No.

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF WATER RESOURCES AND IRRIGATION OF THE GOVERNMENT OF THE SOUTHERN SUDAN ((MWRI / GOSS)

MINISTRY OF HOUSING, PHYSICAL PLANNING AND ENVIRONMENT OF THE GOVERNMENT OF THE SOUTHERN SUDAN (MHPPE / GOSS)

MINISTRY OF PHYSICAL INFRASTRUCTURE OF THE CENTRAL EQUATORIA STATE (MOPI / CES)

JUBA URBAN WATER SUPPLY AND CAPACITY DEVELOPMENT STUDY IN THE SOUTHERN SUDAN

FINAL REPORT (APPENDIX)

SEPTEMBER 2009

TOKYO ENGINEERING CONSULTANTS CO., LTD. (TEC)
EIGHT-JAPAN ENGINEERING CONSULTANTS INC. (EJEC)

EID
JR
09-105

Foreign Exchange Rate:

USD 1 = JPY 98.33

USD 1 = SDG 2.21

(Average Between August 2008 and February 2009)

APPENDICES

APPENDIX – A

STUDY ON GROUNDWATER SOURCES

IN TOKIMAN PALEOCHANNEL

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A.1 Introduction

The feasibility of groundwater of existing wells and Tokiman Paleochannel as urban water supply source is evaluated in this study.

The background of the groundwater survey is that the result of the interview to the households in Juba city by the JICA study team, about 60 % of households are using a public borehole with a hand pump. In addition, groundwater quality of a borehole in the area is clean than with respect to color and turbidity compared to water supplied by the water tankers. The source of water for private water venders is raw water of the Bahr el-Jebel. Chlorine is injected into the tank water for disinfection. The price of water of private venders is very expensive. And moreover, the previous study by IFRC reported that the aquifer in Tokiman Paleochannel where locate at about 10 km south from Juba city may have very high potential of groundwater discharge. The aquifer of this high discharge is composed of very thick alluvial deposits, and connect with the Bahr el-Jubel. If the potential of groundwater in the paleochannel is confirmed in terms of water quality and quantity, groundwater shall be developed first since this resource can supply water without expensive water treatment.

However, the study area is classified as the Sudan hydro-geological unit C2 that indicates porous and fractured rocks dominates with relatively very low hydro-geological importance in the country. Some part of groundwater in the study area contains salinity, heavy metal such as arsenic, iron or manganese of higher concentration than the drinking water quality standards. Also, sometime shallow groundwater contains slightly high turbidity. Therefore, JICA Study Team executed geo-electrical survey, test well construction and groundwater analysis to evaluate the groundwater development potential in the study area for the urban water supply source.

This section details on the natural conditions of the study area, existing groundwater uses, review of the field investigation report of Tokiman Paleochannel, result of geo-electrical survey, test well construction, groundwater quality analysis, and evaluation of groundwater development potential as the urban water supply source.

The result of this groundwater development study shows that groundwater in Tokiman Paleochannel is not be feasible for the urban water supply source due to groundwater quantity and quality.

(1) Item of the field survey for groundwater development

The items of the field survey for groundwater development in the study area are listed in Table A.1.

Table A.1 Groundwater Survey Item in the Study Area

Item	Survey site	Specification	Quantity
Geo-electrical survey	Tokiman Paleochannel	2D resistivity sounding ・ Pole-pole method ・ Wenner method	・ 800 m×4 lines ・ 800 m×1 line
Test Well Construction	Tokiman Paleochannel	Test Well drilling ・ >300mm with 8 inch screen pipe Observation well drilling ・ >300mm with 4 inch screen pipe Electrical well logging Pumping test Water sampling	・ 50 m×1 well ・ 100 m×1 well ・ 200 m×1 well ・ 50 m×2 wells ・ 450 m / 5wells ・ 3 wells ・ 4 L ×3 samples
Groundwater Quality Analysis	Tokiman Paleochannel	Laboratory test On site test	・ 11 samples/5wells ・ 5 samples/5wells
	Juba city and its surrounding area	Laboratory test On site test	・ 18 samples/18wells ・ 89 samples/89wells

(2) Progress of the groundwater survey

The groundwater survey was carried on from October 2008 to April 2009. Progress of the survey is described in Table A.2.

Table A.2 Progress of Groundwater Survey in the Study Area

Item	2008				2009			
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.
GE*	Nov.3	●——	——●	Dec.22 (include analysis)				
TW*			Jan.23	●——	————	————	——●	Apr.27
WQ*	On site test and laboratory test		●- - -	- - - -	- - - -	- - - -	- - - -	- - -●

Note*: (GE) Geo-electrical survey, (TW) Test well construction, (WQ) Groundwater quality analysis.

A.2 Review of Existing Groundwater Development

A.2.1 Review of Existing Groundwater Survey

(1) Outline of Existing Survey

As far as groundwater survey in Tokiman Paleochannel is concerned, following two study reports are available for reviewing. The review by the Study Team is summarized as follows:

- IFRC-JUBA SUB-DELEGATION SOUTHERN SUDAN, Project, “Juba Town Water Supply Paleochannel Investigations”, Exploratory Geophysical Report No. 064/07, 2007.
- IFRC-JUBA SUB-DELEGATION SOUTHERN SUDAN, Project, “Juba Town Water Supply Paleochannel Investigations”, Detailed Hydro geological & Geophysical Report No. 083/07

1) IFRC-JUBA SUB-DELEGATION SOUTHERN SUDAN, Project, “Juba Town Water Supply Paleochannel Investigations”, Exploratory Geophysical Report No. 064/07, 2007.

a. Background

The study was conducted by IFRC to investigate the existence of buried old river channels (paleochannels) along the Nile River (Bar el-Jebel) basin in Juba and its surroundings with the objective of supplying safe and potable groundwater to Juba city and its surroundings.

b. Study Area

The investigations were carried out in two areas in the north and south of Juba city along the western bank of the Bahr el-Jebel within a maximum radius of 25 km from the town. The investigated area called Mobil is located about 12 km in the north of Juba city while the southern area of investigations is located around 10 km from Juba city next to Tokiman Island.

c. Geophysical Investigations

A combined geophysical and hydro-geological fieldwork was carried out between 30th March and 25th May 2006. In total 41 soundings and 18.3 km of profiling was executed in both areas. The survey consists of resistivity sounding, electro-magnetic sounding (EM) and Very Low Frequency method (VLF).

d. Results and Recommendations

The result of geophysical investigations in Juba city and its vicinity indicated that deeper fluvial deposits are found in the southern survey area up to a maximum depth of 160 m but the deposits are shallower in the northern area up to a maximum depth of 100 m below ground level.

It was evaluated that the geological formation material in the northern area is clayey, the aquifer thickness is limited and the lateral extent of the paleochannel in the northern area does not exceed 120 m in the most area.

It was evaluated that aquifers in the paleochannel in the southern area of Juba city have a larger vertical and lateral extent and is composed of high fraction of sandy and coarse materials thus the drilling conditions especially in coarse material, which most likely is also made up of quartz gravels and boulders, are expected to be difficult.

The following are recommended based on the result of the study:

- Exploratory borehole drilling in both areas should be carried out to determine the potential of the aquifers and to confirm the nature of the underlying formations.
- Detailed investigation in the paleochannel in the south area of Juba city should be carried out as it may have higher potential for groundwater development.

2) IFRC-JUBA SUB-DELEGATION SOUTHERN SUDAN, Project, “Juba Town Water Supply Paleochannel Investigations”, Detailed Hydro geological & Geophysical Report No. 083/07.

a. Background

This study, conducted by IFRC, was a follow-up survey of the previous study, which had included the findings of the exploratory geophysical investigation and highlighted the initial indications of presence of buried old river channel (paleochannel) with high groundwater development potential in the south of Juba city. This study was to investigate the existence of paleochannel in the south of Juba city along the Bahr el-Jebel.

b. Study area

The investigated area is a stretch of about 2.9 km from Tokiman Island to Khor Romla river (seasonal river), where the old river channels under the ground might exist. The study area is generally composed of thick series of large and fine-grained alluvium sand and clay sediments, which almost completely cover the underlying undifferentiated Basement Complex formation. Groundwater in the

Basement Complex Formation regions exists as discontinuous pockets formed in relatively weathered matrix, in fracture and fault zones, or in the overlying sediments with relatively coarse texture. In the study area, the target potential aquifer may exist in the form of fluvial sand beds along the old river channels. The high potential aquifer may exist in sandy bars or stringers, which are hydraulically connected to water bodies and recharged in both lateral and vertical directions.

c. Geophysical Investigations

A detailed geophysical and hydro-geological fieldwork was carried out on 29th May and 28th June 2007. Twelve (12) short VLF were carried out along the line of south to north in the paleochannel with a total distance of 5.8 km. A total of sixty five (65) Vertical Electric Sounding (VES) were carried out within the anomalous zone along the short profiles.

d. Interpretation of Geophysical Investigation

According to the result of investigation, the area is geo-physically divided into 4 zones by appearance of resistivity. The description of aquifers by appearance resistivity zone is shown in Figure A.1 and as follows:

- Zone 1: the area from the surface to about 50 m bgl with resistivity value of over 100 ohm-m has a possibility that it consists of alluvial deposits.
- Zone 2: the area from about 50 m to 200 m bgl with resistivity value of over 100 ohm-m in south part of the study area has a possibility that it consists of unconsolidated coarse material of sediments or weathered rocks of the Basement Complex.
- Zone 3: the area of the depth from about 50 m to 200 m bgl with resistivity value of less than 50 ohm-m in central part of the Tokiman Paleochannel has a possibility that it consists of unconsolidated material such as clay or highly weathered rocks of the Basement Complex.
- Zone 4: in the area below 200 m bgl with resistivity value of over 1000 ohm-m, there is a high possibility that it is composed of the Basement Complex Formation.

The feature described above indicates that Zone 1 and Zone 2 have a potential as aquifer, while Zone 3 and Zone 4 holds a very low potential as aquifer to develop groundwater due to the resistivity that falls in the range of highly weathered basement rocks or clayey materials.

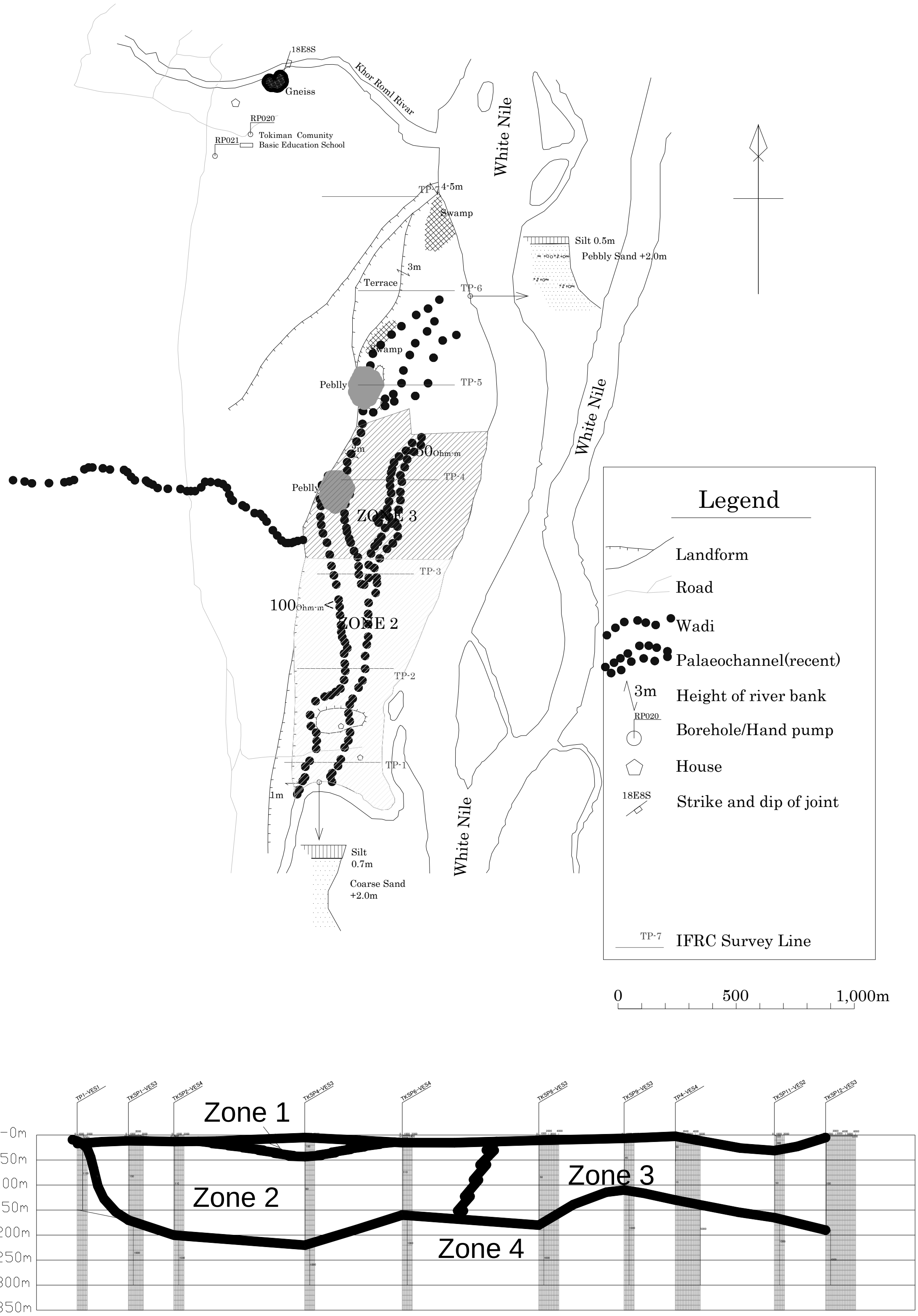


Figure A.1 Appearance Resistivity Zone in Tokiman Paleochannel

Source: IFRC-JUBA (2007)

(2) Results and Recommendations

- A paleochannel exists in the Tokiman area of the Southern area.
- Comparing the size of the Bahr el-Jebel River in Juba and the Sabaki River in Kenya, where Sabaki paleochannel has yielded 180,000 m^3/day of groundwater, it could be concluded that the yield of Tokiman paleochannel could exceed that of Sabaki paleochannel.
- The deepest aquifer of the paleochannel is likely to be located in between TSP1 and TSP4 and the depth is likely to be up to 220 m bgl.
- The lateral extent of the Tokiman paleochannel is estimated to be around 300 m at maximum and the longitudinal extent is estimated to be around 3 km.
- Drilling conditions especially in the southern part are expected to be very difficult due to the presence of sand and coarse material in underground, which is also most likely made up of quart gravels and boulders.
- By exploratory drilling, groundwater development potential should be evaluated by identifying aquifer material and aquifer parameters like storativity, transmissivity and hydraulic properties. Once these parameters are decided, it is easy to make an accurate estimate of yield or daily production capacity of groundwater in the entire paleochannel.
- Exploratory borehole drilling (test production and piezometer boreholes) shall be carried out both in south and north parts to decide the groundwater development potential of the aquifers and to identify the nature of the underlying formation.
- At least two test production boreholes in each part, upstream and downstream of the paleochannel will be required to establish uniformity of the aquifers and water quality. Each borehole will be served by three piezometer wells.
- Piezometer wells should be installed with three piezometer tubes, each located at the bottom, middle and close to the top of aquifer respectively.
- The exploratory boreholes should be drilled and constructed up to the depth of 200m under the supervision of an experienced hydro-geologist.
- Since drilling conditions are expected to be very difficult, it is highly recommended to engage a well experienced drilling contractor, preferably one that has drilled such boreholes previously. In addition, the contractor should have ability to drill boreholes with up to 24 inch in diameter.

A.2.2 Review of Existing Well

(1) Existing Well Data

The groundwater is used for drinking purposes mainly in the study area. On the basis of the existing well data, present conditions of groundwater use in the study area are described as follows. Existing well data were collected from MC&RD and the location of wells are shown in Annex A-1.

According to the above data, a total of 439 wells are listed for analysis consisting of 417 wells in Juba Payam and 22 wells in Rejaf Payam. All wells are equipped with tube-well and hand-pump and used for drinking and other domestic purposes. The type of wells such as shallow or deep tube-well cannot be identified in the list.

1) Successful Wells

Table A.3 shows the number of successful existing wells in Juba and Rejaf Payams.

- Out of a total of 439 wells, 306 are reported as successful well on the list.
- The successful well ratio is 70 % in Juba Payam, 64 % in Rejaf Payam.

Table A.3 Successful Existing Wells in the Study Area

Completion of Well	Juba Payam (1977-2008)	Rejaf Payam (1981-1986)	Total
Successful	292 (70 %)	14 (64 %)	306 (70 %)
Dry	125 (30 %)	8 (36 %)	133 (30 %)
Total	417 (100 %)	22 (100 %)	439 (100 %)

Source: Existing well data record, MC&RD, Juba.

a. Well Yield

The yield record of existing wells in the Study area is summarized in Table A.4.

- The range of yield is from 0.1 to 7.2 m^3/hr with an average of 1.67 m^3/hr.
- The maximum well yield is 7.2 m^3/hr at Koba, Koba Boma in Juba Payam in 2006 with 10.47 m of static water level (bgl) and 24 m total depth of well.

Table A.4 Well Yield of Existing Wells in the Study Area

Well Yield (m^3/hr)	Juba Payam (1977-2008)	Rejaf Payam (1981-1986)	Total
Max.	7.20	2.10	7.20
Min.	0.10	0.30	0.10
Ave.	1.67	1.16	1.67

Source: Existing well data record, MC&RD, Juba.

b. Static Water Level (SWL)

The record of static water level (SWL) of existing wells in the Study area is summarized in Table A.5.

- The SWL in the study area ranges from 1.2 m to 42.29 m with an average of 12.21 m.

- The maximum SWL was recorded as 42.29 m (bgl) at Dare, Juba Boma in Juba Payam with 68 m of the total depth of well.

Table A.5 Static Water Level of Existing Wells in the Study Area

SWL (m bgl)	Juba Payam (1977-2008)	Rejaf Payam (1981-1986)	Total in the two areas
Max.	42.29	21.0	42.29
Min.	1.20	5.80	1.20
Ave.	12.21	12.42	12.21

Source: Existing well data record, MC&RD, Juba.

c. Depth of Well

The record of the depth of existing wells in the Study area is summarized in Table A.6.

- The depth of well ranges from 15 to 93 m in Juba and Rejaf Payams with an average of 49 m.
- The maximum depth of well was recorded as 93 m (bgl) at Rejaf East site in Rejaf Payam with a yield of 0.3 m^3/hr.

