Chapter 5

Observation Well Drilling

5 Observation Well Drilling

5.1 Purpose and methodology

5.1.1 Purpose

The observation well drilling in this study was conducted for the following purposes.

- To obtain subsurface geological information by observing drill cutting and slimes
- To evaluate the location and potential of potential aquifers using the data obtained above and the data from geophysical logging and pumping test conducted in the drilled boreholes
- To use the completed borehole for long-term groundwater observation to access the groundwater regime of the area

5.1.2 Methodology

In the study, a total of 10 wells were planned to be drilled and completed as regular water supply wells. The wells were used for water level observation purpose during the study period and they may be used for water supply after the study. The general specification of the well is shown in Figure 5.38 and summarized in the table below.

Table 5.1: Specification of the Planned Well Drilling Work in the Study

	Details
Period	・ First year April 2010 to June 2010 ・ Second year : December 2010 to March 2011
Number of wells	・ First year 3 sites ・ Second year: 7 sites
Quantity of drilling	・ First year : Total depth of drilling : 650 m (average/well 217m) ・ Second year : Total depth of drilling : 1,650 m (average/well 235m)
Drilling specification	・ Drilling method: Rotary method, DTH (Down-the-hole hammer) method ・ Drilling diameter : 10 inch ・ Diameter of casing and screen pips : 6 inch ・ Material of casing and screen pipe: steel or PVC ・ Screen opening ratio : more than 5 % ・ Bottom plug: installed at the bottom end of the well ・ Sealing: cement sealing
Drilling method and well finish	・ Take sample cutting/slime at every meter of depth ・ Geophysical logging of borehole (resistivity, spontaneous potential, continuous or every 1m) ・ Screen and casing installation ・ Gravel packing and sealing ・ Well finish, development ・ Observation pipe installation ・ Protective housing at well head

The work was sub-contracted to the same drilling contractor as in the first year. As a result of the drilling work in the first year, which turned out to be very tedious and difficult due to abundance of highly collapsible and permeable formations intercalated with relatively thin layers of hard rock, some special measures were taken to secure the success of drilling in the second year as follows.

・ Use of longer surface casing to cover upper collapsible section in borehole

- Use of mud rotary drilling when there is a risk of collapse
- Use of additional drill collar in mud rotary drilling
- Preparation of sufficient materials (such as bentonite) at site

5.1.3 Selection of drilling sites

Drilling of a total of 10 boreholes was first planned for this study. Approximate areas of the 10 drilling sites were first determined with consultation of local geologists at the time of the preliminary study. Then, the information was again confirmed with available geological and hydrogeological information (maps and well drilling data) at the beginning of the study. In principle, the planned drilling sites were selected according to the following criteria:

1) Drilling sites should be spatially evenly distributed across the study area,
2) Each site should be located in an area of characteristic geology that represents the area, and
3) The drilling points are conveniently lined to form transects through the study area to create corresponding geological profiles.

The selected sites of drilling are shown in Figure 5.39. Actual field survey was then conducted at the beginning of the study to confirm the site condition and the target sites were further narrowed down. The criteria for the site selection at this stage were as follows:

1) The rocks and sediments expected from the investigation of surface geology is likely to exist under the site,
2) Access to the site by car is not too difficult, and
3) No problems related to land use during the drilling was anticipated

Afterwards, a geophysical survey was conducted at each selected site to estimate the subsurface geological and hydrogeological conditions. The details of geophysical survey are explained in chapter 4 in the supporting report. The electrical resistivity survey covered an area of about 36 ha (roughly 600 x 600m) at each site and 10 vertical resistivity survey (VES) points and a few horizontal resistivity survey (HES) were conducted. As a result, resistivity profile maps were created to give an indication of the subsurface structure at each site.

Finally on the basis of produced resistivity profile maps, exact points of drilling were determined using the following criteria:

1) Select the point where potentially water bearing layer exists close to the ground surface, and
2) Avoid selecting points of problematic access to the actual points.

The list of selected 10 drilling points and their areas are shown in Table 5.2.

The locations of the determined drilling points were again reviewed by a team of geologists (Japanese and Ethiopians) at the beginning of the second year of the study. As a result, two sites (No-9 and No-10) were relocated from the originally selected sites (southern edge of the study area) to the northern part of the study area. The rational for the relocation is as follows.

4) It is better to concentrate the boreholes in the northern part of the study area (to the north of lake Abaya): This is because there are some existing data to compare with in the area to achieve higher resolution of the terrain in the hydrogeological maps and cross sections.

5) As a result of the study in the first year, much more data was found available for the area to the north of Lake Abaya than for the area to the south.

6) There is a deep test borehole drilled in the geothermal project available to the south of Lake Ziway.

The locations of the selected sites of drilling in the Study Area are shown in Figure 5.39 and their detailed locations in Figure 5.40 to Figure 5.49. At each site, actual field survey was conducted at the beginning of the second year of the study to confirm the site condition. Then, the drilling points were determined also in consideration of the results of geophysical survey. Note that Electromagnetic survey (TEM) was conducted in the two sites (No-9N, No-10N) that were newly selected in the second year as a result of relocation. The list of the selected seven drilling sites is shown in the table below.

Table 5.2: List of Selected Drilling Sites for the Study

Site No.	Region	Planned depth	Area	GPS Coordinates	
				E	N
No-1	SNNPRS	150	Abaya North	383591	734651
No-2	Oromiya	250(150)	Meki	486414	908188
No-3	Oromiya	250	Sheshemene	448141	796423
No-4	SNNPRS	250 m	Yirga Alem	424918	745467
No-5	SNNPRS	250 m	Dimtu	402611	763729
No-5N	NA	250 m	Dimtu	404289	765682
No-6	SNNPRS	400 m	Kenche	420139	807171
No-7	SNNPRS	200 m	Arba Minch	341712	670506
No-8	SNNPRS	150 m	Chamo south	327946	630717
No-9N	Oromiya	200 m	Langano SW	464826	829769
No-10N	Oromiya	200 m	Ziway East	500516	889860

* coordinates are of actual drilling points in UTM, datum Adindan

Site No-9N and No-10N were moved to the current sites from the original plan made during the first year of the study. Site No-5N was moved to the current site from the first site (No-5) during the second year of the study. The planned depth of drilling at each sites were also reviewed and changed from the original plan at that time. See Progress Report (1) for comparison.

5.2 Results of well drilling

5.2.1 Summary of the drilling work

A total of 10 wells (3 in the first year and 7 in the second year) were drilled and completed as observation wells in the project. Well logging was conducted prior to installation of casing and screen pipes and an automatic water level recorder was installed at each well.

Three out of the 10 wells (No-1, 2 and 3) were drilled in the first year of the study. The work was subcontracted to a local drilling company. The drilling work started at site No-2 in early April 2010 and it turned out to be very difficult and tedious because of succession of collapsible volcaniclastic sediments and intercalated hard consolidated volcanic layers. Consequently, the drilling work continued beyond the originally planned period and took nearly four months to complete. The following table summarizes the result of drilling work conducted in the first year of the project.

