings (6") were determined. Casing was lowered down the borehole by their own weight and no force was allowed to push the casing down. All the casing pipes, from the bottom of the hole up to 15 m below ground level had to be centralized using carbon steel centralizers spaced at a minimum of 10 m intervals.

The bottom of the casing (6") was completely closed by a bottom-plug of the same material as used for the casing. Where the cement grout or full hole cementing was to be installed, the string of connected casings had to be suspended from the surface without resting the column on the bottom of the hole until after the cementation have been completed.

All welding joints for casing and/or screens had to comply with the standard for welding as described in SABS 044. The welding joints outside of the casing and screens were painted with epoxy tar.

7) Development

After the casing and screen pipes have been installed, the development work was conducted by air lifting, or by bailing or surging in case of very low yielding boreholes. The water level in the borehole prior to the commencement of air-lift operations was measured and recorded.

After installing a test pump, surging of the borehole was achieved by starting and stopping the pump, or by changing the discharge rate in order to induce reversal of water flow through the screen openings. The development was carried out until the borehole was adequately developed.