Table A.6 Depth of Existing Wells in the Study Area

Depth (m bgl)	Juba Payam (1977-2008)	Rejaf Payam (1981-1986)	Total in the two areas
Max.	84	93	93
Min.	15	27	15
Ave.	49	55	49

Source: Existing well data, MC&RD, Juba.

A.3 Natural Condition

A.3.1 Topography

Figure A.2 shows the topographic map of the study area. The Bahr el-Jebel flows from south to north along the eastern border of the study area. Five seasonal streams called Luri, Khorbou, Lobulyet, Wallan and Kor Ramula from north to south, which flow during only rainy season, pass through from west to east and join the Bahr el-Jebel.

The study area is highly susceptible to erosion and the topography is undulating in the north to south direction, underlain by clayey top soil. Generally, the terrain includes gently sloping alluvial surfaces and the place near the valley floor becomes swampy in the rainy season. Basement rocks are found in small bodies sporadically scattered in the stream bed.

Figure A.3 shows the general topographic section of the study area. The terrain of Juba starts from the foothill of Mt. Jebel Körök (Kujur) with a peak of 744 m above sea level and slopes gently towards east with an inclination of 0.5 % on the average.

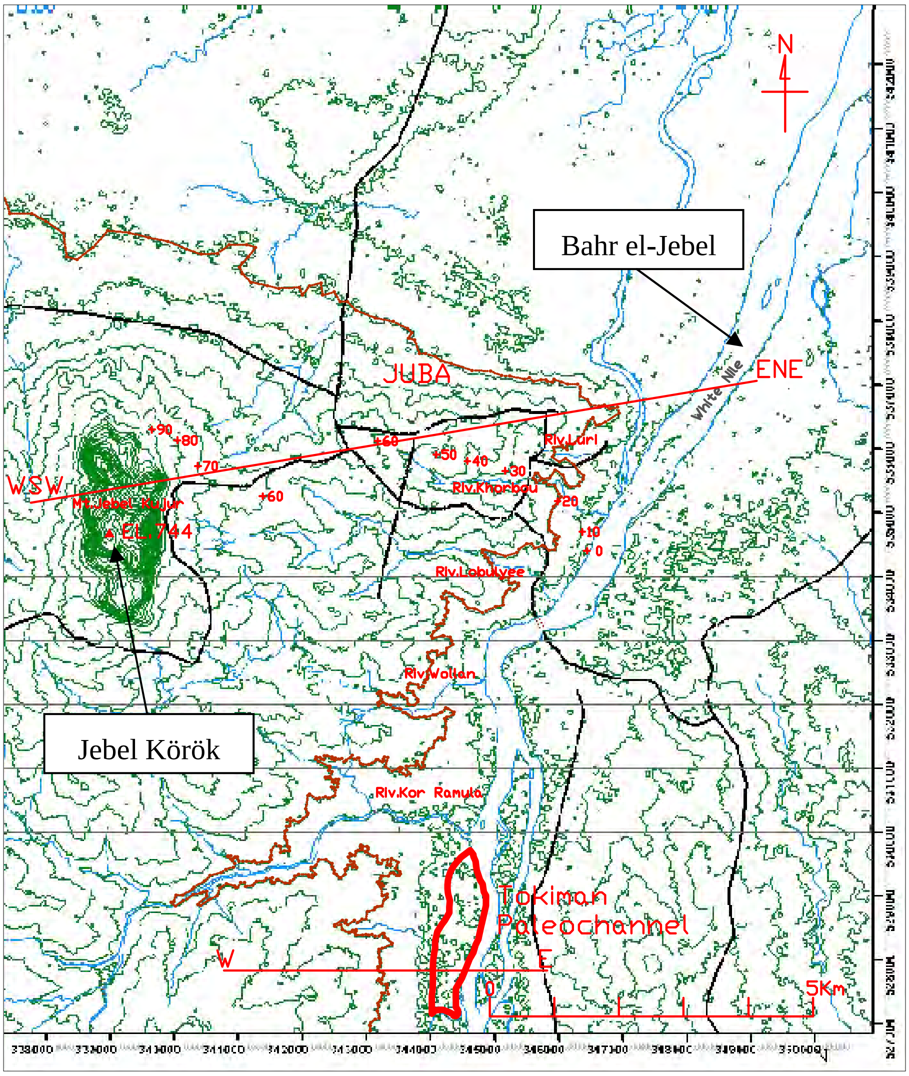


Figure A.2 Topographic Map of the Study Area

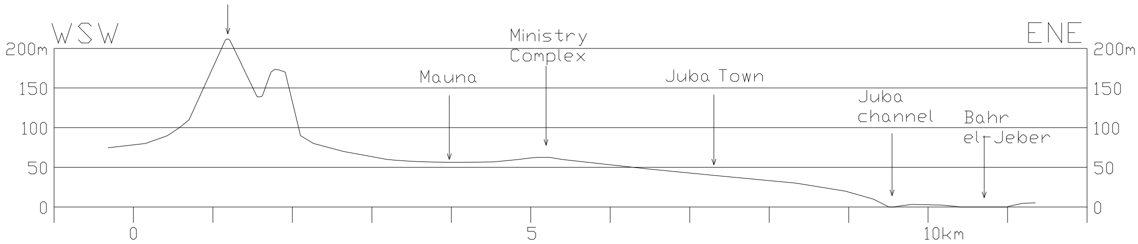


Figure A.3 General Topographic Section of the Study Area

Figure A.4 shows topographic map of Tokiman Paleochannel. Tokiman Paleochannel is located in

Rejaf Payam at about 10 km to 13 km to the south of Juba city at the west bank of the Bahr el-Jebel where at around 04°52′N in latitude, 31°36′E in longitude and situated at about 460m above sea level.

Tokiman Paleochannel covers about 3.0 km^2 with about 3 km in length from north to south direction and about 1.0 km wide from east to west direction. The terrain of the paleochannel is formed by alluvium of old and present rivers, due to change of river course. The ground level in the south-end of the area is about 3 m above the river surface (Bahr el-Jebel), while it in the north-end is same level as the river. The surface very gently goes down to north from south at a slope of 1 in 1,000.

Figure A.5 shows the topographic section of the paleochannel and surround area. The terrain composed of remnant eroded from basement rocks slopes gently down to the east with an inclination of about 1 % on the average in direction of the paleochannel.

The surface of Tokiman Paleochannel is uneven as a result of eroded by river flood. The surface is covered by stagnant water during the rainy season. A few terraces dominate in the north of it where downstream of the river. The each height of terrace is 1 m to 3 m and not less than 3-stages. In contrast, the surface is undulate on a parallel with river in the south which forms like a small hill with height of maximum 3 m. An outcrop of basement rock is not distributed in the area, sand and or pebbly sand layer are distributed along river side. The terrain of Tokiman Paleochannel is formed by alluvium of old and present rivers.

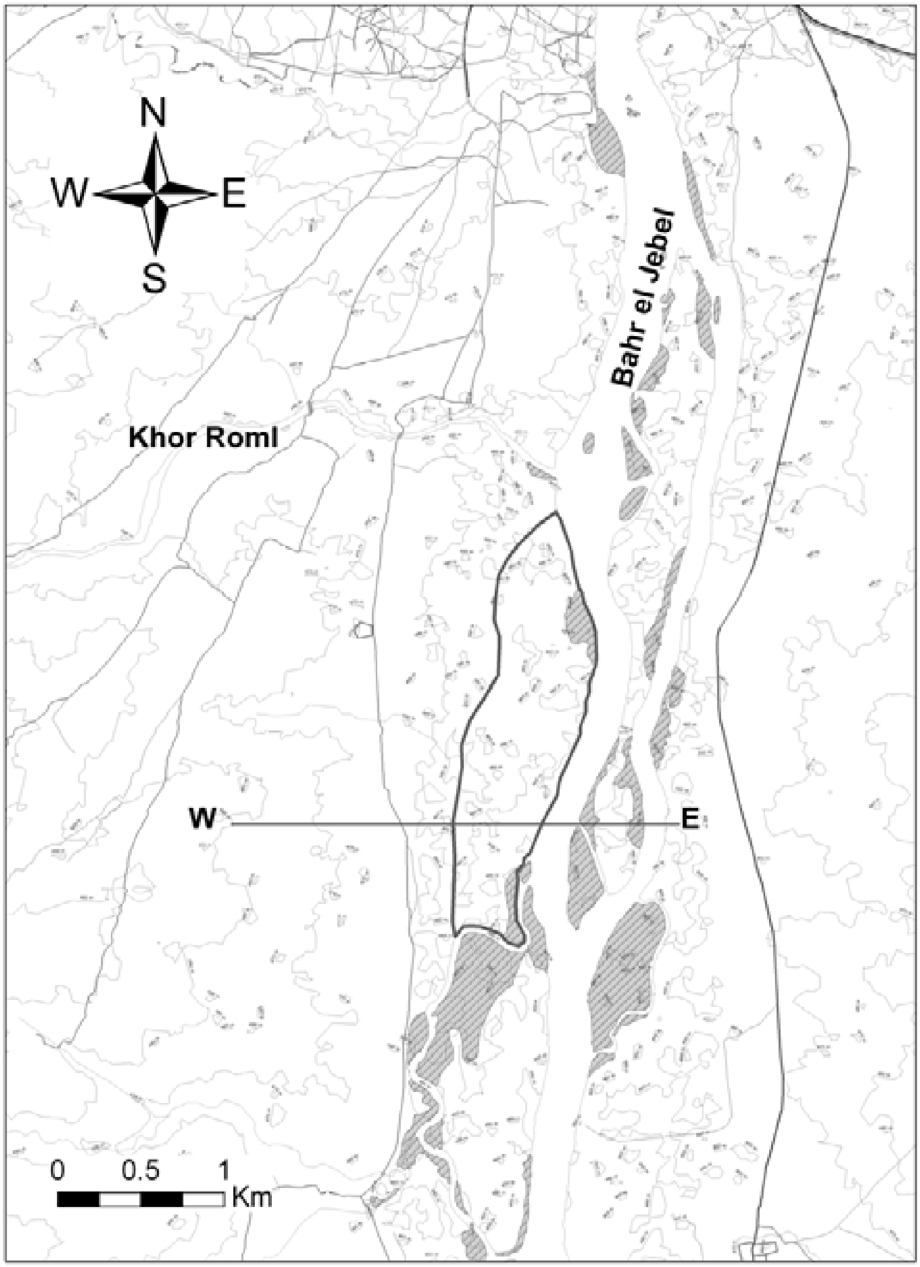


Figure A.4 Topographic Map of Tokiman Paleochannel

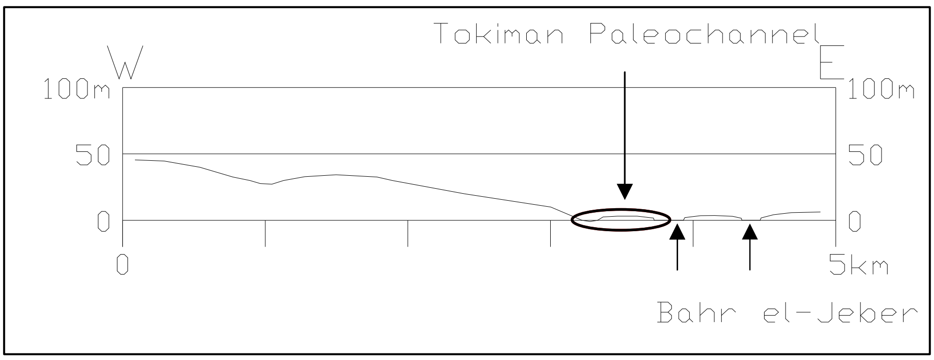


Figure A.5 Topographic Section of Tokiman Paleochannel

A.3.2 Geology

The stratigraphic classification and outline of the general geology around Tokiman Paleochannel are shown in Table A.7 and Figure A.6. Tokiman Paleochannel and its surrounding area can be tectonically and geologically divided into two zones that consist of the alluvial deposits and the Undifferentiated Basement Complex.

The alluvial deposit, un-conformably overlying the Undifferentiated Basement Complex, is extensively distributed in the area. The Undifferentiated Basement Complex consists of metamorphic and intrusive rocks of various grades of metamorphism

(1) Alluvial deposits

Alluvial deposits consist of alluvium, wadi fills, terrace deposits, delta and swamp deposits. This layer composed of mostly fine sand, gravel, silt and clay. They occur along the river valleys and in swamps and marshes.

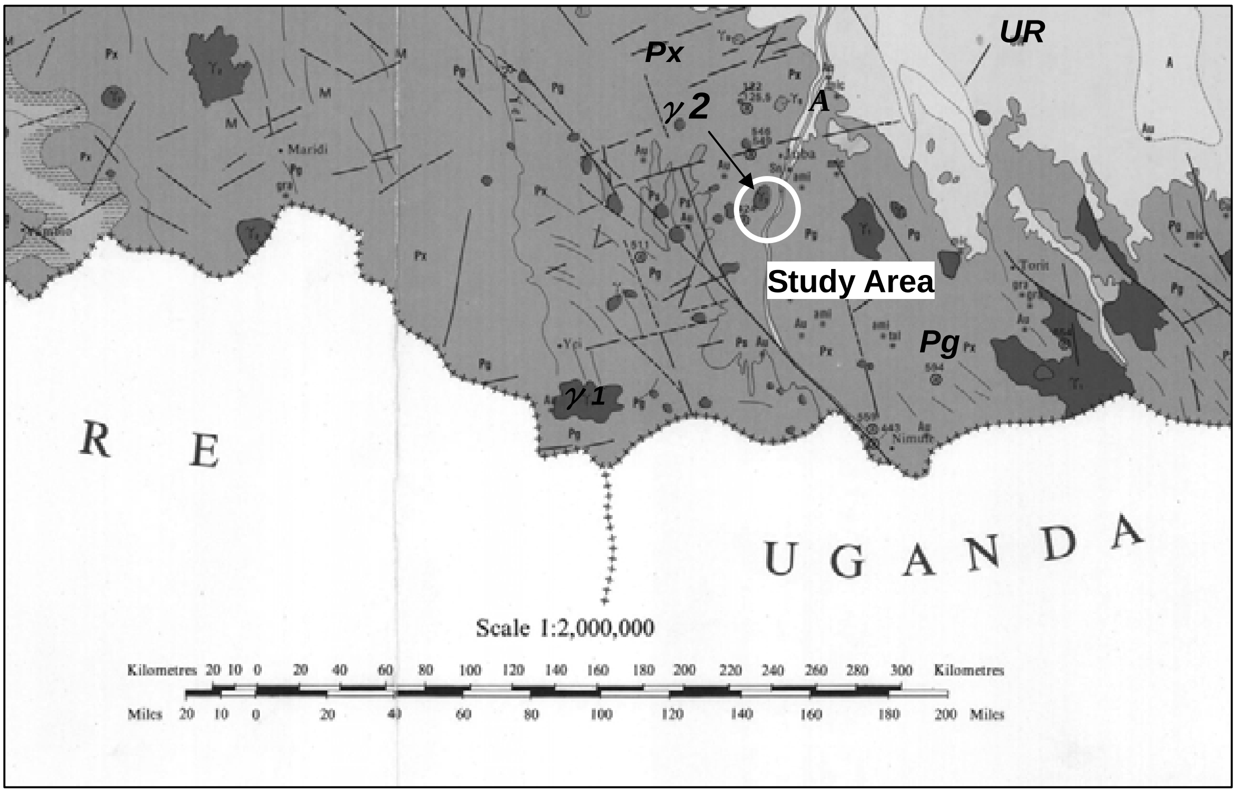
(2) Undifferentiated Basement Complex

This complex is composed of granites, granitic gneisses, banded biotite-hornblende, and migmatites in the field. The latter display classic migmatitic structures like feldspar and boudinage veins. The danker banded rocks show schistose cleavage in some outcrops. This means that the so-called Undifferentiated Schist Group occurs in further north than expressed in the contemporary geological map. These rocks dip to north-west around Juba, plunging south-west with strike of foliation NE-SW. Locally, exemplary outcrops occur on Mt. Jebel Körök (Jebel Kujur).

Table A.7 Stratigraphic Classification of the Study Area

Geological Age	Geological Class	Geological Formations
Quaternary (Recent)	A) Alluviums, wadi fills, terraces, delta and swamp deposits	Boulder, Gravel, sand and Silt-Clay
Upper - Lower Middle Proterozoic	Px) Undifferentiated Basement Complex Ps) Undifferentiated Schist Group Pg) Undifferentiated Gneiss Group	Ps) Meta-sediments, marble, quartzites, graphite and mica schists. Pg) Granitic gneisses, migmatites, charrockitic granites, amphibolites and pyroxene granulites.

Source; Geological Map of the Sudan (1981) Geological & Mineral Resources Development of Sudan



Source; Geological Map of the Sudan (1981) Geological & Mineral Resources Development of Sudan

Figure A.6 Geological Map of the Study Area

A.3.3 Hydro-geology

(1) Hydro-geological Classification

According to the hydro-geological map of South Sudan, Tokiman Paleochannel is divided into two (2) main groups in terms of hydro-geological importance. Hydro-geological units of South Sudan relates between geology and groundwater development of the area. The units in the study area are shown in Table A.8 and Figure A.7

Tokiman Paleochannel is classified under A3 and C2 in the hydro-geological units of South Sudan (Hydro-geological Map of the Sudan, 1989). Feature of the units are summarized as follows:

1) Unit A3

- Continuous or sub-continuous aquifers of local to sub regional extent.
- Unconsolidated.
- Saturated thickness generally small.
- Permeability variable.

- Water quality generally good.
- Importance generally great and potential variable.
- Alluvium, wadi fills and swamp deposits.