Table 5.3: Outline of the Drilling Work in the First Year

Site No	No-1	No-2	No-3
Drilling work	31 May 2010 – 6 June, 2010	7 April 2010 – 27 May, 2010	10 June 2010 – 11 July, 2010
Pumping test	7 June 2010 – 10 June, 2010	31 May 2010 – 2 June, 2010	30 July 2010 – 2 August, 2010
Drilling method	DTH with foam	DTH with foam and water Mud rotary	DTH with foam
Drilled depth (actual/planned)	150m / 150m	172m / 250m	250m / 250m

In the second year、the drilling work started at site No-5 from the beginning of December 2011. However, due to technical problems during the drilling, the wells were not completed within the expected work period of 4 months and eventually took eleven months to complete. To accelerate the progress in the drilling work in the first few months, two additional drilling rigs were mobilized in April 2011. The following table summarizes the result of drilling work conducted in the second year of the project.

Table 5.4: Outline of the Drilling Work in the Second Year

Site No	No-4	No-5 (site shifted)	No-5N	No-6
Drilling work	29 February 2011 – 8 November 2011	3 December 2010 – 29 January, 2011	23 May, 2011 – 31 July, 2011	29 August, 2011 – 4 September, 2011
Pumping test	15 November 2011 – 17 November 2011	Not conducted (site shifted)	Not conducted (artesian)	28 October, 2011- 30 October, 2011
Drilling method	DTH with foam/air and Mud rotary	DTH with foam/air	Mud rotary and DTH with foam/air	DTH
Drilled depth (actual/planned)	247m /250m	83 m / 250m	250 m / 250 m	400 m / 400 m
Site No	No-7	No-8	No-9N	No-10N
Drilling work	20 May, 2011 – 24 August, 2011	20 July, 2011 – 26 August, 2011	30 April 2011 – 22 May, 2011	1 February, 2011 – 21 February, 2011
Pumping test	13 - 17 August, 2011	27 - 29 August, 2011	4 – 7 June, 2011	4 – 7 March, 2011

Drilling method	Mud rotary	Mud rotary	Mud rotary	Mud rotary
Drilled depth (actual/planned)	200 m / 200 m	152 m / 150m	201 m / 200 m	202m / 200m

5.2.2 Proceedings of drilling and Lithology of boreholes

Cutting samples were taken from the borehole at one meter intervals during the drilling operation according to the technical specifications. It is generally difficult to accurately identify subsurface lithology by just observing the cuttings coming out of the borehole, because such samples are crushed fragments of original rock/sediment and do not usually preserve the structure or texture of the rock/sediment. Also, such samples inevitably contain some amount of cuttings that come from the upper section of the borehole (contamination). Nevertheless, effort was made to estimate the subsurface lithology through observation of the cuttings and also using other relevant information such as drilling rates and the results of the surface geological survey (see chapter 2 for details).

Detailed result of observation of the cutting samples from each depth of boreholes is given as Well Drilling Data in the Appendix along with other relevant information collected during the drilling work. Note that the geological description in these data sheets is primarily based on the observation of cutting samples. The observed lithology of the formations in each borehole was compared with that of the established stratigraphy and the results are summarized in Table 5.19. The following sections summarize the proceeding of the drilling work and the results of the sample observation at each drilling site.

a. Site No-1 (RVS BH No-1)

The site is located on top of a gentle rocky hill right beside the junction of three gravel roads. The drilling was conducted relatively smoothly up to the planned depth without major problems. Warm water was encountered at around 123m after hitting water around 66m. It is not surprising since there are some hot spring sites in the vicinity.

The lithology of this borehole is characterized by a thick pumice layer of up to 42 m from the ground level and also a thick formation of welded tuff and hard rhyolite underneath. The welded tuff is greenish grey in color and hard. Its upper section is especially hard. The rhyolite is reddish grey and peculiarly crystalline, containing many feldspar crystals. For detailed description of samples, see Well Drilling Data in the Annex.

The upper welded tuff in this borehole may correspond to “Hantate strongly green welded-tuff” and the welded tuff that’s overlying the rhyolite may correspond to “Wendo Genet Rhyolite” identified in the geological investigation in Awassa area in this study.

b. Site No-2 (RVS BH No-2)

The site is located on a vast flat farmland. The drilling was difficult and took a long time because of the collapsing sand layer under the water level. The first attempt failed because the drill bit got stuck in the borehole which was abandoned after the bit was fished out. The second trial by the mud rotary system faced problems of massive mud loss and thus the drilling was terminated at a depth of 172m.

The lithology of this borehole is characterized by a thick layer of pumice and pumice tuff. The color is pale grey and its 11 to 46m section contains only pumice and pumice fragments.

These pumice fall deposits are also highly permeable and collapsible and especially susceptible to borehole enlargement by air drilling operation. From 61 to 65m is a layer of loose and coarse gravel. The gravel is rounded and well sorted. This clearly indicates some of this succession of sediments was deposited under the influence of water current. From 74m to 89m is a greenish hard welded tuff layer. The rock is the same as the one that commonly occurs in the study area and is used for construction purposes. It is hard, but also seems to develop an extensive network of fractures because frequent mud loss occurred during the drilling of this layer. Below this is another deposit of pumice underlain by sand and gravel layer. Especially from 127m below, the section has large amount of loose sand that contains some allochtonous grains and gravels. The sand is moderately sorted without fines and some sand grains and gravel are sub-rounded to rounded. Abundant water also occurs within this section of sand and gravel. The sand seems to be a reworked deposit of pumice flow deposits that settled in a channel or lake shore like settings. For detailed description of samples, see Well Drilling Data in the Annex.

The thick pumice formation in the upper part of the borehole may correspond to “Mt. Aluto volcanics”, and the welded tuff below may correspond to “Kulmusa highly welded tuff”, and the bottom sand/gravel/ pumice formation to “Ketar river acidic volcano sedimentary rocks” that are all identified in the strategraphy of Ziway area in this study.

c. Site No-3 (RVS BH No-3)

The site is located in the middle of a vast flat farmland with a network of vehicle path with hedges on both sides. The drilling was conducted by the DTH throughout the borehole. The crew experienced heavy collapse in the first 40m section and had to install temporary work casing and even had to cement some section of it to prevent collapse. The borehole was completed up to the planned depth of 250m and casing installed up to 247m with considerable effort.

The lithology of this borehole is characterized by a thick succession of pumice and tuff, and slightly welded tuff layers in the upper 100m section. The pumice tuff formation contains a lot of fine tuff material and the ratio of pumice fragments is only up to 20% in the sample. This unconsolidated formation is highly susceptible to air blow by the compressor. There is a thin layer of dark brown paleo soil (decayed tuff) around 70m. The lower section of the borehole produced sand and gravel size cuttings that probably came from unconsolidated to semi-consolidated tuff breccia with yellowish matrix. This formation typically contains fragments of welded tuff, rhyolite, and basaltic volcanic rocks along with some pumice. For a detailed description of samples, see Well Drilling Data in the Data book.