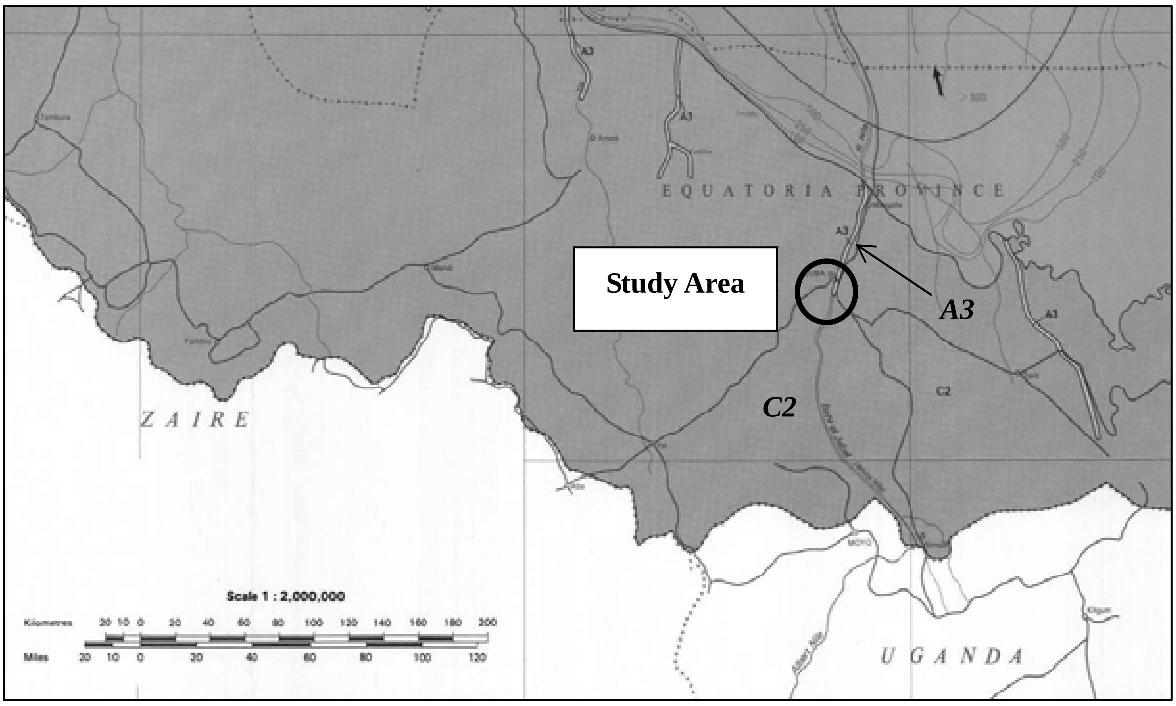
2) Unit C2

- Rocks which are generally none water bearing.
- Water occurs in fractured or weathered zones.
- Local perched perennial or ephemeral aquifers may occur as well as thin saturated layers at depth.
- Hydro geological importance low.
- Potential very low.
- Undifferentiated Basement Complex, acid intrusions.

Table A.8 Clarification of Hydro-geological Units of Tokiman Paleochannel

Hydro-geological Unit *	
A3	Continuous or sub-continuous aquifers of local to sub regional extent, unconsolidated, saturated thickness generally small, permeability variable, water quality generally good, the importance generally great and potential variable. Alluvium, Wadi fills and swamp deposits. Note: this unit has generally not been indicated on the map when underlain by unit A1 or A2.
C2	Rocks which are generally none water bearing. Water occurs in fractured or weathered zones. Local perched perennial or ephemeral aquifers may occur as well as thin saturated layers at depth. Hydro geological importance low. Potential very low. Undifferentiated Basement Complex, acid intrusions.

Source: Hydro-geological Map of the Sudan (1989) National Corporation of Rural Water Resources, Sudan



Source ; Hydro-geological Map of the Sudan (1989) National Corporation of Rural Water Resources, Sudan

Figure A.7 Hydro-geological Map of the Study Area

A.4 Groundwater Survey Plan

A.4.1 Target and Procedure of the Survey

The result of the hydro-geological survey by the International Federation of Red Cross (IFRC) in 2006 indicated that Tokiman Paleochannel may have high potential of groundwater development. The study team has decided to carry out a detail survey to evaluate the groundwater potential in this area in terms of quantity and quality.

At the result of review of the past groundwater studies, the meaning, the objectives and the procedure of groundwater study by JICA study team is shown in Figure A.8. The following are summaries of the results of the review of past groundwater studies in Tokiman Paleochannel and hydro-geological analysis using existing data:

- The area is underlined by Basement Complex Formation and Alluvial deposits.
- The area is classified into Hydro-geological Unit A3 in the South Sudan.
- Aquifers in the south part of Tokiman paleochannel were evaluated to be composed of unconsolidated sediment material from the surface to 200 m below ground level.
- However, it is not sure whether aquifers are composed of alluvial deposits or weathered rocks

of Basement Complex.

- The thickness of aquifers is so deep due to the fact that the area is classified as Unit A3 of the hydro-geological units of South Sudan.

Therefore, to confirm the above and evaluate groundwater development potential, it is required to construct test well and investigate the groundwater potential in the area.

The item of groundwater survey includes:

- Geo-electric survey.
- Test well construction.
- Pumping test and measurement of groundwater level.
- Groundwater quality analysis.

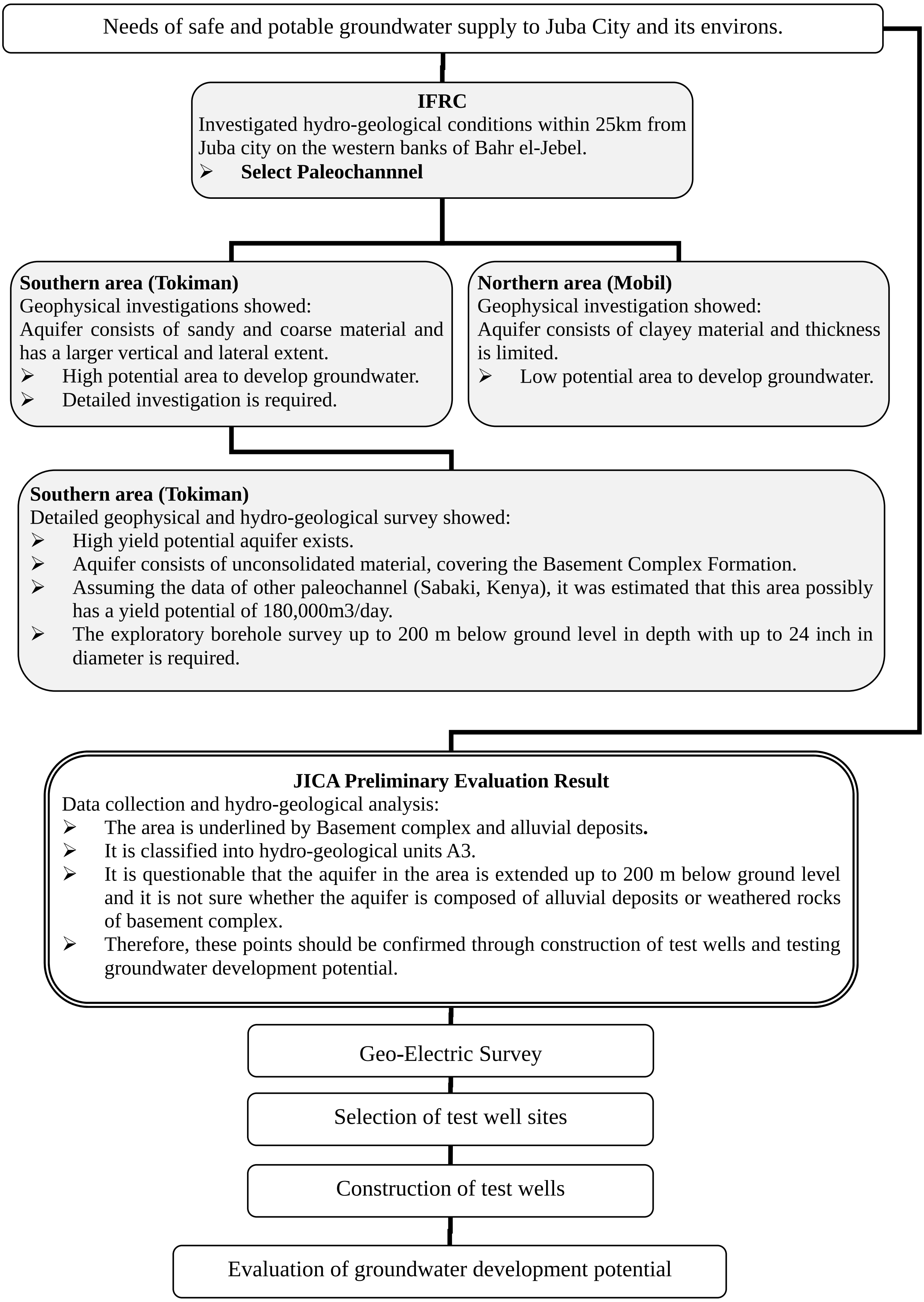


Figure A.8 Flowchart of Groundwater Survey

A.4.2 Land Use and Community

The Study Team organized Stakeholders' Meeting on November 21st and December 6th 2008, to discuss on approval of land use for the test well construction in the area with the authorities. The participants were cooperative and constructive opinions were exchanged with authorities and all stakeholders. The authorities refused permission to use the lands for the test well construction to the study team. The memorandums of meeting are attached in Annex A-2.

Aim of first step of meeting was to announce and introduce about the study and plan to use land for the test well construction in Tokiman Paleochannel that was explained by the study team to the authorities using pictures and maps on a screen at meeting room in Juba.

Aim of second meeting included request for approval of land use and to confirm the site proposed for the test well construction in the field with authorities and native residents at their village nearby Tokiman Paleochannel.

A.5 Geo-electrical Survey

A.5.1 Outline of Survey

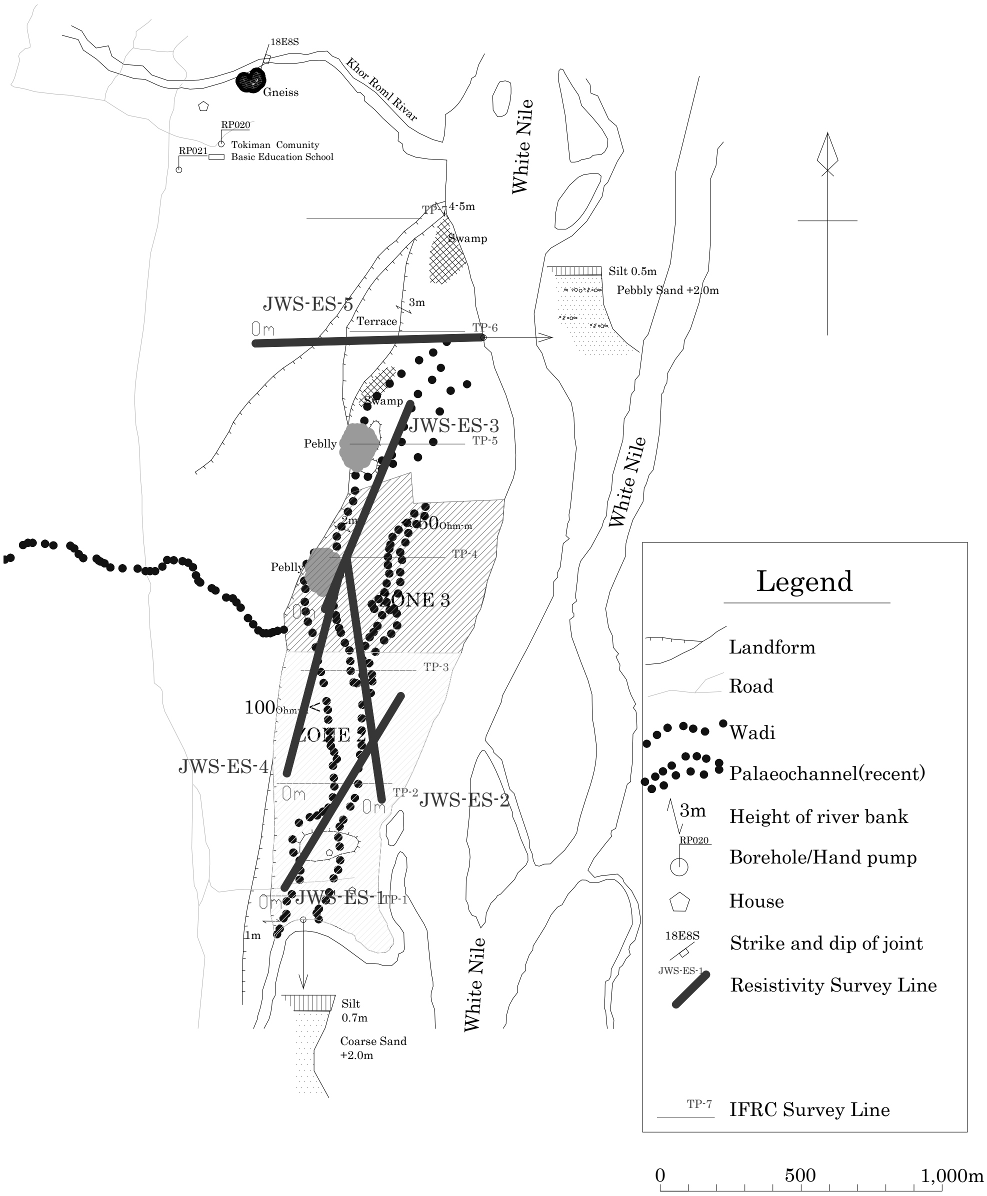
The study team carried out a geo-electrical survey in Tokiman paleochannel from November 3rd to December 22nd 2008.

(1) Purpose and Scope of Survey

The purpose of the geo-electric survey is to identify the location of a paleochannel and its geological structures and to select the suitable sites for construction of test wells and observation wells. The final objective is to find a potential groundwater source of water supply for Juba town.

(2) Survey Plan

The location map of the geo-electric survey line in Tokiman Paleochannel is shown in Figure A.9. The target area is within a stretch of 3 km from 9 to 12 km south of Juba city. Based on the results of the previous studies, the location of survey lines was selected. The geo-electrical survey lines are carefully located in relation with the result of existing survey results and existing known geological conditions. The major target of each survey line is summarized in Table A.9. The study team used electrical resistivity tomography (ERT) to acquire ground images up to the depth of 300 m (bgl) with 5 profiles each of at least 600 m long symmetrically across the paleochannel.



Line	Location	X (deg)	Y (deg)	X (coodinate)	Y (coodinate)
JWS-ES-1	SP	4.7694	31.5939	344061	527332
	EP	4.7755	31.5976	344469	528011
JWS-ES-2	SP	4.7722	31.5970	344402	527646
	EP	4.7794	31.5956	344252	528436
JWS-ES-3	SP	4.7783	31.5952	344204	528316
	EP	4.7848	31.5979	344502	529039
JWS-ES-4	SP	4.7731	31.5940	344067	527737
	EP	4.7800	31.5959	344279	528501
JWS-ES-5	SP	4.7868	31.5930	343960	529252
	EP	4.7870	31.6001	344755	529275

Figure A.9 Location Map of Geo-electrical Survey Lines in Tokiman Paleochannel

Table A.9 Major Target of Geo-electrical Survey Line

LINE (length)	Location	Target of Survey	Array
JWS-ES-1 (800 m)	Southern part	To confirm the distribution of resistivity value of Zone 2. To confirm the distribution of the sandy layer found in the south-end of the area.	Pole-pole
JWS-ES-2 (800 m)	Southern-Central part	To confirm the boundary between Zone 2 and Zone 3	Pole-pole
JWS-ES-3 (800 m)	Central part	To confirm the distribution of resistivity value of Zone 3	Pole-pole
JWS-ES-4 (800 m)	Southern part	To confirm the boundary between Zone 2 and Zone 3	Pole-pole
JWS-ES-5 (800 m)	Northern part	To confirm the distribution of sandy layer distributed along west bank of the river. To confirm the continuity of the bedrock in the area.	Wenner*

Note:

- Resistivity value of Zone 1 was measured on all survey lines.
- Zone 1: From surface up to about 50m bgl with resistivity value of over 100 ohm-m in the area.
- Zone 2: In depths ranging from about 50m to 200m bgl with resistivity value of over 100 ohm-m in south part of the area.
- Zone 3: In depths ranging from about 50m to 200m bgl with resistivity value of less than 50 ohm-m in central-north part of the area.
- Zone 4: In the area, below 200m bgl with resistivity value of over 1000 ohm-m.
- * Wenner method was adopted considering the local geological and surface conditions.

A.5.2 Survey Method

(1) Survey Equipment

The equipment used for geo-electrical survey is shown in Table A.10 and in the following photo.

Table A.10 List of Geo-Electrical Survey Equipment

Model	Maker	Quantity	Remarks
SAS4000 Terrameter	ABEM	1	
ES10-64C Electrode Selector	ABEM	1	
LUND cable	ABEM	4sets	21-takeouts, 10m separation
Single-core cable		6pcs	750m 2pcs 600m 2pcs 250m 2pcs
Stainless steel electrode			
Special stainless steel remote electrode			
Electrode connector			

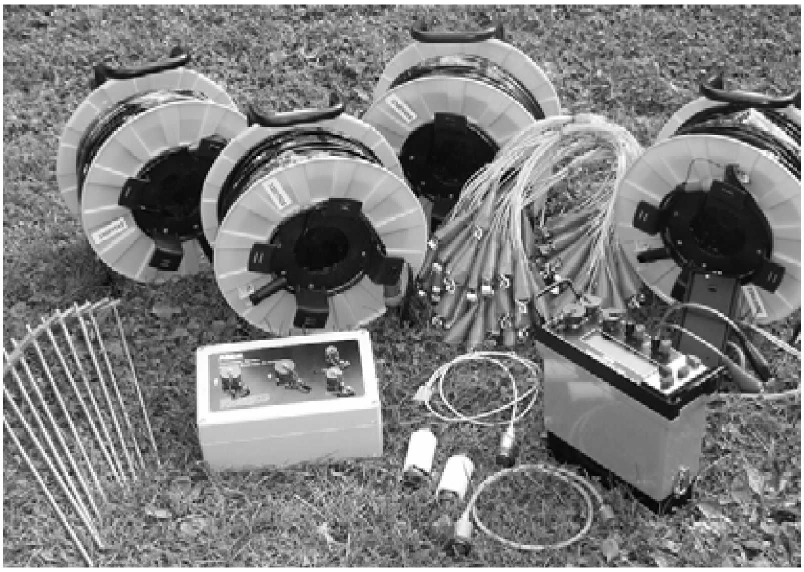


Photo: ABEM Terrameter SAS 4000 main instrument

(2) Principles and Technology

1) Basic Principles of Resistivity Method

The electric current, I, in a short, thin linear conductor is given by Ohm's Law as

$$I = - dV/ R$$

Where dV is the potential difference (volt, V), between the ends of the conductor and R (ohm, Ω) is the resistance of the conductor. The minus sign expresses the fact that the current flow is from high to low potential. R is directly proportional to the length dL (m) of the conductor and inversely to the cross-section, s (A, m^2) so that

$$R= \rho a * L/A$$

Where ρa is the resistivity of the material, in ohm-m

In the resistivity method, a commutated direct or low-frequency alternating current is introduced into the ground by means of two metal electrodes connected to a voltage source. This results into potential distribution on the ground, which depends on the properties of the ground material. This potential distribution is in turn mapped by means of another two electrodes and yields information about the distribution of electrical resistivity below the surface.

On a non-homogeneous earth, the measured potentials when current is introduced into the ground will differ from those calculated under the assumption that the ground is homogeneous. The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent" value that is the resistivity of a homogeneous ground that will give the same resistance value for the same electrode arrangement. The relationship between the "apparent" resistivity and the "true" resistivity is complex.

To determine the true subsurface resistivity from the apparent resistivity values is the “inversion” problem.

The resistivity of rocks is extremely variable, ranging from 10-6 ohm-m for graphite to as high as 1012 ohm-m for dry quartzitic rocks. Most rocks and minerals are insulators in the dry state, but acquire ionic conductivity due to interstitial water with dissolved salts.

2) 2D Resistivity Sounding Technique

The 2D resistivity sounding technique attempts to provide a more accurate presentation of the ground conditions. This is accomplished by employing techniques that record resistivity changes both laterally and vertically. Two-dimensional electrical imaging/tomography surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable. A microcomputer controlled measurement protocol together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement.

Several different arrays may be used to acquire 2D resistivity data. The choice of array depends on the objectives of the investigation because each array has its limitations in terms of resolution and depth of investigation. Some arrays like the Wenner are good for resolving vertical structures, while dipole-dipole is good for horizontal anomalies. The following are schematic representations of some of the arrays, with their geometrical factors.

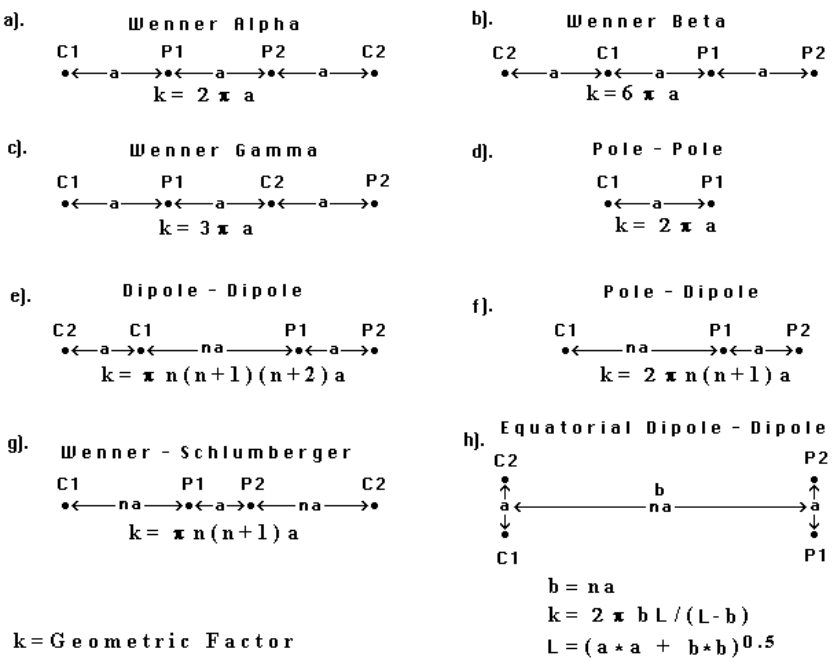


Figure A.10 Schematic layout of the most commonly used arrays

(3) Forward modeling of the 2D data

The data acquired through the 2D-multi-electrode technique has to undergo an inversion process in order to calculate apparent resistivity values. There are three main methods to calculate the apparent resistivity values for a specified model. These are

- Analytical methods
- Boundary element methods and
- Finite-difference and finite-element methods

Analytical methods are probably the most accurate methods, but they are restricted to relative simple geometries (such as a sphere or cylinder). Boundary element methods are more flexible, but the number of regions with different resistivity values that is allowed is somewhat limited (usually less than 10). In engineering and environmental surveys the subsurface can have an arbitrary resistivity distribution, so the finite-difference and finite-element methods are usually the only viable choice. These methods can subdivide the subsurface into thousands of cells with different resistivity values.
Consider the pseudo-section and the model blocks used for the forward modeling, below.

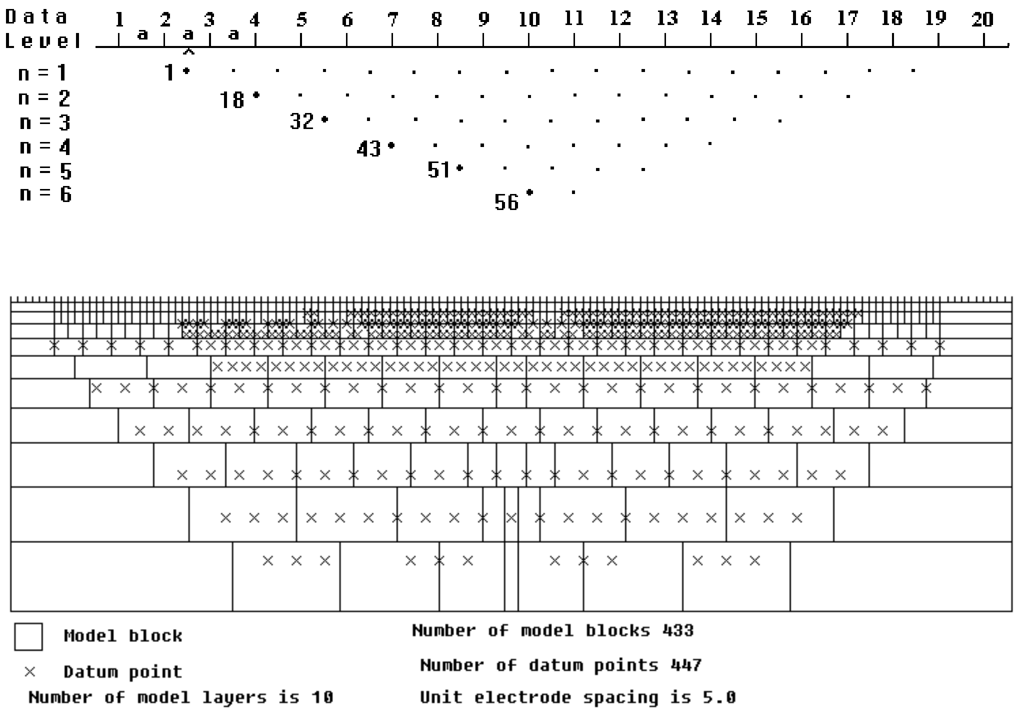


Figure A.11 Arrangement of Model Blocks and Apparent Resistivity Datum Points
(after Loke, 2004)

The inverse resistivity models were derived using the RES2DINV version 3.56.17 software from Geotomo Corporation.

For ease of reference and analysis, all the model data was displayed on a unified user-defined logarithmic contour interval. It would be surmised that 3 litho logic units which are the clayey sediments, sandy/ gravel material and basement are distributed in this area. There were then assigned resistivity ranges based on the model color scheme and reference to field observations. However, it should be noticed that the resistivity can be different because of fracture, groundwater, weathering and minerals that are included in bedrock.

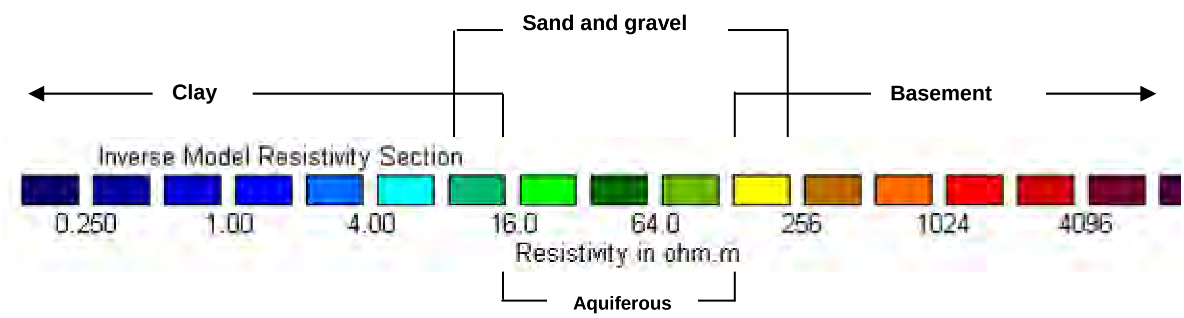


Figure A.12 Indicators of Inverse Resistivity Model Results (Pole-Pole method) for this Study using ABEM Terrameter SAS 4000 Instruction Manual

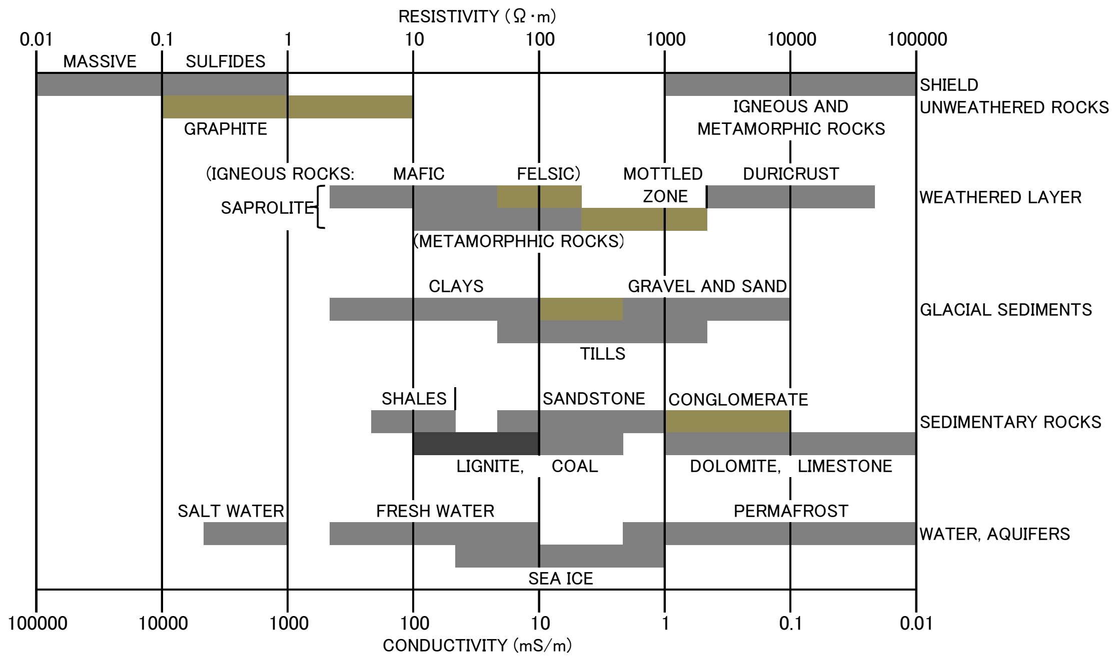


Figure A.13 Typical Ranges of Electric Resistivity of Geological Materials
Source：ABEM Terrameter SAS 4000, Instruction Manual

A.5.3 Result of Survey

(1) Inverse Model Resistivity Section

1) JWS-ES-1

The sectional result of inverse resistivity model for JWS-ES-1 is presented in Figure A.14. This tomogram shows that the Basement is generally 50 m or less below ground level. This depth increases to 100 m near the end of the image. In places, there are lenses of water-bearing sediments overlying the Basement. Through field examination of the surface sediments it was confirmed that the lenses comprise sand and clay layers in various mixes. Gravel was however not encountered.

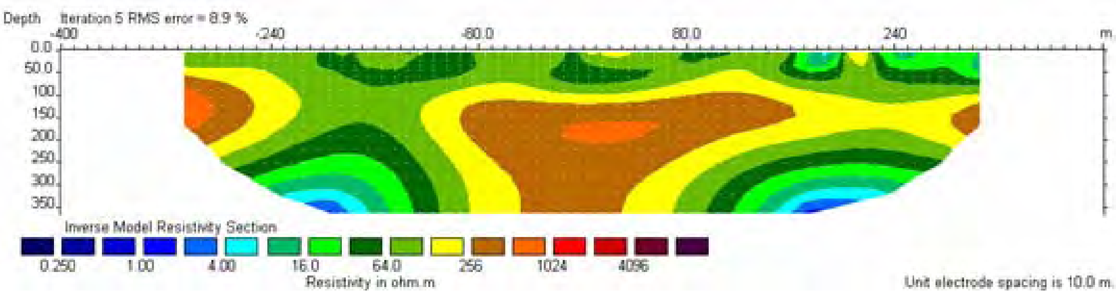


Figure A.14 Inverse model resistivity section of JWS-ES-1

2) JWS-ES-2

The sectional result of inverse resistivity model for JWS-ES-2 is presented in Figure A.15. The strongest feature of this image is the distinct geological boundary like a fault fracture that dominates the centre of the tomogram. The Basement rock here appears highly fractured and the resultant graben to the right of the image is filled with sediments to great depth. A gravel-rich sediment lens sits atop the clayey low-resistivity zone at centre-right of the image. Apparently, this gravel unit can be traced on the field examination of the surface sediments. There is a possibility of a fault running through the centre of the tomogram.

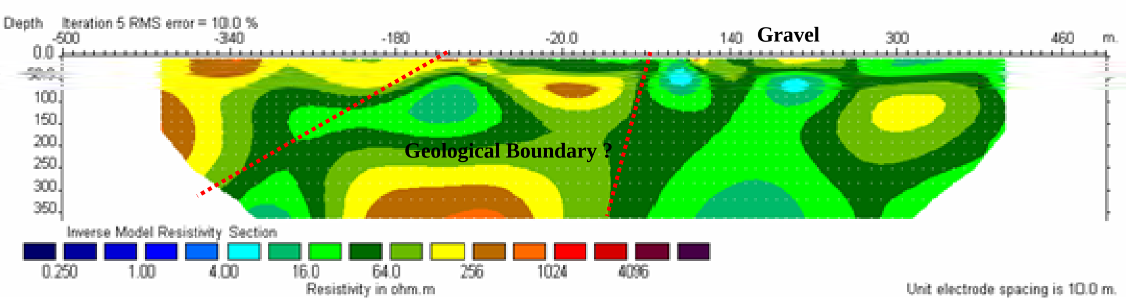


Figure A.15 Inverse model resistivity section of JWS-ES-2

3) JWS-ES-3

The sectional result of inverse resistivity model for JWS-ES-3 is presented in Figure A.16. The line starts within a seasonal water channel and this is reflected in the image. It then runs through an area underlain by a rather thin layer of sandy superficial deposits which in turn overlie Basement rocks. There is a possibility of geological boundary running through the centre of the tomogram.

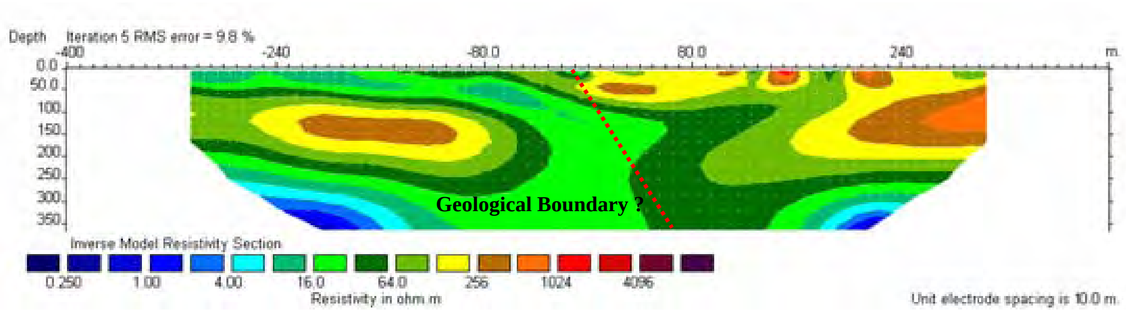


Figure A.16 Inverse model resistivity section of JWS-ES-3

4) JWS-ES-4

The sectional result of inverse resistivity model for JWS-ES-4 is presented in Figure A.17. At the start of JWS04, the Basement is just under the surface sediment deposits. Toward the centre of the line, a lens of medium resistivity is seen. It is apparent that this lens represents the gravel unit at the centre of the line. Such is the detail and precise location of the gravel unit that its occurrence is confirmed. There is a possibility of geological boundary like a fault running through the centre of the tomogram.

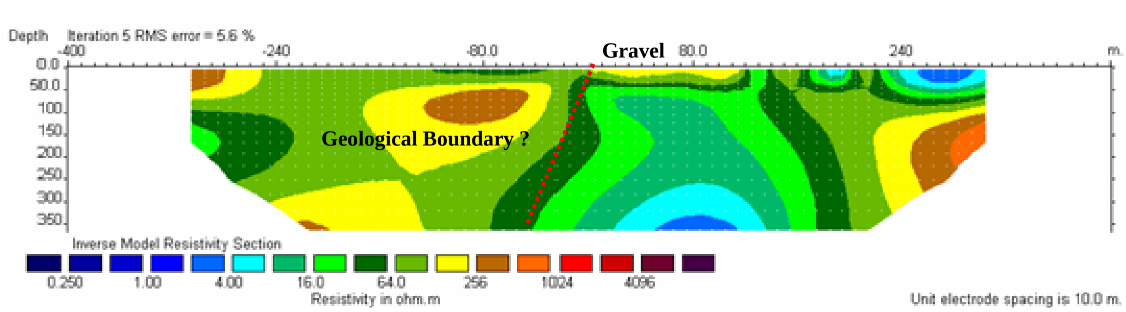


Figure A.17 Inverse model resistivity section of JWS-ES-4

5) JWS-ES-5

The sectional result of inverse resistivity model for JWS-ES-5 is presented in Figure A.18. As stated previously, this image was acquired from a Wenner-ά protocol. This image provides insight into the resistivity range for wet gravel because its end was in gravel by the bank of the Bahr el-Jebel. It starts at the centre of a swamp covered with black cotton clay.