At this site, the formation appearing on the borehole log clearly displays the established stratigraphy in Awassa area. The top pumice layer seems to correspond to “Corbetti volcanics”, the welded tuff from 98 to 133m may correspond to “Hantate strongly green welded tuff”, and the lower tuff breccia probably to “Abaye ridge basaltic pyroclastics”.

d. Site No-4 (RVS BH-4)

The site was located on the edge of the bottom of a wide valley that becomes swampy during rainy season. The drilling was started by air rotary first and by DTH after around 20 m. Since the terrain is in a waterlogged area, the first 30 m was drilled in a wet clay layer. The water table was hit at relatively shallow depth of around 10m. A thin weathered basalt layer was struck right below the thick clay layer and it was followed by a 50m thick welded tuff formation. Then this was followed by succession of volcanic sand and basaltic breccia. The drilling was relatively smooth up to around 130 m below ground where a crystalline basalt lava was stuck. The drilling rate dropped and frequent jamming occurred in this lava formation due partly to high water pressure in the borehole. After reaching 162 m, the drilling equipment had frequent mechanical trouble. The drilling bit got caught in the borehole and an attempt to fish out the bit failed. Then, the drilling work was started again at a point 20 m away from the previous point in early May. Drilling was conducted smoothly afterwards up to 157m. The drilling method was switched to mud rotary in consideration of the compressor problem and of the high static water pressure (SWL 8 GL -m). A series of mechanical problem with the equipment and shortage of bentonite significantly delayed the work at this site. Finally the drilling was finished in early November 2011 by mud rotary.

Lithologically, the top 30 m of the borehole is silty clay. Especially the first 10 m is black sticky clay without a trace of original materials. This is underlain by a 3 m thick weathered basalt layer. Below it is an 11 m thick yellowish brown clay layer that is underlain by a 50 m thick welded tuff formation. The welded tuff is greenish overall and moderately hard and fine grained. It contains some volcanic rock fragments at some parts. Underneath the welded tuff, from 106 m, are layers of volcanic sand and tuff breccia made probably of coarse basaltic rocks and small amount of yellowish acidic tuff fragments with small amount of fines as matrix. Finally after 129 m is a thick formation of dark grey solid basalt lava. It is a crystalline basalt and relatively fresh and drilling rate was significantly low after this section. Below 174m, the formation became acidic. The samples from this section are in coarse to fine sand form and made up of pieces of welded tuff, tuff and quartz and feldspar crystals.

e. Site No-5 (RVS BH-5)

The site was located on a flat farmland. The drilling work was smooth for the first 65m in the pumice tuff formation but encountered a problem of jamming of drilling bit within the underlying basalt layer. There was a few meters of blocky/breccia section of borehole within the basalt layer from which large fragments of up to 10 cm came out during the drilling by DTH. The drill bit was frequently caught within this section. As a counter measure, the crew attempted to install unconventionally long surface casing to cover up the problematic section in the basalt layer. Although the crew managed to penetrate this basalt layer and hit the volcanic sand layer below it, the drilling work was temporarily suspended due to unsuccessful installation of the surface casing to the targeted depth of 76 m.

The lithology of this borehole is characterized by existence of 17 m thick basalt layer underneath the top 65 m of pumice tuff formation. The basalt is fresh and develops pores. The top halt of the layer is made of basalt blocks up to probably 15 cm in diameter. Especially the section from 71 to 73 m is highly collapsible due to loosely accumulated larger blocks of basalt. For detailed description of samples, see Well Drilling Data in the Appendix.

f. Site No-5N (RVS BH-5N)

After some interval, drilling work was resumed at another site (Site No-5N) on the other side of the river Bilate, some 300 m off the gravel road on the river bank. The drilling was started by mud rotary system and a basalt layer was encountered, same one as that was observed at Site No-5, around 18 m. The drilling was a little slow but smooth without any problem until the crew changed the drilling method to DTH around 42m. The jamming problem occurred after 42m and effort was made to install a surface casing pipe up to 20 m to cover the problematic section. The installation however eventually failed and the crew was forced to shift the drilling point 20 m away from the first point. The drilling continued by DTH up to 96 m. Water was struck at around 26 to 31 m and after that another large amount of water was observed at around 54 to 58 m. Since the formation changed to quartz-rich sand, for fear of bit jamming, the drilling was shifted to mud rotary system again after 96m. After the mud rotary drilling was started, the remaining depth was drilled within only a few days in rhyolitic volcaniclastic formation and the borehole was completed on 31 July 2011.

The well suddenly started to overflow during the well development by air lifting. The water was hot with a temperature about 54°C, without any sign of high concentration of dissolved components when sniffed and tasted. The flow rate of overflowing water measured in the draining channel indicated that it was nearly 100L/sec. Because of the flowing artesian condition and the heat of the water, pumping test could not be conducted in this well. In order to protect the well against tampering, a metal fence was constructed around the well.

Lithologically, the formations drilled up to 42 m are weathered to fresh basalt and some basaltic breccia around 13 to 24 m. These basaltic layers are considered to correspond to the basalt that was observed at No-5 point after 65m below ground. Massive fresh basalt alternates with reddish basaltic breccia up to 90m. The formation changes to acidic members such as rhyolitic tuff and welded tuff of white to pale green color below 90m up to around 160m. These acidic volcanic sediments are moderately to highly weathered. The remaining section is the dark gray to green tuff and welded tuff nearly up to the bottom. This section is highly weathered and the samples are in clay form in most cases and the drilling rate is very low.

g. Site No-6 (RVS BH-6)

The site is located in a farm land with slightly wavy topography. Since there had been a political boundary dispute at the site, the drilling point was chosen in a land that was less likely to be affected by this issue later. The drilling work started by DTH on 30 August, 2011 by a new contractor who has a large capacity drilling machine. It made a remarkable progress and completed drilling up to 400m within a week.

In spite of the smooth drilling of borehole, the installation of casing and screen pipes took some effort because of collapse of well wall around the bottom 40m section. The installation of casing pipes, thus, took additional two weeks. One reason for this collapse is the existence of three-day blank period due to the national new-year holiday.

Lithologically, the entire section of the borehole is acidic volcaniclastic formations. The first 5 m is the top soil of brownish clay and this is underlain by loose and yellowish pumice tuff layer up to 25m. From 25m to 50 m is a succession of tuff, welded tuff, with thin layers of reworked volcanic sediments. From 50m to 87m is weathered acidic tuff containing fragments of acidic volcanic rocks with flattened obsidian. This is underlain by a thick formation of acidic volcaniclastic sediments and some reworked materials. The samples are in fine to coarse sand size and contain rock fragments of up to 1 cm in diameter and little amount of fine materials. There is a layer of crystal-rich sand around 170m. Below 223m is the formation of greenish welded tuff that is moderately weathered and fractured. The 250m to 269m section is slightly yellowish crystalline sand and welded tuff layers where drilling rate is relatively low. Below 301m is the succession of coarse grained volcanic sand and gravel containing large amount of pumice. More than half of the grains are rounded to sub-rounded, indicating the possibility of secondary deposition of the acidic volcaniclastic materials. The maximum size of the gravel is 4 cm in diameter. Below 348 m is another succession of volcanic sand and gravel. The section below 366m is characteristically dark colored fine to medium sand grains of volcanic origin. The water was encountered at around 275 m first and a larger amount of water was struck at around 310 m where the reworked materials are exposed in the borehole.

h. Site No-7 (RVS BH-7)

The site is located in a large scale commercial farm land across the road from Arba Minch University. Drilling work started by mud rotary method. Although the top 30 m was mostly made of alluvial sediment layers, the drilling rates were relatively low. Two drill collars were used to increase drilling efficiency and drilling rods were also changed to heavier ones afterwards. The drilling work was relatively smooth other than several events of collapsing of borehole wall within the upper 30 m section during the down time (a few days to one week). Samples were lost from 173m to 180m in spite of the maintained mud circulation. Drilling was completed in about 50 days after the rig was set up at the site. Since the drilling was performed with relatively thin drilling mud all the way to the bottom, and also the static water level is high (approximately 8 m), no clear indication of water bearing zone was detected.