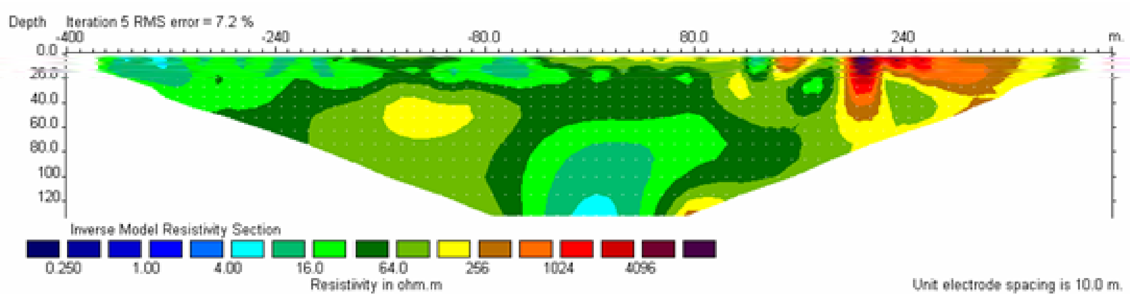


Figure A.18 Inverse model resistivity section of JWS-ES-5

A.6 Site Selection of Test Well Construction

A.6.1 Condition of Selection

Three types of aquifer in the paleochannel are established from the result of the geo-electrical survey with hydro-geological conditions in Tokiman Paleochannel. Future of the aquifer is described below.

- Aquifer 1 consists of mainly unconsolidated material such as alluvial deposits except clayey layer with apparent resistivity range from approximately 50 ohm-m to 150 ohm-m in the geological condition of the area.
- Aquifer 2 consists of mainly weathered rock of the Basement Complex Formation with apparent resistivity range from approximately 50 ohm-m to 300 ohm-m in the geological condition of the area.
- Aquifer 3 consists of mainly weathered rock and unconsolidated rocks of the Basement Complex Formation except clayey layer with apparent resistivity range from approximately 50 ohm-m to 300 ohm-m in the geological condition of the area.

A.6.2 Test Well Construction Site

Proposed construction site of the test well is shown in Figure A.19. Future of the site is summarized below.

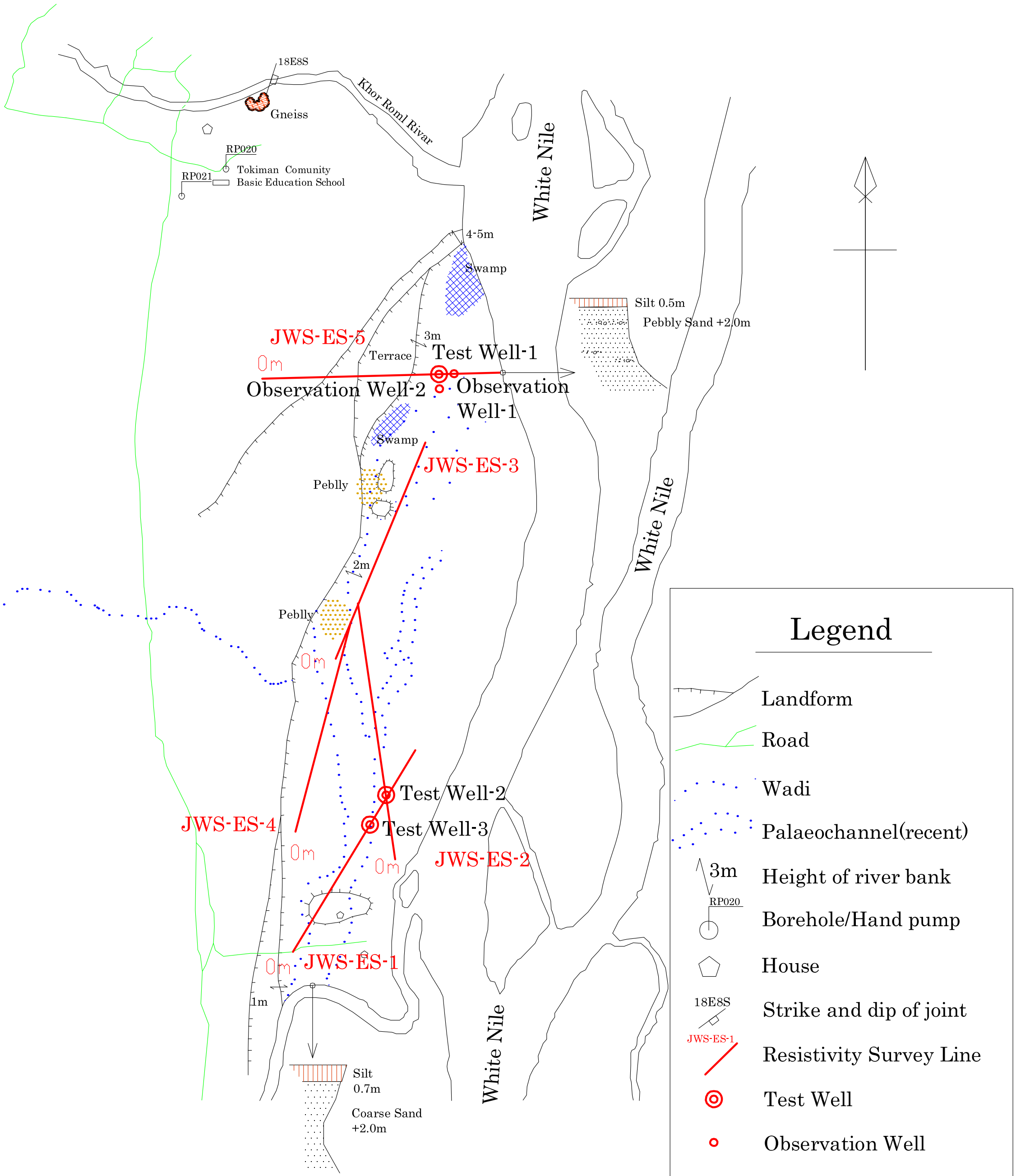


Figure A.19 Proposed Site for Test Well Construction in Tokiman Paleochannel

(1) Test Well-1

Test Well-1 is located at 205 m from end-point of JWS-ES-5 to west on the survey line. It is arranged to drill mainly Aquifer-1 and Aquifer-2 up to 50 m bgl (Figure A.20). Observation Well-1 is located at 50 m east of the Test Well-1 on the survey line and it is for measuring groundwater level during pumping test. Also, Observation Well-2 is located at 50 m south of the Test Well-1 in upstream of recent channel for measuring groundwater level during pumping test.

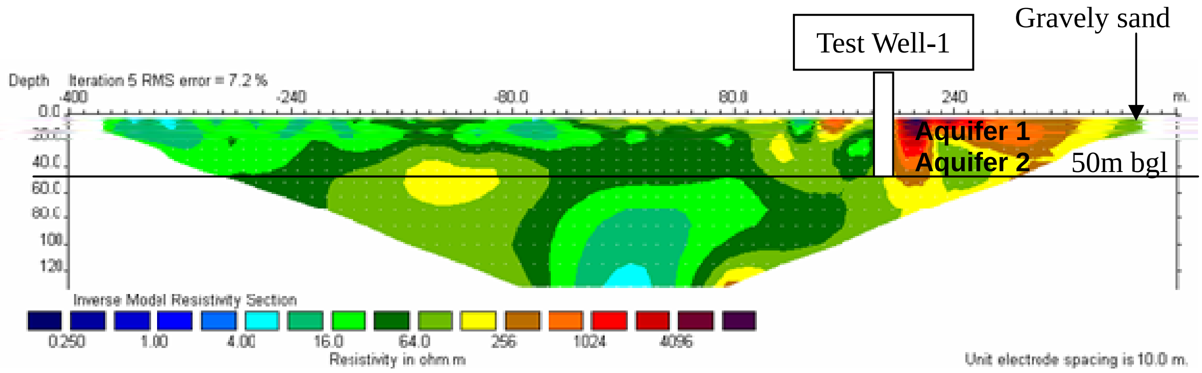


Figure A.20 Test Well-1 Construction Site

(2) Test Well-2

Test Well-2 is located at 10 m from the cross point between JWS-ES-1 and JWS-ES-2 to north on the survey line JWS-ES-2. It is arranged to drill Aquifer-1, Aquifer-2 and Aquifer-3 up to 200 m bgl (Figure A.21).

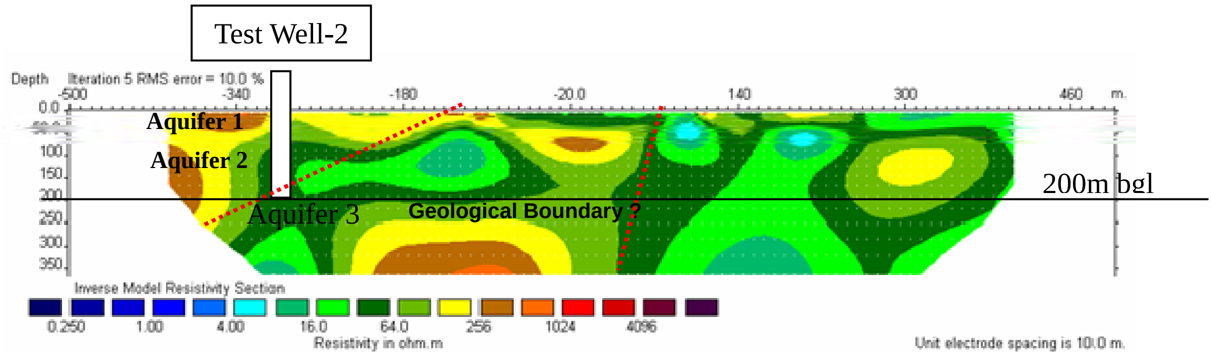


Figure A.21 Test Well-2 Construction Site

(3) Test Well-3

Test Well-3 is located at 105 m from the cross point between JWS-ES-1 and JWS-ES-2 to south on the survey line JWS-ES-1. It is arranged to drill Aquifer-1 and Aquifer-2 up to 100 m bgl (Figure A.22).

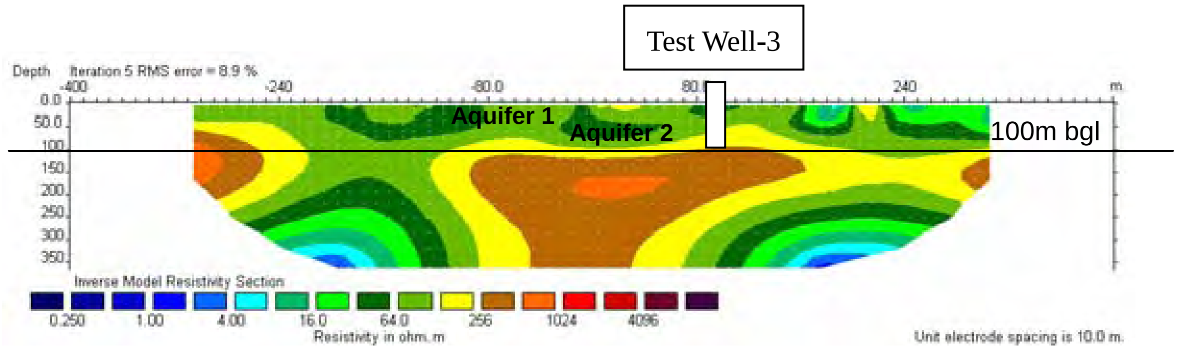


Figure A.22 Test Well-3 Construction Site

According to the geo-electrical survey results, geological condition of possible aquifer in the paleochannel is assumed to have following 2 patterns:

- Northern part of the paleochannel : Sand and gravel layer of alluvial deposit and weathered zone of Basement Complex
- Southern part of the paleochannel: Alluvial deposit, Fracture and weathered zone of Basement Complex

A.7 Test Well Construction

A.7.1 Outline of Survey

One test well and two observation wells are planned at northern part of the paleochannel. While two test wells are planned at southern part of the paleochannel. The specification of test well and observation well is decided considering geo-electrical survey results as follows:

(1) Test Well-1

- Aquifer: Sand and gravel layer of alluvial and weathered zone of Basement Complex
- Scheduled drilling depth: 50 m
- Drilling diameter: more than 20 inch (500 mm)
- Casing diameter: 8 inch (>200 mm)
- Material of casing: Steel casing (Open ratio: more than 15 %)

(2) Test Well-2

- Aquifer: Sand and gravel layer of alluvial and fracture and weathered zone of Basement Complex
- Scheduled drilling depth: 200 m

- Drilling diameter: more than 12 to 14 inch (>300 mm)
- Casing diameter: 8 inch (>200 mm)
- Material of casing: uPVC (Open ratio: more than 10%)

(3) Test Well-3

- Aquifer: Sand and gravel layer of alluvial and weathered zone of Basement Complex
- Scheduled drilling depth: 100 m
- Drilling diameter: more than 12 to 14 inch (>300 mm)
- Casing diameter: 8 inch (> 200 mm)
- Material of casing: uPVC (Open ratio: more than 10 %)

(4) Observation Well-1 and Observation Well-2

- Purpose of well : Observation well of Test Well-1
- Scheduled drilling depth: 50 m
- Drilling diameter: more than 8 to 12 inch (>200 mm)
- Casing diameter: 4 inch (>100 mm)
- Material of casing: uPVC (Open ratio: more than 5 %)

The summary specification of Test Well and Observation Well is shown in Table A.11.

Table A.11 Summery of Specification of Test Well and Observation Well

Well	Drilling depth	Drilling diameter	Material and diameter of casing / screen	Open ratio of screen	Prospected aquifer
Test Well-1	50 m	20 inch or more	8 inch steel	> 15 %	Sand and gravel layer of alluvial deposit and weathered zone of Basement Complex
Test Well-2	200 m	12 to 14 inch	8 inch uPVC	> 10 %	Fracture and weathered zone of Basement Complex and alluvial deposit
Test Well-3	100 m	12 to 14 inch	8 inch uPVC	> 10 %	Weathered zone of Basement Complex and alluvial deposit
Observation Well-1	50 m	8 to 12 inch	4 inch uPVC	> 5 %	-
Observation Well-2	50 m	8 to 12 inch	4 inch uPVC	> 5 %	-

A.7.2 Result of Well Drilling

The study team constructed three (3) test wells and two (2) observation wells for investigate into geological conditions, groundwater quantity and groundwater quality in Tokiman Paleochannel for planning as an alternative water source for Juba urban water supply.

The location of test well construction site in the Paleochannel where selected based on the result of electrical resistivity survey is shown in Table A.12 and Figure A.23. Test Well 1 (T-1), Observation Well 1 (O-1) and Observation Well 2 (O-2) are arranged in northern part of the Paleochannel. Test Well 2(T-2) and Test Well 3 (T-3) are arranged in southern part of the Paleochannel.

Table A.12 List of Test Well Construction Site

Well	Coordinates	Bench mark of location
Test Well-1	N04°47’12.8”	205 m from end-point of JWS-ES-5 to west.
	E31°35’54.1”	
Test Well-2	N04°46’26.8”	10 m from the cross point between ES-1 and ES-2 to north on JWS-ES-2.
	E31°35’47.7”	
Test Well-3	N04°46’23.8”	105 m from the cross point between ES-1 and ES-2 to south on JWS-ES-1.
	E31°35’45.6”	
Observation Well-1	N04°47’13.0”	155 m from end-point to west on JWS-ES-5.
	E31°35’55.7”	
Observation Well-2	N04°47’11.2”	50 m from Test Well-1 to south.
	E31°35’54.5”	

Note: JWS-ES-5 is name of the resistivity survey line.

The well construction works consist of drilling work, pumping tests, electrical logging and water sampling. The summary specification of Test Well and Observation Well is shown in Table A.13.

Table A.13 Investigation Items of Test Well and Observation Well

Well	Drilling depth	Electrical Logging	Pumping Test	Water Sampling
Test Well-1	50m	• Electrical resistivity (long and short normal) • Spontaneous Potential • Natural Gamma	• Step drawdown test • Constant rate test • Recovery test	Two Samples
Test Well-2	200m			One Sample
Test Well-3	100m			One Sample
Observation Well-1	50m		Water level measure only	-
Observation Well-2	50m			-

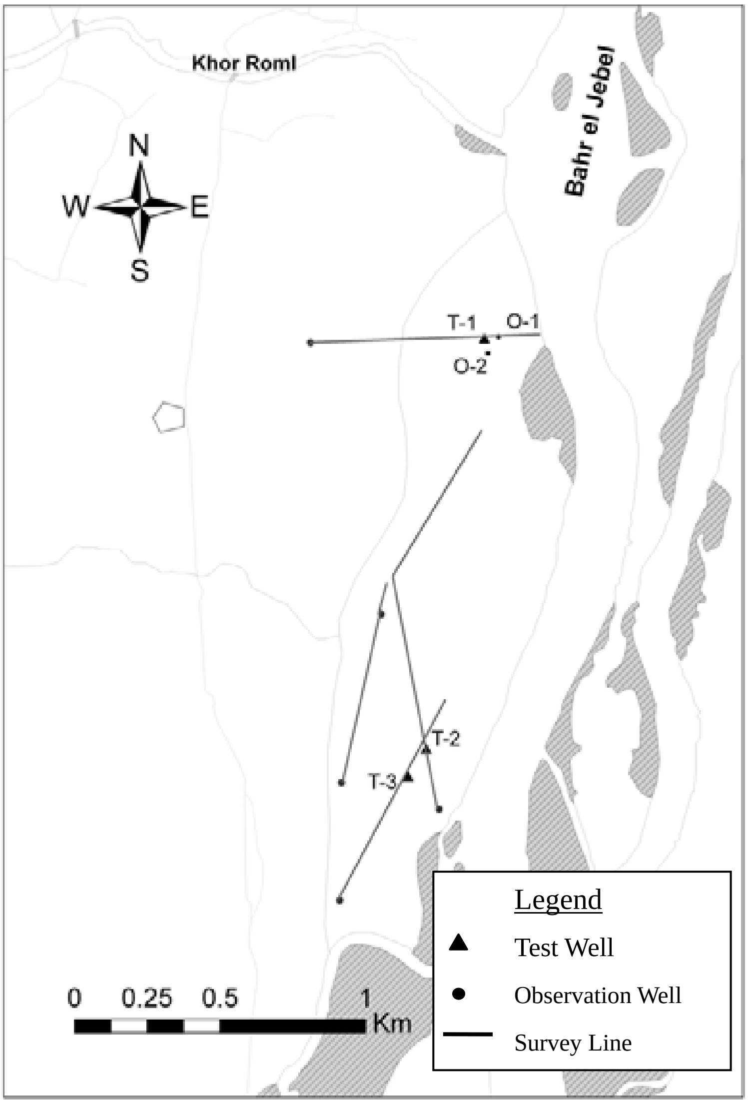


Figure A.23 Location Map of Test Well Construction Site in Tokiman Paleochannel

Summary of test well structure is shown Table A.14. Structure of the test well and the observation well are described in Annex A-3.

Table A.14 Summary of Test Well Structure

Well Name	Drilling Depth	Drilling Diameter	Well Diameter (Casing)	Depth of Screen
Test Well-1	50m	310mm (12-1/4inch)	200mm (8-1/2inch) (Steel)	4.1-10.6m 22.66-25.85m* 31.85-35.10m* 41.10-44.35m*
Test Well-2	200m	310mm (12-1/4inch)	200mm (8-1/2inch) (uPVC)	143.0-152.0m 161.0-197.0m
Test Well-3	100m	310mm (12-1/4inch)	200mm (8-1/2inch) (uPVC)	6.54-12.48m 23.49-32.48m 76.22-88.11m
Observation Well-1	50m	200mm (8-1/2inch)	100mm (4inch) (uPVC)	5.05-11.01m 20.09-23.07m 32.10-35.08m 41.06-44.06m
Observation Well-2	50m	200mm (8-1/2inch)	100mm (4inch) (uPVC)	6.21-12.09m 17.95-20.88m 26.76-29.74m 41.53-44.48m

Note: The screen below 20m in Test Well-1(*) is sealed for pumping test of an aquifer between 5 to 11m in depth.

(1) Geological Feature of the Northern Part of Tokiman Paleochannel

Test well and Observation well logs are attached in Annex A-3. On the basis of the litho-logy data of T-1, O-1 and O-2, the site may be divided into two geological classes that are alluvial deposit and Undifferentiated Gneiss Group. Geological section of the northern part of the Paleochannel is shown in Figure A.24. Geological feature of the drilling site is shown in Table A.15.

1) Geological Structure

Northern part of the Paleochannel is underlain by alluvial deposit which un-conformably overlies Undifferentiated Gneiss Group of Basement Rock.

2) Geological Formation

Alluvial deposit of the site is divided into three geological formations which are consists of top soil layer, fine to medium sand layer and sand with gravel layer, total thickness of it is about 8 meters.

- Top soil layer is about 1 meter thick and mainly consists of dark gray to black silt.
- Fine to medium sand layer is 2 to 5 meter thick at depth from 3 to 7 meters below surface and it is composed mainly fine to medium-grained brownish sand with occasional coarse-grained sand.

- Sand with gravel layer consists mainly medium to coarse-grained brownish-white sand and partly contained gravels, which is 2 to 5 meters thick.

Undifferentiated Gneiss Group of Basement Rock in the site is composed mainly granitic fine gneiss. Granitic fine gneiss is divided into three geological formations as follows.

- Weathered gneiss is brownish gray and 3 to 5 meter thick at depth from 11 to 13 meters below surface. Partly, highly weathered layer occurs at just below alluvial deposit with about 2 meter thick.
- Slightly weathered gneiss is greenish gray or brownish gray and 4 to 9 meter thick at depth from 18 to 20 meter below surface.
- Granitic fine gneiss is gray or white and mainly fresh-hard rock. Fracture zone occurs at irregular intervals and contains green schist with 1 meter thick at around 45 meters below surface in T-1.

3) Relation between Geology and Aquifer

Aquifer characteristic of the site is established from borehole log of T-1, O-1 and O-2 presented in the Annex A-3. Two major aquifers are identified named as Aquifer 1 and Aquifer 2 which is also estimated based on the result of electrical resistivity survey at the site. Aquifer 1 is unconfined type whereas Aquifer 2 is distributed in the fracture zone of granitic gneiss.

Aquifer 1;

- Aquifer 1 consists of alluvial deposit and weathered gneiss.
- The thickness of Aquifer 1 varies from 11 to 13m.
- This layer is composed of mainly sand.
- Static water level (S.W.L.) is from 2.35 to 2.60 meter below surface which is distributed in fine to medium sand layer.

Aquifer 2;

- Aquifer 2 consists of slightly weathered gneiss and fresh rock of granitic fine gneiss.
- Aquifer 2 occurs at irregular intervals in fracture zone of granitic fine gneiss.
- The thickness of Aquifer 2 is unknown.

Table A.15 Geological Feature of Northern Part of Tokiman Paleochannel

<table>
<tr><th>Geological Class</th><th>Geological Formation</th><th>Aquifer</th><th>Groundwater</th></tr>
<tr><td>Alluvial deposit</td><td>Top Soil
Fine to medium Sand
Medium to coarse Sand</td><td>Aquifer 1</td><td>S.W.L: 2.35m-2.62m.</td></tr>
<tr><td rowspan="2">Undifferentiated Gneiss Group</td><td>Weathered Gneiss
Slightly weathered Gneiss</td><td rowspan="2">Aquifer 2</td><td>Distribute in along the boundary of Aquifer 1.</td></tr>
<tr><td>Granitic fine Gneiss
Schist (T-1 only)</td><td>Distribute in a fracture zone</td></tr>
</table>

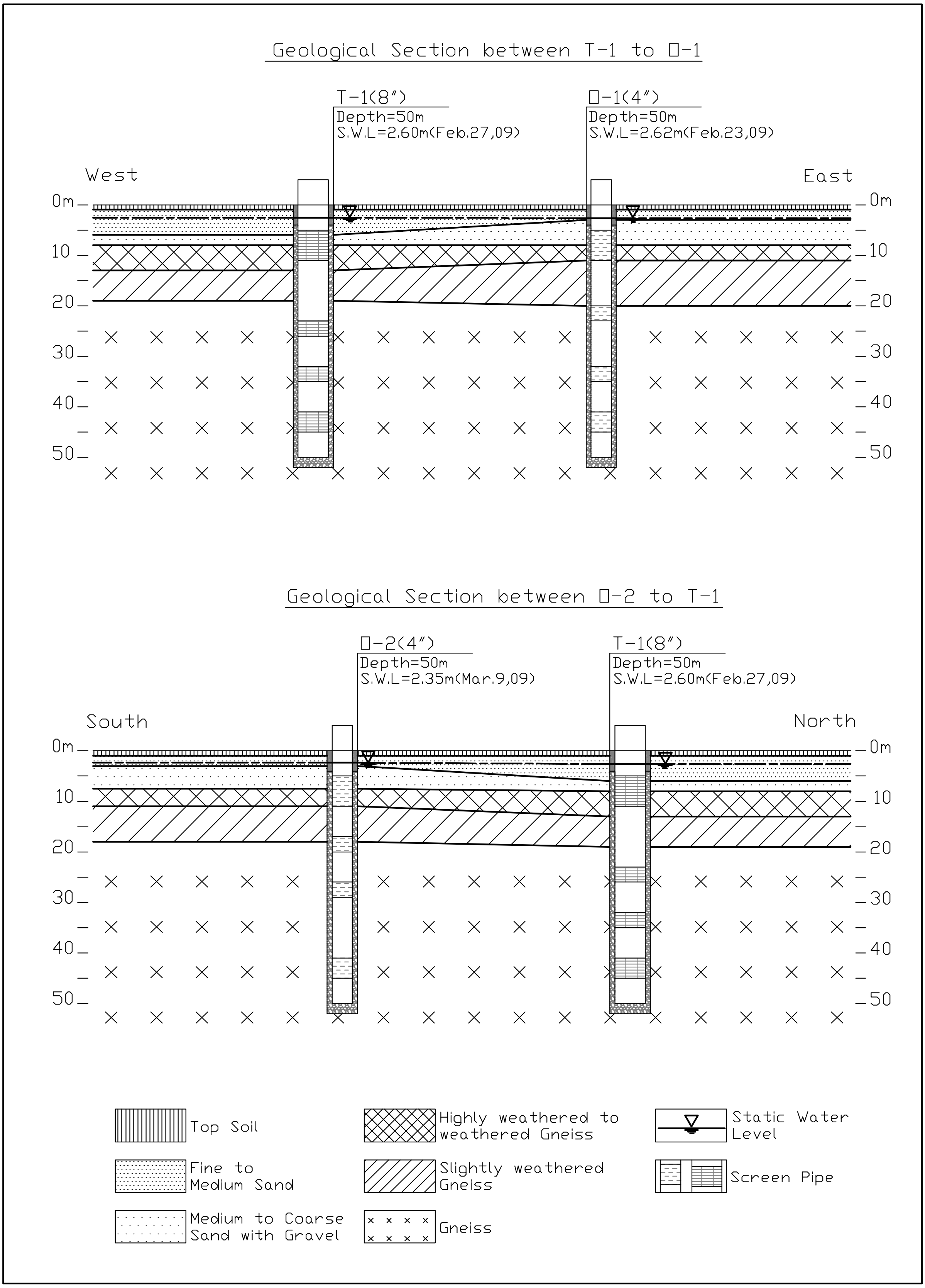


Figure A.24 Geological Section of Northern Part of Tokiman Paleochannel

(2) Geological Feature of the Southern Part of Tokiman Paleochannel

Geological section of southern part of the Paleochannel is shown in Figure A.25. On the basis of the litho-logy data of T-2 and T-3, the site may be divided two geological classes that are alluvial deposit and Undifferentiated Gneiss Group. Geological feature of the drilling site is shown in Table A.16.

1) Geological Structure

Southern part of the Paleochannel is underlain by alluvial deposit which un-conformably overlies gneiss of Undifferentiated Gneiss Group. There are extensive fracture zone at about 150m below surface in the gneiss.

2) Geological Formation

Alluvial deposit of the site is divided into two geological formations which are consists of top soil layer and medium to coarse sand layer, total thickness of it is about 7 meters.

- Top soil layer is about 3 meter thick and mainly consists of dark brown silt and clay.
- Medium to coarse sand layer is 4 meter thick at depth from 7 meters below surface and it is composed mainly medium-grained brow sand with occasional coarse-grained sand.

Undifferentiated Gneiss Group in the site is composed mainly gneiss. The gneiss is divided into five geological formations as follows.

- Highly weathered gneiss is brownish light gray and 3 meter thick at depth from 12 meters below surface and occurs at just below alluvial deposit.
- Weathered gneiss is brownish white and 3 meter thick at depth from 17 meters below surface.
- Upper slightly weathered gneiss is light greenish gray and 21 meter thick at depth from 38 meter below surface. Lower slightly weathered gneiss is greenish gray and 31 meter thick at depth from 69 meter below surface.
- Gneiss is dark greenish gray or black-white and mainly fresh-hard rock with 87m thick at 156m below surface in T-2.
- Slightly fracture zone is black-white and occurs at from 156 meter to 177 meter below surface in T-2. The thickness is 21 meter.
- Fracture zone is black-white and occurs at from 177 meter to 200 meter below surface in T-2. The thickness of it is unknown.

3) Relation between Geology and Aquifer

Aquifer characteristic of the site is established from borehole log of T-2 and T-3 presented in the

Annex A-3. Two major aquifers are identified named as Aquifer 1 and Aquifer 3 which is also estimated based on the result of electrical resistivity survey at the site. Aquifer 1 is unconfined type whereas Aquifer 3 is distributed in fracture zone of granitic gneiss.

Aquifer 1;

- Aquifer 1 consists of alluvial deposit.
- The thickness of Aquifer 1 is about 8 meters.
- This layer is composed of mainly sand.
- Static water level (S.W.L.) is 4.7 meter below surface.

Aquifer 2;

- Aquifer 2 consists of weathered gneiss.
- The thickness of Aquifer 2 is unknown.

Table A.16 Geological Feature of Southern Part of Tokiman Paleochannel

Geological Class	Geological Formation	Aquifer	Groundwater
Alluvial deposit	Top Soil Medium to coarse Sand	Aquifer 1	S.W.L.: 4.7m
Undifferentiated Gneiss Group	Highly weathered Gneiss Weathered Gneiss Slightly weathered Gneiss	Aquifer 2	Distribute in along the boundary of Aquifer 1 and fracture zone
	Slightly fractured Gneiss Fractured Gneiss	Aquifer 3	Distribute in a fracture zone

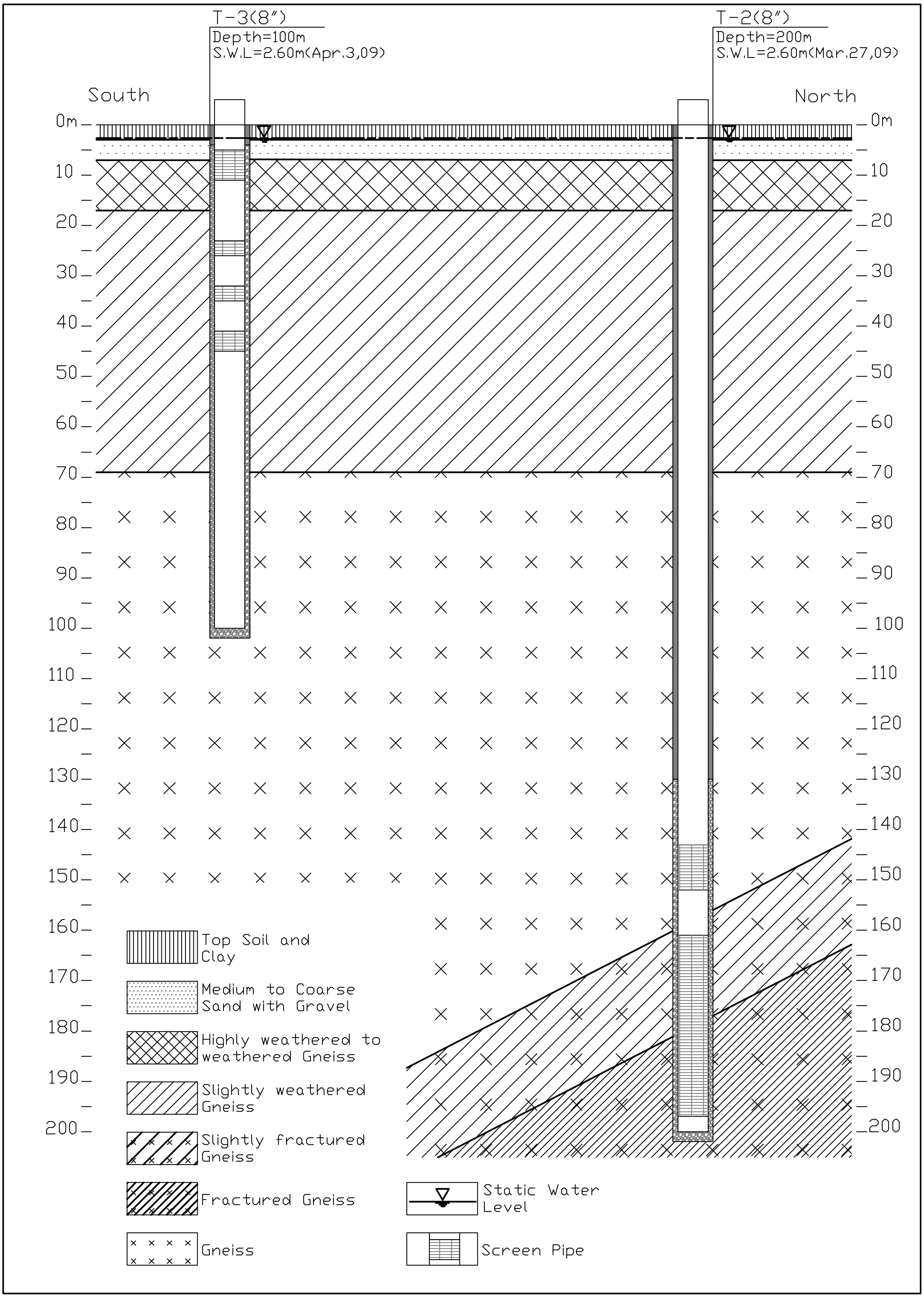


Figure A.25 Geological Section of Southern Part of Tokiman Paleochannel

A.7.3 Result of Electrical Logging Test

Electrical logging test is conducted on all test wells and observation wells for planning the casing programs after the completion of well drilling. It is composed of spontaneous potential (SP) test, electrical resistivity test (long and short normal) and gamma ray test. Result of electrical logging test is shown in Annex A-3 with well log.

(1) Northern Part of Tokiman Paleochannel

1) Spontaneous Potential (SP)

Relationship between geology in the site and spontaneous potential (SP) of each geological formation is summarized in Table A.17. Spontaneous Potential (SP) has a general tendency to become higher in the gneiss than alluvial deposits.

Table A.17 Relationship between Geology and SP in Northern Part of the Paleochannel

Unit: mV

Geology	Aquifer	T-1	O-1	O-2
Fine to Medium Sand	Aquifer 1	-80	-80	-80
Sand and Gravel		-90	-100 to -80	-100 to -80
Highly weathered to weathered Gneiss	Aquifer 2	-100	-100	-100 to -10
Slightly weathered Gneiss		-50	-65	-20 to +5
Fracture in Gneiss	Aquifer 3	-25 to -5	-80 to -65	-100 to -20
Gneiss (Fresh Rock)	-	-50 to -5	-80 to -65	-100 to -20

2) Electrical Resistivity

Relationship between geology in the site and electrical resistivity value of each geological formation is summarized in Table A.18. Electrical resistivity value has a general tendency to become higher in the gneiss than alluvial deposits. Electrical resistivity value of the weathered gneiss is lower than the fresh rock. However the value of the fractured zone is almost same as the gneiss.

Table A.18 Relationship between Geology and Electrical Resistivity Value in Northern Part of the Paleochannel

Unit: ohm-m

Geology	Aquifer		T-1	O-1	O-2
Fine to Medium Sand	Aquifer 1	SN	-	140 - 180	130 - 200
		LN	-	140 - 200	30 - 200
Sand and Gravel		SN	70 - 80	70 – 180	100 - 130
		LN	< 50	50 – 180	10 - 170
Highly weathered to weathered Gneiss	Aquifer 2	SN	70 - 110	30 – 70	250 - 300
		LN	45 - 200	35 – 90	250
Slightly weathered Gneiss		SN	50 - 130	20 – 150	300 - 500
		LN	< 75	10 – 130	300 - 500
Fracture in Gneiss	-	SN	80 - 200	80 -200	300 - 1100
		LN	75 - 125	100 – 135	300 - 1400
Gneiss (Fresh Rock)	-	SN	35 - 240	70 – 220	300 - 1100
		LN	70 - 200	100 – 220	300 - 2000+

SN: Short NORMAL
LN: Long NORMAL

3) Gamma ray

Relationship between geology in the site and gamma ray value of each geological formation is summarized in Table A.19. Gamma ray value has a general tendency to become lower in the gneiss than alluvial deposits at T-1 and O-2 whereas the value is opposite in O-1.