Lithologically, the top 40 m of the borehole is alluvial deposits of Quaternary period. It is made of sand and silt with some gravel layers and typically contain rounded pebbles and sand grains. At 33 m a thin weathered basalt layer was encountered and the following formations become acidic volcanic tuff breccia. Below 61 m is yellowish clay and it is followed by fine brown tuff deposits. Below, 85m, this is underlain by series of layers of medium sand to fine gravel (max. 2cm). Majority of the grains, especially those of black basalt, are well rounded and relatively well sorted, indicating that the layer was deposited under the influence of water current. The section of lost samples (173 to 180m) could be clay layer in consideration of the fact the circulation was maintained during the drilling.

i. Site No-8 (RVS BH-8)

The site is located on the edge of small farming area on a right bank of an ephemeral river. The drilling work started by the mud rotary system on 23 July, 2011 and ended on 13 August 2011. The drilling work progressed steadily without interruption except for the drilling of a thin layer of hard basalt around 36 m that took a whole day and for the problem with the water tank.

Lithologicaly, the top portion of the borehole up to 36 m is sand and silt layers of recent alluvial origin. These are yellowish grey in color. This is underlain by a thin layer of grey basalt of eight meters in thickness. Below this basalt layer is a thick sedimentary sequence of clay, silt, sand and gravel layers of grayish in color. There are several layers of dark grey to brawn basalt of 5 to 15m in thickness. The sand and gravel grains of the sedimentary sequence are of volcanic rocks, some are exclusively basaltic. The grains are mostly well rounded and indicate that there was an effect of flowing water in their deposition. The last six meter section is the basaltic sand made of sub-angular gravel sized basalt grains.

j. Site No-9N (RVS BH-9N)

The site is located on the fringe of a vast flat farmland at near the junction of a gravel road and the main paved road. The drilling work was started by mud rotary system through pumice and tuff layers. The drilling encountered a circulation loss at around 23 m. Then a 10 inch surface casing was installed up to 28m to seal the leaky section. The work continued without major trouble after that and the drilling of borehole was finished in 3 weeks. A total of 18 m screen was installed (87m to 105m) to capture the upper aquifer after the borehole logging.

Lithologically the top 65m is the alternation of yellowish white highly weathered pumice and slightly welded tuff with a layer of tuff breccia at the bottom. This is underlain by about 20 m thick hard welded tuff. The top 15 m of this formation is very hard and water was first struck around the bottom of this formation at 89 m. The underlying formation is a 25 m thick tuff and volcanic sand in which the drilling rate was much higher. Below this was a thick deposition of greenish grey clay, probably decayed fine tuff, that continues up to the bottom.

k. Site No-10N (RVS BH-10N)

The site was located on a farmland gently sloping toward the east. The drilling work was started by mud rotary since thick unconsolidated pyroclastic sediments had been expected in the area. The drill crew saw a sign of small amount of water in the borehole at around 17m, and afterwards, they recognized water much larger water from 66 to 86 m and also from around 92 to 120 m. A 21 m surface casing was installed for fear of collapsing of top part of the borehole. The drilling was very fast throughout the borehole except for the section of fresh welded tuff from 122m – 128m that took four hours to drill through. The drilling encountered a heavy mud loss problem after 140m. In spite of repeated attempt to seal the leaking section, the circulation was not regained. The drilling was, thus, continued without mud circulation and completed at 202 m.

Lithologically, the top 36 m section of the borehole is fresh to weathered pumice tuff. This is underlain by a think layer of volcanic sand (pumice sand with rock pieces). After 38 m lies a layer of slightly weathered fine-grained acidic tuff. Degree of welding of the tuff layer is very weak judging from the sample and the drilling rates. Below this tuff layer, from 61 m is a succession of welded tuff and volcanic sand/gravel that form the main aquifer at the site. The tuff is greenish and slightly to strongly welded but in most part, weathered and fractured to show very large drilling rates (defined as “drilled length/time”). The samples were lost after 141m due to excessive circulation loss. However, judging from the situation, the lithology of that section is assumed to be un-welded pumice tuff or pumicious lacustrine formations that have probably developed small caverns within. The geological log of this borehole is given in the Data Book .

5.2.3 Results of geophysical logging

Geophysical logging was conducted right after the borehole drilling was completed and before installation of casing and screen pipes. The logging was conducted in drill mud or natural groundwater that stood in the borehole but in the case of drill mud, the mud was diluted as much as possible before the logging was conducted. The specification of the logging is summarized in the table below. The results of the logging are shown in graphs along with corresponding geological logs in Figure 5.50 to Figure 5.59. The data sheets are attached in the Data Book.

Table 5.5: Specifications of Borehole Logging

Items	Interval
Spontaneous potential (SP)	1m
Electrical resistivity short (Short Normal)	1m
Electrical resistivity long (long Normal)	1m

The following is the brief description of the logging results at each site. The borehole logging data is given in the Data Book and also graphed in Figure 5.50 to Figure 5.59.

a. Site No-1 (RVS BH No-1)

The logging was conducted for a 100m section of the borehole starting from 48m below ground. The first 20m section of borehole is welded tuff and the middle part of this section exhibits high resistivity values (800 Ω-m) in both short and long. This probably shows the portion is fresh and without cracks. The remaining section below the welded tuff shows relatively stable resistivity profiles up to 125m and rises after that where there is hard rhyolite. However, even the rhyolite section has narrow band of lower resistivity around 145m, probably indicating a fissure zone.

b. Site No-2 (RVS BH No-2)

The logging was conducted for a 56m section of the borehole starting from 90m below ground level. The first 10m sections is a well consolidated welded tuff layer and the corresponding resistivity (short and long) values are as high as nearly 1000 Ω-m. The values suddenly drop to around 100Ω-m and stabilize after 100m where unconsolidated permeable sediments occur. The result indicates that the borehole section below 100m is the aquifer.

c. Site No-3 (RVS BH No-3)

The logging was conducted for a 58m section of the borehole starting from 172m below ground level. Lithology of this borehole section is semi-consolidated tuff breccia made of a number of blocks of volcanic rocks in tuff matrix and uniform in general. Only the proportion of blocks of different type and level of consolidation seems to change slightly throughout the section. The first 20m section shows relatively low resistivity values (short and long) of around 300 Ω-m, indicating that this is a good aquifer. However, after 194m the curve sharply rises to around 500 Ω-m and keeps rising to the bottom. This change, however, can not be reasonably correlated to any changes in lithology. It is suspected that the sensor may not have entered the borehole after 194m due to back filling. Actually, the drill team found that the borehole had been filled up to this level at the time of casing installation.