Table A.19 Relationship between Geology and Gamma ray (γ) n Northern Part of Tokiman Paleochannel

Unit: cps

Geology	Aquifer	T-1	O-1	O-2
Fine to Medium Sand	Aquifer 1	3.8	3.5	3.5
Sand and Gravel		3.8	3.5	3.5
Highly weathered to weathered Gneiss	Aquifer 2	3.8	3.5	2.0 – 3.5
Slightly weathered Gneiss		2.5	4.0 – 4.2	2.0
Fracture in Gneiss	-	2.5	4.0 – 4.2	2.0
Gneiss (Fresh Rock)	-	2.5	4.0 – 4.2	2.0

(2) Southern Part of Tokiman Paleochannel

1) Spontaneous Potential (SP)

Relationship between geology in the site and spontaneous potential (SP) of each geological formation is summarized in Table A.20. Spontaneous Potential (SP) has a general tendency to become lower in the gneiss than alluvial deposits.

Table A.20 Relationship between Geology and Spontaneous Potential (SP) in Southern Part of Tokiman Paleochannel

Unit: mV

Geology	Aquifer	T-2	T-3
Top soil and Clay		5 to 10	-
Medium to Coarse Sand	Aquifer 1	-15 to 5	-240
Highly weathered to weathered Gneiss	Aquifer 2	-50 to 50	-240
Slightly weathered Gneiss		-50 to 50	-100
Slightly fractured Zone (Gneiss)	-	-10 to 5	-
Fracture Zone(Gneiss)		-50 to 5	-
Gneiss (Fresh Rock)	-	-25 to -20	-90 to -20

2) Electrical Resistivity

Relationship between geology in the site and electrical resistivity value of each geological formation is summarized in Table A.21. Electrical resistivity value has a general tendency to become higher in the gneiss than alluvial deposits.

Table A.21 Relationship between Geology and Electrical Resistivity in Southern Part of Tokiman Paleochannel

Unit: ohm-m

Geology	Aquifer		T-2	T-3
Top soil and Clay		SN	-	-
		LN	-	-
Medium to Coarse Sand	Aquifer 1	SN	-	20 to 50
		LN	-	35 to 50
Highly weathered to weathered Gneiss	Aquifer 2	SN	150<	40 to 45
		LN	150<	25 to 50
Slightly weathered Gneiss		SN	50 – 110	<100
		LN	80 -130	50 to 250
Slightly fractured Zone (Gneiss)	Aquifer 3	SN	200 – 520	-
		LN	390 – 980	-
Fracture Zone(Gneiss)		SN	170 – 210	-
		LN	350 – 500	-
Gneiss (Fresh Rock)	-	SN	110 - 900	100 to 1000<
		LN	110 – 1000<	100 to 1000<

SN: Short NORMAL
LN: Long NORMAL

3) Gamma ray

Relationship between geology in the site and gamma ray value of each geological formation is summarized in Table A.22. There are no variations of gamma ray value in the geological formation.

Table A.22 Relationship between Geology and Gamma ray (γ) in Southern Part of Tokiman Paleochannel

Unit: cps

Geology	Aquifer	T-2	T-3
Top soil and Clay		3.5	-
Medium to Coarse Sand	Aquifer 1	3.5	7.5
Highly weathered to weathered Gneiss	Aquifer 2	3.5	5.5 to 7.5
Slightly weathered Gneiss		3.5	3.1
Slightly fractured Zone (Gneiss)	Aquifer 3	3.5	-
Fracture Zone(Gneiss)		3.5	-
Gneiss (Fresh Rock)	-	3.5	3.1

A.7.4 Result of Pumping Test

Pumping test is operated for the three test wells by JICA Study Team. The test specifications summarized in Table A.23.

Table A.23 Pumping Test Specifications

Specifications		Test Well 1	Test Well 2	Test Well 3
Depth of well (m-bgl)		21.0 m	200.0 m	100.0 m
Diameter of well (mm-casing)		200 mm	200 mm	200 mm
Casing type		Steel	uPVC	uPVC
Type of screen & Open ratio		Wire wounded (15%)	Slit (10 %)	Slit (10 %)
Thickness of Aquifer (m)		9.0m	45.0 m	27.0 m
Pump	Type	GRUNDFOS SP30-8		GRUNDFOS SP8A-25
	Output	7.5 kw		4.0 kw
	Diameter	75 A		50 A
	Voltage	400 V		400 V
	Set depth	19.0 m	84.0 m	34.0 m
Measure	Type	V-Notch		
	Wide of V-notch	200 mm		
	Height of V-notch	50 mm		

(1) Test Well 1

Aquifer 1 and Aquifer 2 were identified at drilling site. Main discharge of groundwater is measured in Aquifer 1 during drilling works. Therefore, pumping test was conducted in Aquifer 1 only when Aquifer 2 had been closed in the well.

Two observation wells drilled around Test Well 1 to interpret the boundaries of the environment that might be affected on drawdown groundwater level by pump up from the well. Observation Well 1 locates at about 50 m east from Test Well 1where is between Test Well 1 and Bar el Jubel. Obsevation

Well 2 locates at about 50 m south from Test Well 1 in upstream of a recent channel for measuring of groundwater level during pumping test.

Pumping test at Test Well 1 was conducted between Apr. 24 and Apr. 27 2009 in dry season. The test records are shown on Annex A-4. Table A.24 shows the result of pumping test.

Table A.24 Result of Pumping Test of Test Well 1 (Aquifer 1)

Analysis methods	Theis	Jacob	Recovery Test	Average
Transmissivity (T)	4.55 E^{-03} (m^2/sec)	4.11E^{-03} (m^2/sec)	8.26E^{-03} (m^2/sec)	5.64E^{-03} (m^2/sec)
Hydraulic conductivity (k)	9.28 E^{-02} (cm/sec)	8.39E^{-02} (cm/sec)	1.69 E^{-01} (cm/sec)	1.15 E^{-01} (cm/sec)
Storage coefficient (S)	1.09 E^{-10}	1.79 E^{-09}	-	9.49E^{-10}
Critical Discharge	230.0 (l/min)			

Table A.26 shows the groundwater level movement between Test Well 1 and Observation well 1 and Observation Well 2 during pumping test. There is no relationship of groundwater movement between Test Well 1 and the two observation wells.

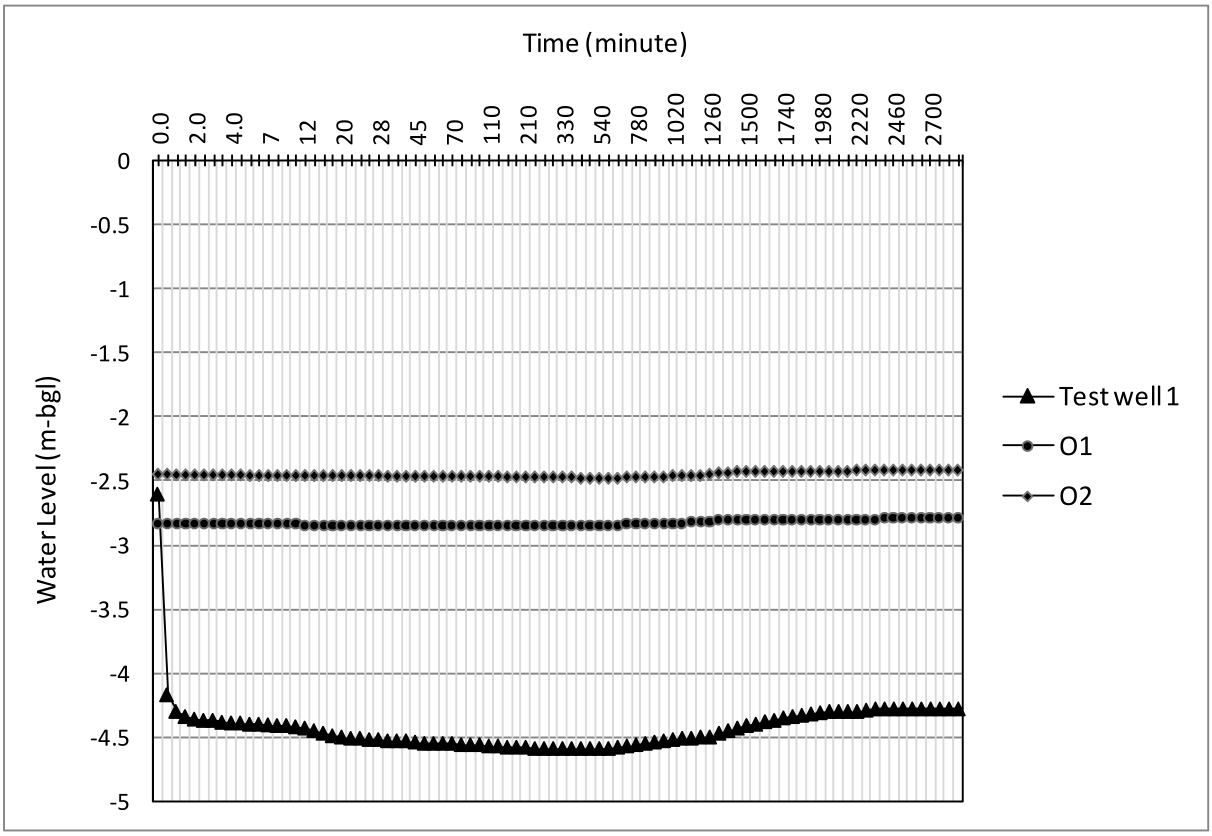


Figure A.26 Relationship of Groundwater Movement between Test Well 1 and Observation Well

(2) Test Well 2

Aquifer 1, Aquifer 2 and Aquifer 3 were identified at drilling site. Main discharge of groundwater is measured in Aquifer 3 during drilling works with about maximum 700 l/min in discharge at around 180 m-bgl by air compressor. Therefore, pumping test was conducted in Aquifer 3 only that the test well installed screen pipes in Aquifer 3 without Aquifer 1 and Aquifer 2. The test records are shown in Annex A-4. Table A.25 shows the result of pumping test.

Table A.25 Result of Pumping Test of Test Well 2 (Aquifer 3)

Analysis methods	Theis	Jacob	Recovery Test	Average
Transmissivity (T)	4.17 E^{-05} (m^2/sec)	$3.66E^{-05}$ (m^2/sec)	$2.74E^{-05}$ (m^2/sec)	$3.52E^{-05}$ (m^2/sec)
Hydraulic conductivity (k)	$8.34E^{-04}$ (cm/sec)	$7.32E^{-04}$ (cm/sec)	$5.47E^{-04}$ (cm/sec)	$7.04E^{-04}$ (cm/sec)
Storage coefficient (S)	$1.43E^{-01}$	$2.00E^{-01}$	-	$1.72E^{-01}$
Critical Discharge	220.0 (l/min)			

(3) Test Well 3

Aquifer 1and Aquifer 2 were identified at drilling site. Main discharge of groundwater is measured in Aquifer 2 during drilling works. Therefore, pumping test was conducted in Aquifer 2 only that the test well installed screen pipes in Aquifer 2 without Aquifer 1. The test records are shown on Annex A-4. Table A.26 shows the result of pumping test.

Table A.26 Result of Pumping Test of Test Well 3 (Aquifer 2)

Analysis methods	Theis	Jacob	Recovery Test	Average
Transmissivity (T)	3.19 E^{-04} (m^2/sec)	$3.04E^{-04}$ (m^2/sec)	$3.00E^{-04}$ (m^2/sec)	$3.32E^{-04}$ (m^2/sec)
Hydraulic conductivity (k)	$7.19E^{-03}$ (cm/sec)	$5.59E^{-03}$ (cm/sec)	$5.52E^{-03}$ (cm/sec)	$6.10E^{-03}$ (cm/sec)
Storage coefficient (S)	$9.38E^{-10}$	$6.18E^{-08}$	-	$3.45E^{-08}$
Critical Discharge	30.0 (l/min)			

A.8 Groundwater Quality Analysis

A.8.1 Outline of Survey

The Study team selected 89 existing wells in Juba city and its surrounding area for groundwater analysis. All wells are tested with on-site test methods and 18 wells samples are collected for a laboratory test of drinking water quality. Groundwater samples of three test wells in Tokiman

Paleochannel are analyzed for drinking water quality. On-site test is conducted by the JICA study team and laboratory test is executed by SSMO and Central Water Testing laboratories of Ministry of Water and Irrigation of Republic of KENYA.

A.8.2 Groundwater Quality of Tokiman Paleochannel

(1) On-Site Test Result

Groundwater samples of each test wells are tested during drilling works and pumping test. Conductivity was measured contiguously during drilling works after confirmation of the groundwater distribution in the well is shown on the borehole log in Annex A-5. Also, conductivity, salinity, TDS, pH and temperature are measured several times during drilling works. On –site test result in the pumping test of the test wells shown on Table A.27.

Table A.27 On-site Test Result of Test Well Groundwater Quality

Parameter	GV* (mg/l)	Test Well 1 (Aquifer 1)	Test Well 2 (Aquifer 3)	Test Well 3 (Aquifer 2)
Taste	Acceptable	Metallic	Very salty	Acceptable
Odor	Acceptable	Acceptable	Acceptable	Acceptable
Color (NTUs)	≦15	Light brown	Clear	Clear
Temperature	-	28.0 ℃	29.6℃	31.8℃
pH	6.0 – 8.5	6.98	7.86	7.66
TDS	≦1,000	56	4,200	250
Conductivity	≦1,500	87	6,430	380
Salinity	-	45	3220	189

GV*; UNICEF draft proposal of Southern Sudan water quality guidelines value (Oct. 2008)

(2) Laboratory Test Result

Groundwater color changed from clear to light brown 2 or 3 minutes after the water was sampled from Aquifer 1 in test wells and it stained a white canvas to brown at Teat Well 1. Therefore, groundwater samples of Aquifer 1 are tested on Iron (Fe) and Manganese (Mn). Laboratory test result of Fe and Mn are shown on Table A.28.

Table A.28 Laboratory Test Result of Fe and Mn in Aquifer 1 of the Test Wells

Parameter	GV* (mg/l)	Test Well 1	Observation Well 2	Test Well 2	Test Well 3
Iron (Fe)	0.5	5.4	5.06	0.47	0.53
Manganese (Mn)	0.4	0.622	0.335	0.628	0.060
Color (NTUs)	≦15	Light brown	Light brown	Clear	Clear

GV*: UNICEF draft proposal of Southern Sudan water quality guidelines value (Oct. 2008)
Groundwater samples were collected during drilling works and test was done by SSMO.
Colored cell: The parameter exceeds the guideline value.

Table A.29 shows result of bacteriological analysis of three test wells (see the original data sheet on Annex A-5). Groundwater sample of Test Well 2 is collected during pumping test while samples of Test Well 1 and Test Well 3 were collected by a manual water sampler that installed to the test well by hand.

Table A.29 Laboratory Test Result of Bacteriological Analysis of Test Well

Parameter	GV*	Test Well 1	Test Well 2	Test Well 3
Total coliforms	0 – 50 cfu/100ml	180	25	180
APC-37c		980	258	116
Escherichia coli		positive	positive	positive

GV*; UNICEF draft proposal of Southern Sudan water quality guidelines value (Oct. 2008)
cfu; colony forming units.
Colored cell; The parameter exceeds the guideline value.

27 parameters of drinking water quality are analyzed for the groundwater of test wells. Laboratory test result of it is shown on Table A.30.

Table A.30 Laboratory Test Result of Groundwater Quality in the Test Wells

Parameter	GV (mg/l)	Test Well 1 (Aquifer 1)	Test Well 2 (Aquifer 3)	Test Well 3 (Aquifer 2)
Aluminum (Al)	0.2	0.10	0.10	0.05
Ammonia (NH_4)	NS	0.01	0.4	0.3
Antimony (Sb)	0.005	0.01	0.01	0.01
Arsenic (As)	0.05	Nil	Nil	Nil
Barium (Ba)	0.7	Nil	Nil	Nil
Boron (B)	0.5	Nil	Nil	Nil
Cadmium (Cd)	0.003 - 0.005	Nil	Nil	Nil
Chloride (Cl)	200	26	410	26
Chromium (Cr)	0.05	Nil	Nil	Nil
Copper (Cu)	1.5	Nil	Nil	Nil
Cyanide (CN_2)	0.05	Nil	Nil	Nil
Fluoride (F)	1	0.1	0.52	0.39
Hardness	200	32	660	120
Sulfide	NS	0.1	1	0.2
Iron (Fe)	0.5	2.96	0.02	0.52
Manganese (Mn)	0.4	1.2	0.08	0.06
Lead (Pb)	0.01	Nil	Nil	Nil
Mercury (Hg)	0.006	Nil	Nil	Nil
Molybdenum (Mo)	0.07	Nil	Nil	Nil
Nickel (Ni)	0.07	Nil	Nil	Nil
Nitrate (NO_3)	30	4.1	5.2	1.3
Nitrite (NO_2)	0.5	0.25	0.01	0.59
Selenium (Se)	0.01	Nil	Nil	Nil
Sodium (Na)	100	488	775	20
Sulfate	200	0.3	491	7.8
TDS	1,000	1,358	3,677	197
Zinc (Zn)	3	0.02	0.04	0.02

Note :GV*; UNICEF draft proposal of Southern Sudan water quality guidelines value (Oct. 2008)
Test by Central Water Testing laboratories of Ministry of Water and Irrigation of Republic of Kenya.
NS; Not specified.
Colored cell; The parameter exceeds the guideline value.

(3) Groundwater Quality of Tokiman Paleochannel

There are three aquifers identified in Tokiman Paleochannel. The result of on-site test and laboratory test of groundwater quality in the paleochannel is summarized as below.

1) Aquifer 1

Total 6 parameters of drinking water quality exceed the guideline value as follows.

- Water color changed to light brown after pumping up 2 or 3 minutes.
- Iron of the samples collected during drilling works range from 0.47 to 5.4 mg/l which 75% of sample exceeds the guideline value.
- Manganese of the samples collected during drilling works range from 0.335 to 0.628 mg/l which 50% of the sample exceeds the guideline value.
- Antimony (0.01 mg/l) of the sample collected in pumping test exceeds the guideline value.

- Manganese (1.2 mg/l) of the sample collected in pumping test exceeds the guideline value.
- Sodium (488 mg/l) of the sample collected in pumping test exceeds the guideline value.
- TDS (1,358 mg/l) of the sample collected in pumping test exceeds the guideline value.

2) Aquifer 2

Total 3 parameters of drinking water quality slightly exceeds the guideline value as follows.

- Antimony (0.01 mg/l) of the sample collected in pumping test exceeds the guideline value.
- Iron (0.52 mg/l) of sample collected in pumping test exceeds the guideline value.
- Nitrite (0.59 mg//g) of the sample in pumping test exceeds the guideline value.