d. Site No-4

The logging was conducted for a 185 m section of the borehole starting from 45 m below ground level that corresponds to the end of the surface casing. The high resistivity section of the welded tuff layer and basaltic breccia was clearly detected by the long normal logging that showed 200 - 400 Ω-m of resistivity. There is a sudden drop in resistivity at around 95 m at the bottom of the welded tuff layer. This drop probably corresponds to a fractured and weathered zone of the welded tuff and also coincides with the depth zone where a large amount of water was detected during the drilling operation. The SP reading shows no fluctuation throughout this section up to 120m. The borehole section from 120 m to 160 m has much lower resistivity values of up to 100 Ω-m. The SP values of this section are also lower than the first 70 m section shows some fluctuation. The 140 to 150 m section within the basalt lava shows relatively high resistivity and low SP values. Both resistivity and SP flatten out below 170 m at the lowest values throughout the volcanic sand section. However the values are considered unusually low for this kind of lithology. Thus it may be a result of logging error due to backfilling in the borehole.

e. Site No-5N

The logging was conducted for a 230m section of the borehole starting from 23m below ground. The resistivity logs of both short and normal show very high values of 150 to 400 Ω-m for the top 70 m section, up to around 90 m. This anomaly obviously reflects the existence of the impermeable basalt layer. Within this section, however, there are several clear drops in resistivity values. These drops seem to correspond to fractured and weathered zones within the entire basalt layer. The SP logging shows small but clear shifts in its values around 60 to 110 m but the reason is not clear. Otherwise it is stable throughout the borehole. The section below 90 m up to 170 m shows intermediate resistivity values of up to 100 Ω-m within the welded tuff and tuff section of the borehole. The resistivity values are probably much smaller because of the existence of fine decayed tuff matrix of these formation.

f. Site No-6

Since the static water level was as low as 247 m below the ground level, the logging was conducted over a 150 m section of the bottom of the borehole. The resistivity log show relatively high values of around 600 Ω-m (Long normal) throughout the borehole except for the section between 270 m to 310 m where the values are as high as 1500 Ω-m. In consideration of high contrast between short and long normal resistivity values, this high resistivity zone, especially 280 m to 290 m zone, is considered to correspond to massive impermeable zone within the welded tuff formation.

g. Site No-7

The logging was conducted nearly from the top (5m GL -) to the bottom of the borehole due to the high static water level. The logging results are influenced by the drill fluid in the borehole. Top 50 m section of the borehole shows relatively high resistivity values of 100 to 200 Ω-m (Long normal). The majority of the remaining section shows the resistivity values of around 100 Ω-m. The bottom 15 m of the borehole shows higher resistivity values of up to 400Ω-m within the coarse sand layer. The SP values gradually decrease from 370 mV to 330 mV towards the bottom. It seems that the SP values are higher for the upper 50 m section where the resistivity values are also high and lower for the bottom 15 m section where the resistivity values are also high.

h. Site No-8

The logging was conducted for nearly the whole section of the borehole because the static water level at the time was logging was much higher at around seven meters. Though the logging results are influenced somehow by the drilling fluid, the data shows distinctive pattern with depth. The range of values are also larger compared with the logging data in other boreholes. The resistivity values (long normal) of top 70 m section is stable at around 100 Ω-m. The last 20 m section displays remarkable drops in the values, especially in short normal. These drops may correspond to clay layers within the section, although the abnormally low values of the short normal logging may carry some noises. The following 30 m section has a little higher resistivity values (long normal) of around 120 Ω-m. The basalt layer could not be detected by this logging data because the layer is fractured and weathered. The bottom 40 m section below 110 m carry the long normal resistivity values of as high as 3000Ω-m while the short normal values even smaller than the values for the section above. In other words, the contract between short and long resistivity values are high in this section. This may indicate that this entire section is impermeable solid rock formation although the geological logging result suggests existence of clay within this section.

i. Site No-9N

The logging of the borehole was conducted on the following day after the completion of borehole. The results shown in a graph indicates a strong effect of drilling mud: similar fluctuation pattern between long and short resistivity values and relatively stable SP curve throughout the borehole except for the section of 60 to 80 m. The section from 65m to 88m, corresponding to the welded tuff in geological log, shows very high resistivity values of up to 4000 Ω-m, which indicates that the formation is solid and nearly impermeable. The both upper and lower 10 to 20 m sections of the massive welded tuff have resistiviy (short) of around 100Ω-m and considered to be potential aquifer, in consideration of lithology and drillers observation, screen was planned to cover 87 to 105m section to capture the confined aquifer below the welded tuff. The resistivity curves show characteristic fluctuation after 120m within the clay layer. However the clay layer is considered uniform from cutting observations. Thus the cause of the fluctuation is unknown.

j. Site No-10N

The logging of the borehole was conducted two days after the completion of borehole. After the first attempt to lower the sensor in the borehole filled with mud failed, the borehole was reamed to the bottom with diluted mud and the logging was conducted. The results shown in a graph indicates a strong effect of drilling mud. This can be seen from the very coherent patters of long and short normal curves and from relatively stable SP curve. Nevertheless, the resistivity logging somehow detected the water-bearing zone from 60 to 80m and 130 to 140m, and also the impermeable zone of massive welded tuff from 122 to 128m.

5.2.4 Hydrogeological aspects

Though it was difficult to fully assess the hydrogeological characteristics of the borehole lithology under the water level, the following circumstantial evidences suggest that the water bearing layers at all the drilling sites are all confined or semi-confined aquifers.

- The static water levels measured after the completion of the wells are significantly higher at every borehole than the depth where water was encountered during the drilling.
- When the drilling was done by DTH method that employs foam or air as drilling fluid, recognition of water flow from inside the borehole can be made with a reasonable accuracy as compared to the case of drilling by mud rotary.
- There are usually some layers that can physically serve as confining layers right above the zone where groundwater flow was recognized.
- The results of pumping test analysis that is explained in detail in the following section

also indicate that the value of "S" (storage coefficient) is very small and that puts these aquifers under "Confined aquifer"

The characteristics of the wells and aquifers clarified through all the investigation in this study are summarized in Table 5.20. The following discusses the Hydrogeological aspects of each borehole with reference to observations during drilling operations, logging results and borehole lithology etc.

a. Site No-1

There are possible confining layers right above the depth at which the major water was struck at the time of drilling. (see Well Drilling Data in the Annex). In the case of RVS BH No-1, the welded tuff formation (49 – 67m) can be the confining layer since both resistivity and drill rate for the 5 m zone around the bottom of the formation indicates the rock is solid. The water was encountered around 66 m immediately below this depth. The rhyolite section below 130 m seems to be another impermeable zone judging from the drill rates and the high resistivity values. Thus, the major aquifer is considered the 60 m to 126 m section of weathered and fractured zones of the volcaniclastic formations .

b. Site No-2

For RVS BH No-2, the bottom zone of the welded tuff layer (89 - 100m) that shows very high resistivity values and relatively slow drilling rate can be the confining layer. The water was struck immediately below this zone within the volcanic sand formation that shows sign of reworking and deposition. The borehole section below this depth is considered to be water bearing in terms of the lithology (reworked pumice sand and gravel).

c. Site No-3

As for RVS BH No-3, the water was first struck at around 203 m within the tuff breccia section, but the confining layer was not clearly distinguished within the formation. The static water level is also very low in this area but still higher than 203m in the borehole. The S value obtained from the pumping test was relatively larger than those from other sites. In consideration of these, the aquifer in this well is considered semi-confined.

d. Site No-4

Small amount of water was detected during drilling at around 20 m and 42 m within the top clay and silt layers. In consideration also of the low topography of the site that collects surface water drainage, it is clear that the site has a shallow water table (unconfined aquifer). Major water flow was struck around 96 m around the bottom of the thick welded tuff formation. There are layers of volcanic sand and breccia right below this welded tuff that may be relatively more permeable by nature Thus these layers may form a confined aquifer with the welded tuff layer acting as the confining layer.

e. Site No-5N

At this site, the water was first encountered at around 64 m GL- at the top of basalt layer. The static water level in the borehole measured a few days later indicated a shallower level of 54.8 m. This indicates that the aquifer is confined. There are at least several aquifers in the basalt formation and the major aquifer is in the blocky part of the basalt layer (71 – 73 m) also produced a large amount of water (10L/sec, driller's estimate) during the drilling.

Pumping test was not conducted due to the hot water overflow that occurred during well development. Thus, the above interpretation could not be verified from the pumping test data.

f. Site No-6

During the drilling, water was encountered first at around 274 m and also around 310 m. These depths mark the top and bottom limits of this high resistivity zone. The SP values are a little higher, as compared with the other sections, over the 300 m to 340 m section where the formation contains a lot of pumice fragments. This probably reflects the composition of the formations. The aquifers are the two zones above and below the impermeable welded tuff (223m – 300m) and the lower one is confined. The upper one, also is considered to be within the fractured zone of the welded tuff and confined, in consideration of the lithology and drilling rates of the section above it.

g. Site No-7

The static water level is very shallow at this site and no major zones of water flow was recognized during the drilling. In consideration of the fact the site is situated in a low land between the flood plain of two mid-size rivers, and of the static water level of only 7.8 m and also in consideration of the existence of thick alluvial sand and gravel layers, there should be at least a shallow aquifer at the site. From the logging and drilling record, the 10 m thick basalt layer at around 40 m may be one of the few possible confining layers along with other minor impermeable zones (such as clay layers). Most of the sections are considered to be aquifers from the view point of the lithology. The screen was, however, installed over the sand and gravel section where the amount of fines was considered less.

h. Site No-8

The water flow was detected at around 25 m and 50 m during the drilling operation at this site. The static water level at the time of the pumping test was 15 m below ground. The first water flow was struck just below the bottom of the silty clay layer within the coarse sand formation and this aquifer is considered confined by this clay layer. The second water was encountered within the sand and silty clay formation immediately below a thin clay layer. The water bearing formation is the medium to coarse sand layer of the reworked volcanic deposits. Since the borehole section below this is frequent alternation of sand and gravel, clay and basalt layers, there considered to be many thin aquifers in this section.

i. Site No-9N

At this site, slight sign of water was first detected around 40 to 50 m during the drilling. However the major water bearing layer was encountered after drilling the impermeable massive welded tuff layer that exhibited very high resistivity values (long normal) of up to 4000 Ω-m and of 300 to 800 Ω-m (short normal) throughout the section. No clear sign of fracture zones were detected from the log data. Therefore this underlying layer was considered the confined aquifer and the welded tuff formation was considered as the confining layer. The tuff and volcanic sand and breccia layers that are considered to form the main aquifer on the other hand have resistivity (Short normal) values of around 100Ω-m that are higher than those recorded for the bottom clay formation and lower than the massive welded tuff formation.

j. Site No-10N

Two aquifer zones were identified based on the logging data. The zones were found within the sand and gravel layer (upper) and the fractured and weathered welded tuff layer (lower) having resistivity values of around 50 to 1000 Ω-m. The sand and gravel that is considered the main aquifer show relatively higher values of resistivity and lower values of SP. There was no clear indication of possible confining layer either from resistivity or lithological information although the overlaying fine acidic tuff formation may be the one. The pumping test conducted afterwards indicates that the aquifer is highly confined.

5.2.5 Correlation of results between drilling and geophysical survey

As mentioned briefly in the previous sections, a geophysical survey (VES and HES or TEM) was conducted at all the 10 planned drilling sites (except for No-5N). The detail of the survey is described in Chapter 4 in this report. The survey generated resistivity profile maps of several cross sections at each site and they were used for selecting drilling points. The data was also reviewed after the drilling results came out to try to correlate the results of the survey to the observed geology and groundwater condition. At each site, the survey revealed the depth of the water bearing layer relatively well. Details are explained in the following section.

a. Site No-1

The following figure illustrates the resistivity profile of a survey line that intersects RVS BH -1. The profile shows a very low resistivity layer of 10 to 17 Ω-m for the first 10 to 15m. This zone probably corresponds to the fine weathered tuff layer in the geological log (see Annex). From 10 to 60m is a high resistivity layer of more than 800Ω-m around BH No-1. This zone corresponds to the pumice-rich tuff, sand and welded tuff where there is no pore water in the sediment. In the borehole, below this section is a productive aquifer of sand and gravel and fractured welded tuff. This water bearing layer is clearly detected in the resistivity profile as the deepest layer of the resistivity value of 11 to 17Ω-m.

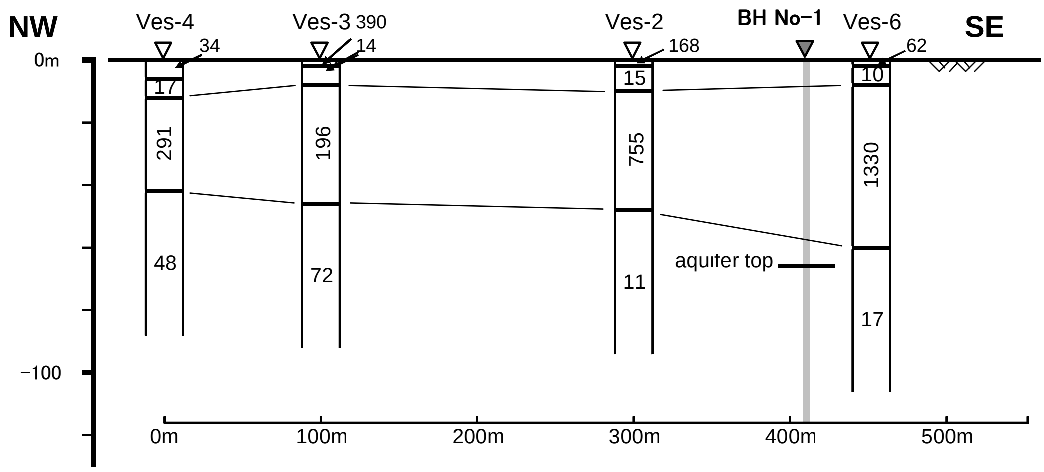


Figure 5.1: Resistivity Profile at Site No-1

b. Site No-2

The following figure illustrates the resistivity profile of a survey line that intersects RVS BH No-2. The profile shows a very low resistivity layer of 30 to 50 Ω-m for the first 5 to 10m.