3) Aquifer 3

Total 9 parameters of drinking water quality exceed the guideline value as follows.

- Conductivity (6,430 μ s/cm) of sample collected during drilling works is exceeds the guideline value.
- Salinity of the sample collected during drilling works is 3,220 mg/l.
- Antimony (0.01 mg/l) of the sample collected in pumping test exceeds the guideline value.
- Chloride (410 mg/l) of the sample collected in pumping test exceeds the guideline value.
- Hardness (660 mg/l) of the sample collected in pumping test exceeds the guideline value.
- Nitrate (5.2 mg//g) of the sample collected in pumping test exceeds the guideline value.
- Sodium (775 mg//g) of the sample collected in pumping test exceeds the guideline value.
- Sulfate (491 mg//g) of the sample collected in pumping test exceeds the guideline value.
- TDS (3,677 mg/l) of the sample collected in pumping test exceeds the guideline value.

A.8.3 Groundwater Quality of Juba City

(1) Result of On-site Test

The result of groundwater quality analysis and location map of 89 existing wells is listed in Annex A-5. Groundwater quality on-site test result is summarized in Table A.31.

- Total 89 samples tested which consist of 32 samples in Juba Payam, 10 samples in Kator, 36 samples in Munuki, 11 samples in Rejaf.
- pH value of the samples range from 6.0 to 8.5 of the guideline value.
- 43% (38/89) of EC value exceeds the guideline value (1,500 μ S/cm).
- Distribution of pH, EC and TDS value shows a same tendency in the study area (see Annex A-5 Distribution Map of EC value of 89 Existing Wells).
- 43% (38/89) of TDS values exceeds the guideline value (1,000 mg/L).

- 2% (2/89) of samples is colored.
- 43% (38/89) of samples is not acceptable taste, “SALTY”.
- 56% (18/32) of samples is “SALTY” in Juba Payam.
- 70% (7/10) of samples exceeds EC and TDS guideline value, and 60% (6/10) of samples is “SALTY” in Kator Payam.
- 55% (6/11) of samples is “SALTY”.

Table A.31 Summary of Groundwater Quality On-Site Test Result

	Southern Sudan Guideline Value	pH	EC	TDS (mg/L)	Salinity (mg/L)	Color (NTUs)	Odor	Taste
		6.0－8.5	150 mS/m	≦1,000	－	≦15	acceptable	acceptable
Study Area	Total Samples	89	89	89	89	89	89	89
	Samples exceeds Guideline Value	0 (0%)	38 (43%)	38 (43%)	0 (0%)	2 (2%)	0 (0%)	38 (43%)
Juba	Total Samples	32	32	32	32	32	32	32
	Samples exceeds Guideline Value	0 (0%)	16 (50%)	16 (50%)	0 (0%)	1 (3%)	0 (0%)	18 (56%)
Kator	Total Samples	10	10	10	10	10	10	10
	Samples exceeds Guideline Value	0 (0%)	7 (70%)	7 (70%)	0 (0%)	0 (0%)	0 (0%)	6 (60%)
Munuki	Total Samples	36	36	36	36	36	36	36
	Samples exceeds Guideline Value	0 (0%)	12 (33%)	12 (33%)	0 (0%)	0 (0%)	0 (0%)	9 (25%)
Rejaf	Total Samples	11	11	11	11	11	11	11
	Samples exceeds Guideline Value	0 (0%)	3 (27%)	3 (27%)	0 (0%)	1 (9%)	0 (0%)	6 (55%)

1) pH

Result of pH test is summarized in Table A.32. The pH value ranges from 6.6 to 7.9 with an average of 7.3. All samples falls within the guideline value (6 to 8.5).

Table A.32 pH value of Groundwater in the Study Area

Area	pH			
	Guideline Value	Max.	Min.	Ave
Study Area	6.0 - 8.5	7.9	6.6	7.3
Juba		7.8	7.0	7.2
Kator		7.6	6.8	7.2
Munuki		7.9	6.6	7.3
Rejaf		7.7	7.0	7.3

2) Electrical Conductivity (EC)

Result of EC test is summarized in Table A.33. Electrical Conductivity (EC) indicates existence of soluble ions of different elements and radicals in groundwater. Electric Conductivity (EC) of the samples ranges from 582 to 3,910 μ S/cm with an average of 1549 μ S/cm. 43% (38/89) of EC value exceeds the guideline value (1,500 μ S/cm).

Table A.33 EC value of Groundwater in the Study Area

Area	EC (μS/cm)			
	Guideline Value	Max.	Min.	Ave
Study Area	150 mS/m (1,500 μ S/cm)	3910	582	1548
Juba		3180	761	1647
Kator		3910	828	2068
Munuki		2550	582	1289
Rejaf		3590	766	1637

3) Total Dissolved Solids (TDS)

Result of EC test is summarized in Table A.34. TDS value ranges from 392 to 2,610 mg/l with an average of 1033 mg/l. 43% (38/89) of samples exceeds the guideline value (1,000 mg/l).

Table A.34 TDS value of Groundwater in the Study Area

Area	TDS (mg/L)			
	Guideline Value	Max.	Min.	Ave
Study Area	≦1,000	2610	392	1033
Juba		2120	582	1097
Kator		2610	588	1374
Munuki		1710	392	861
Rejaf		2390	766	1637

4) Salinity

Result of EC test is summarized in Table A.35. Salinity of the samples ranges from 281 to 1,940 mg/l with an average of 777 mg/l.

Table A.35 Salinity value of Groundwater in the Study Area

Area	Salinity (mg/L)			
	Guideline Value	Max.	Min.	Ave
Study Area	—	1940.0	281.0	777.7
Juba		1590.0	377.0	824.6
Kator		1940.0	410.0	1031.5
Munuki		1290.0	281.0	670.7
Rejaf		1770.0	414.0	823.5

5) Color, Odor and Taste

These parameters were tested using human sense of survey. In testing, if abnormal color, odor or test is perceived in water sample by surveyor, it was marked as "Not Clear"," Odor" or "Salty", respectively. 2 % (2/89) of the samples are classified as Not Clear (3 % in Juba and 9 % in Rejaf). 43 % (38/89) of the total samples are classified as Salty taste (56 % in Juba, 25 % in Munuki, 60 % in Kator and 25% in Rejaf Payam).

(2) Result of Laboratory Test

Total 18 wells were selected in correlation with the distribution of existing wells over the entire study area. The water samples collected from hand-pump. The samples were analyzed by Central Water Testing Laboratories of Ministry of Water and Irrigation of Republic of KENYA.

The result of a laboratory test and location map of 18 existing wells is shown in Annex A-5. Summary of the laboratory test result of groundwater quality is shown in Table A.36. According to the result, seven (7) parameters of test items exceed the Southern Sudan guideline value.

Table A.36 Summary of Laboratory Test Result of 18 Existing Wells

Parameters	Unit	S. S Guidline Value	Max	Min	Ave
Aluminum	mg/L	0.2	0.1	0.01	0.02
Ammonia	mg/L	-	0.08	0.03	0.06
Antimony	mg/L	0.005	0.01	0.01	0.01
Arsenic	mg/L	0.05	0	0	-
Barium	mg/L	0.7	0	0	-
Boron	mg/L	0.5	0	0	-
Cadmium	mg/L	0.003-0.005	0	0	-
Chloride	mg/L	200	405	3	117
Chromium	mg/L	0.05	0	0	-
Copper	mg/L	1.5	0	0	-
Cyanide	mg/L	0.05	0	0	-
Fluoride	mg/L	1	1.6	0.25	0.54
Hardness	mg/L	-	532	104	281
Sulfides	mg/L	-	2	1	1
Iron	mg/L	0.5	0.38	0.08	0.17
Manganese	mg/L	0.4	0.08	0.01	0.02
Lead	mg/L	0.01	0	0	-
Mercury	mg/L	0.006	0	0	-
Molybdenum	mg/L	0.07	0	0	-
Nickel	mg/L	0.07	0	0	-
Nitrate	mg/L	30	260	0.12	38
Nitrite	mg/L	0.5	0.62	0.02	0.16
Selenium	mg/L	0.01	0	0	-
Sodium	mg/L	100	754	35.5	235
Sulfate	mg/L	-	243	1.71	57
TDS	mg/L	1000	2300	369	969
Zinc	mg/L	3	0.11	0.01	0.03

Seven (7) parameters exceed Southern Sudan guideline values and the the test result of these parameters describe in Table A.37.

Table A.37 Parameter Exceed Guideline Values

Parameter	The number of samples exeeded	Remarks
1) Antimony	1 /18 (5.6%)	One sample exceed the guideline value (0.005 mg/l) is 0.01 mg/l at JP001 in MADARA village, JUBA NABARI Boma, JUBA Payam.
2) Chloride	3 /18 (16.7%)	Chloride value range from 3 to 405 mg/l with an average of 117 mg/l. 3 samples exceeds the guideline value (200 mg/l).
3) Fluoride	2 /18(11.1%)	Fluoride value range from 0.25 to 1.6 mg/l with an average of 0.54 mg/l. 2 samples exceeds the guideline value (1 mg/l).
4) Nitrate	3 /18(16.7%)	Nitrate value range from 0.12 to 260 mg/l with an average of 38 mg/l. 3 samples exceeds the guideline value (30 mg/l).
5) Nitrite	1 /18 (5.6%)	One sample exceed the guideline value (0.5 mg/l) is 0.62 mg/l at MP093 in MUNUKI Payam.
6) Sodium	14 /18 (77.8%)	Sodium value range from 35.5 to 754 mg/l with an average of 235 mg/l. 14 samples exceeds the guideline value (100 mg/l).
7) TDS	4 /18 (22.2%)	TDS value range from 369 to 2,300 mg/l with an average of 969 mg/l. 4/18 samples exceeds the guideline value (1,000 mg/l).

Table A.38 shows the result of bacteriological analysis of 18 existing wells. 78% (14/18) of samples were detected some Escherichia coli.

Table A.38 Laboratory Test Result of Bacteriological Analysis of 18 Existing Wells

Parameter		Total coliforms	APC-37c	Escherichia coli
GV*		0 – 50 (cfu/100ml)	-	-
1	JP066	>18	294	Positive
2	JP001	>18	224	Positive
3	KP050	>18	257	Positive
4	MP151	>18	15	Positive
5	MP093	>18	202	Positive
6	MP127	>18	153	Positive
7	JP039	>18	91	Positive
8	KP032	>18	186	Positive
9	JP046	2	128	Positive
10	JP118	0	6	Negative
11	JP116	>18	216	Positive
12	MP068	>18	130	Positive
13	MP046	2	98	Positive
14	MP049	>18	244	Positive
15	RP013	>18	204	Positive
16	RP012	2	198	Negative
17	RP011	0	12	Negative
18	RP021	3	170	Negative

GV*; UNICEF draft proposal of Southern Sudan water quality guidelines value (Oct. 2008)
cfu; colony forming units.
Colored cell; The parameter exceeds the guideline value.

A.9 Groundwater Source of Tokiman Paleochannel

A.9.1 Hydro-geological Condition

(1) Groundwater Distribution

Considering the result of the study, groundwater in the area is distributed in Aquifer 1, Aquifer 2 and Aquifer 3. Aquifer 1 extends from surface to maximum of about 20 m-bgl covering the Tokiman area. As mentioned above, groundwater level (Static Water level) may be observed in Aquifer 1 with depth varying from 2 to 5 m-bgl nearly same as water level of Bahr el-Jebel. Aquifer 2 and Aquifer 3 might be locally existing groundwater in the area. Groundwater in Aquifer 1 is un-confined type while it in Aquifer 2 and Aquifer 3 are confined type. Groundwater distribution and the relationship with geology are summarized on Table A.39.

Table A.39 Groundwater Distribution in Tokiman Paleochannel

Aquifer	Distribution	Hydrogeology
Aquifer 1	From 1m to about 8m below surface. Extensively distribute in the area.	・ Consists of alluvial deposits mainly sand. ・ Apparent resistivity range from approximately 50ohm-m to 150ohm-m. ・ Electrical resistivity range from approximately 50 to 200 ohm-m. ・ Groundwater level may be observed in depth of 2m to 5m below ground level. ・ Un-confined groundwater.
Aquifer 2	About 8m to 20m below ground level in northern part. About 8m to 70m below surface in southern part.	・ Consists of mainly weathered gneiss. ・ Apparent resistivity ranges from approximately 50ohm-m to 300ohm-m. ・ Electrical resistivity ranges from approximately 70ohm-m to 500ohm-m. ・ Groundwater distributes in along the boundary of Aquifer 1 and weathered zone or fracture zone of gneiss. ・ Groundwater is confined type and fissure water.
Aquifer 3	About 160 m to more than 200m below surface. Distribute in southern part.	・ Consists of fractured gneiss. ・ Apparent resistivity ranges from approximately 50ohm-m to 300ohm-m. ・ Electrical resistivity ranges from approximately 170 to 1,000 ohm-m. ・ Confined groundwater. ・ Might be locally existing groundwater in the area.

(2) Groundwater Movement

Figure A.27 shows schematic hydro-geological section between Test Well 1 and the Bahr el-Jebel in the northern part of Tokiman Paleochannel. Groundwater level in the area is higher than the water level of the river in dry season. The feature described groundwater distribution suggests that groundwater in the area recharge to Bahr el-Jebel. From this it may be inferred that the area is discharge area of groundwater to the river. Therefore, rainfall in and around the area, is the principal source of groundwater. Groundwater flows approximately south to north and west to east along the landform in the area. Groundwater in the area has been recharged from hilly area west side of the paleochannel. Both rainfall and groundwater recharges supplies Aquifer 1 directly. Also Aquifer 2 and Aquifer 3 are recharged by rainfall but it is not recharged directly.

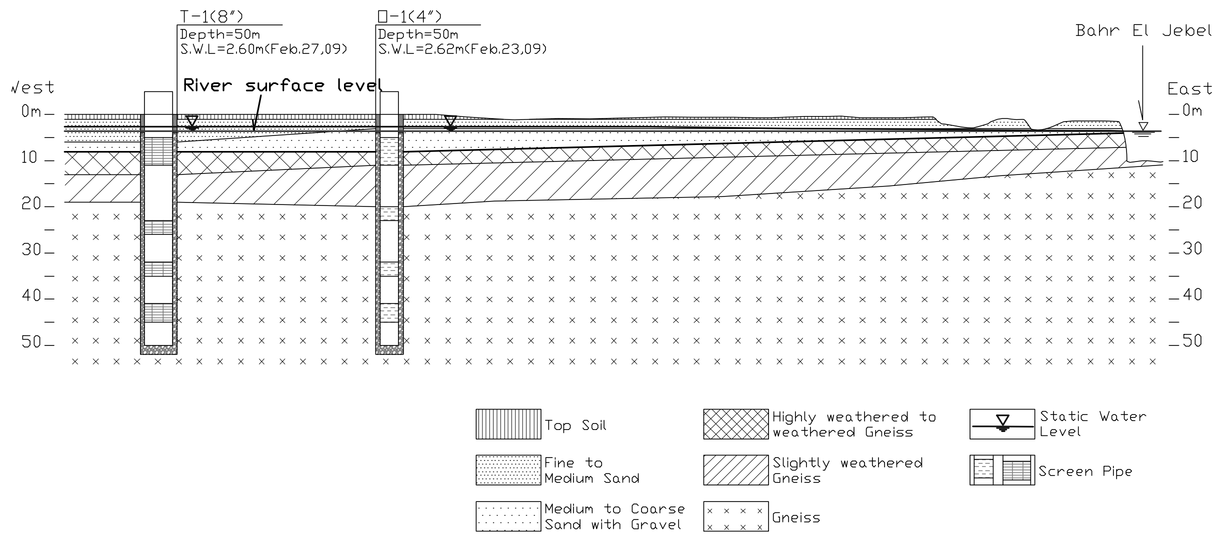


Figure A.27 Schematic Hydro-geological Section between Test Well 1 and the Bahr el-Jebel

A.9.2 Groundwater Development Potential

As the result of groundwater survey in Tokiman Paleochannel, it can be stated that as blow.

- There is no an aquifer that has thickness of more than 150m which consist of alluvial deposits with high potential of groundwater discharge to connect the Bahr el-Jebel directory for recharge system.
- Groundwater is distributed into three type of aquifer in the area.
- Groundwater level exists in the relatively shallow (2 to 5m) subsurface in Aquifer 1.
- Un-confined type of groundwater is distributed into Aquifer 1 in alluvial deposits and few amount of it exists in Aquifer 2 in weathered zone or fractured zone of gneiss.
- Fissure water exists in Aquifer 3 in fractured zone of gneiss that is confined type of groundwater.
- Un-confined type of groundwater is reddish-brown colored.
- Iron, Manganese, Antimony, Sodium and TDS value of groundwater in Aquifer 1 exceeds the

guideline value.

- Iron, Antimony and Nitrate value of groundwater in Aquifer 2 exceeds the guideline value.
- Conductivity, Antimony, Chloride, Hardness, Nitrate, Sodium, Sulfate and TDS value of groundwater in Aquifer 3 exceeds the guideline value.
- Groundwater in the area is not recommends for water source of Juba urban water supply due to low yield and unsuitable water quality.

Groundwater development potential of Tokiman Paleochannel is shown in Table A.40.

Table A.40 Groundwater Development Potential of Tokiman Paleochannel

Aquifer	Aquifer 1	Aquifer 2	Aquifer 3
Groundwater type	Un-confined groundwater	Confined groundwater and Fissure water	Un-confined groundwater and Fissure water
Capacity	Q = 230 l/min T = 5.64E^{-03} m^2/sec k = 1.15 E^{-01} cm/sec s = 9.49E^{-10}	Q = 30 l/min T = 3.32E^{-04} m^2/sec k = 6.10E^{-03} cm/sec s = 3.45E^{-08}	Q = 220 l/min T = 3.52E^{-05} m^2/sec k = 7.04E^{-04} cm/sec s = 1.72E^{-01}
Groundwater Quality	Iron, Manganese, Antimony, Sodium and TDS value exceeds the guideline value.	Iron, Antimony and Nitrate value exceeds the guideline value.	Conductivity, Antimony, Chloride, Hardness, Nitrate, Sodium, Sulfate and TDS value exceeds the guideline value.
Evaluation	Not recommend for water source of Juba urban water supply due to low yield and unsuitable water quality.	Not recommend for water source of Juba urban water supply due to low yield and unsuitable water quality.	Not recommend for water source of Juba urban water supply due to low yield and unsuitable water quality.

Note: Q(Critical Discharge), T(Transmissivity), k(Hydraulic conductivity), s(Storage coefficient)