This zone probably corresponds to the highly weathered tuff and pumice layer in the geological log (see the Annex).

Below this is a thick layer (70 to 130m thick) of very high resistiviy. The resistivity value reaches over 4000Ω-m at point VES-6. This remarkably high resistivity values can be explained by the fact that there is a thick porous pumice layer that is underlain by hard welded tuff. Both layers contain no water. Water bearing layer starts at around 100m where the welded tuff layer ends (aquifer top). The resistivity values of the aquifer ranges 40 to 200Ω-m (about 100Ω-m near BH No-2). This is a reasonable range of value for water bearing pumice and coarse with gravel in the geological log.

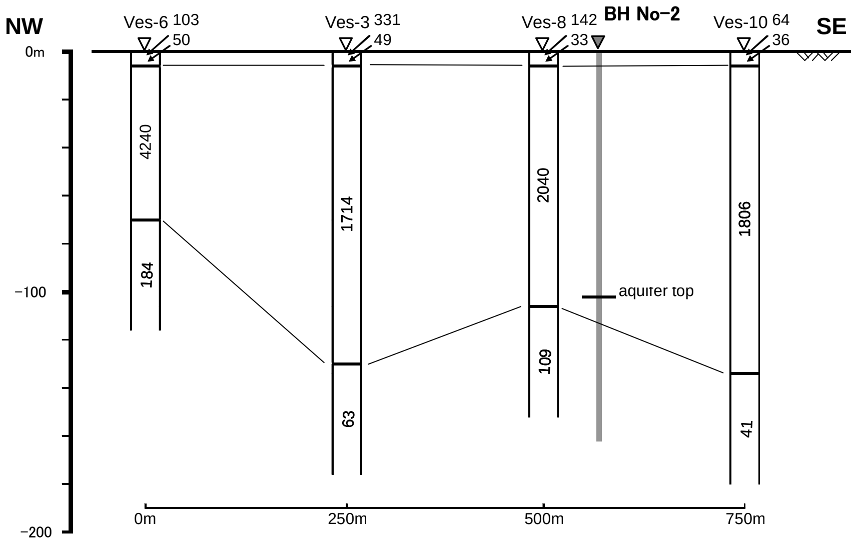


Figure 5.2: Resistivity Profile at Site No-2

c. Site No-3

Figure 5.3 illustrates the resistivity profile of a survey line that intersects survey point VES-8 at site No-3. The well (RVS BH No-3) was drilled about 500m to the south west of VES-8 due to access issues. Thus the profile may not be directly compared with the borehole log of RVS BH No-3. The profile shows a relatively low resistivity layer of 90 to 140 Ω-m for the first 10 to 20m around VES-8. This zone probably corresponds to the weathered tuff layer in the geological log (see the Annex). The underlying middle-high resistivity layer of 100 to 140m thickness seems to correspond to section of alternating tuff, pumice and welded tuff that do not bear water.

In the resistivity profile, the bottom most low resistivity layer occurs at around 150m. This depth coincides with the top of thick tuff breccia formation. This formation is moderately consolidated but it has a block in matrix structure and can hold some water in its loose matrix portion. Though a small of amount water was reported to have been struck around 200m at the time of drilling, but the formation may be saturated up to the bottom of welded tuff layer (143m). If that is the case, the bottom low resistivity layer in the profile may represent the water bearing zone.

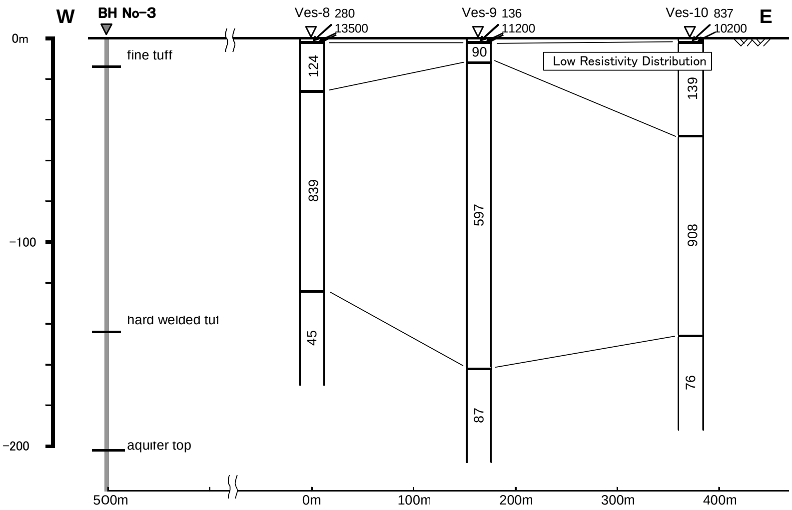


Figure 5.3: Resistivity Profile at Site No-3

d. Site No-4

The following figure illustrates the resistivity profile of a survey line that intersects survey point VES-4-3 at site No-4. The well (RVS BH -4) was drilled about 60m to the north east of VES-4-3 on the survey line. The profile shows a low resistivity layer of around 10 Ω-m for the first 20 to 30m around the well. This zone probably corresponds to the weathered pumice tuff layer that contains water in the geological log (see the Annex). The underlying thick zone of intermediate resistivity of around 50Ω-m seems to correspond to section of welded tuff and basalt layers that exhibit high resistivity values in the borehole logging as well. The aquifer zone could not be clearly indicated in this profile probably due to high static water level (about 8m).

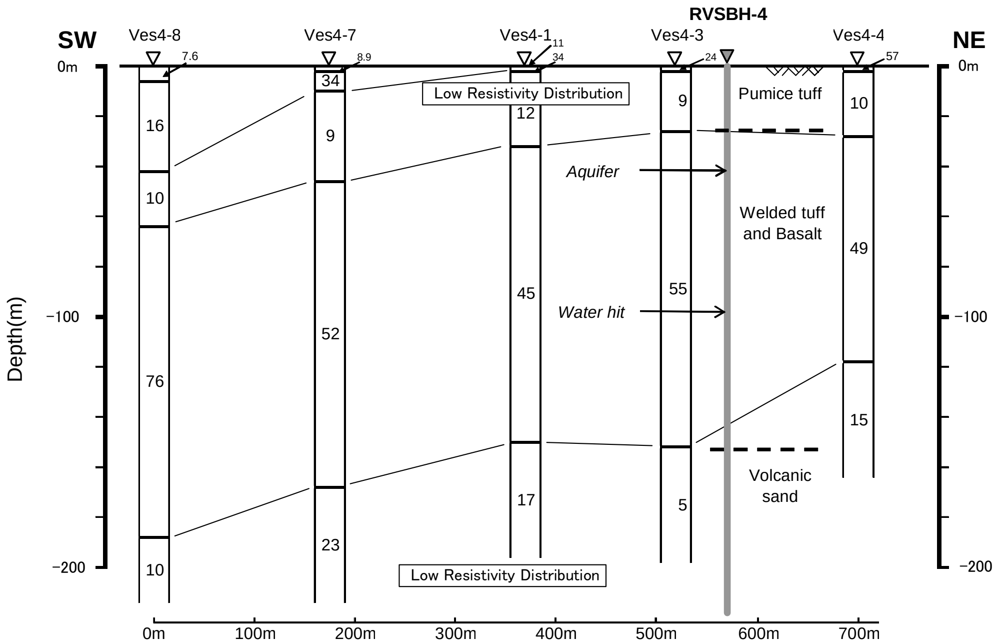


Figure 5.4: Resistivity Profile at Site No-4

The bottom low resistivity layer on the other hand, seems to correspond to the volcanic sand formation in the geological log. At this site, the formations were all water bearing due to abundant shallow groundwater. Thus, resistivity profile did not reflect the water bearing zone but rather the difference in the geological materials.

e. Site No-5

The following figure illustrates the resistivity profile of a survey line that intersects RVS BH-5. The profile shows a layer of low resistivity of 20 to 50 Ω-m starts at various depths of 65 to 170 m at the bottom of the profile. This low resistivity zone probably corresponds to the water bearing layer. At the drilling point of RVS BH-5, the resistivity profiling almost accurately predicted the beginning of water bearing layer (aquifer top) that corresponds to the blocky basalt layer in the geological log (see Annex).. The occurrence of highly variable top surface of the low resistivity layer in the interpreted profile might indicate that the terrain is shredded into small hydrogeologically independent sections due to excessive faulting.

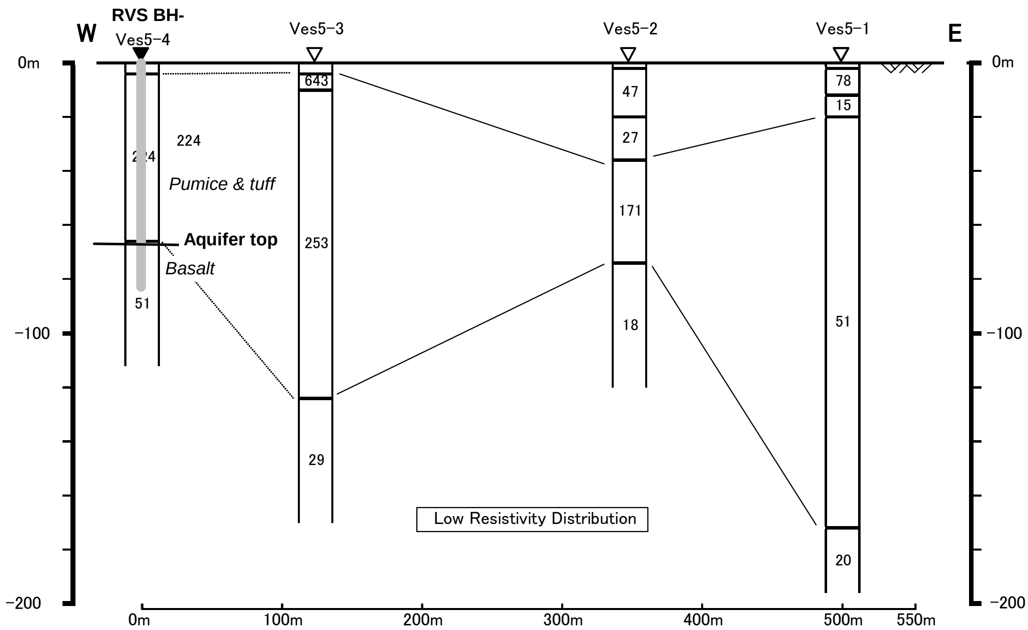


Figure 5.5: Resistivity Profile at Site No-5

g. Site No-6

The following figure illustrates the resistivity profile of a survey line that intersects survey point VES-6-7 and VES 6-4 at site No-6. The well (RVS BH No-6) was drilled between the two points a bout 30 m off the survey line. The profile shows two low layers of intermediate resistivity around 300 Ω-m down to 180 m to 220 m. This zone probably corresponds to the dry formations. The low resistivity layer is found below these depths. However, the water was struck around 274 m during the drilling as indicated as aquifer top. This profiling could not detect the water bearing zone. The assumed resistivity layers rather coincides with different lithological sections in the geological log of the borehole. The depth of the water bearing zone was probably too deep to be detected by the resistivity survey.

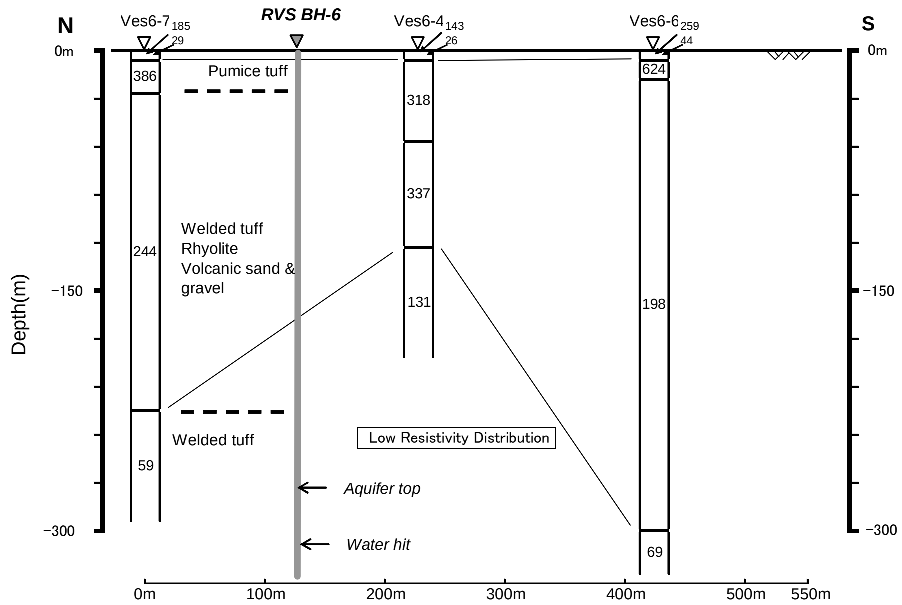


Figure 5.6: Resistivity Profile at Site No-6

h. Site No-7

The following figure illustrates the resistivity profile of a survey line that intersects survey point VES 7-2 at site No-7. The well (RVS BH-7) was drilled about 20 m to the north of VES 7-2 on the survey line. The profile shows a low resistivity layer of 5 to 10 Ω-m from around 30 m below around the well. There is a layer of relatively higher resistivity at the surface and its thickness varies. However, the resistivity values do not show significant change with depth. Also, the static water level at this site is very shallow and no distinct water flow was detected during the drilling operation. The borehole resistivity log data also shows a flat profile but the top 45 m section has slightly higher values of resistivity. This zone seems to be captured in this profiling as indicated in the figure. Geologically the borehole is a succession of volcaniclastic materials including reworked sand and gravel layers and most of the layers are considered water bearing. Thus, no clear correlation was found between the resistivity and geology either.

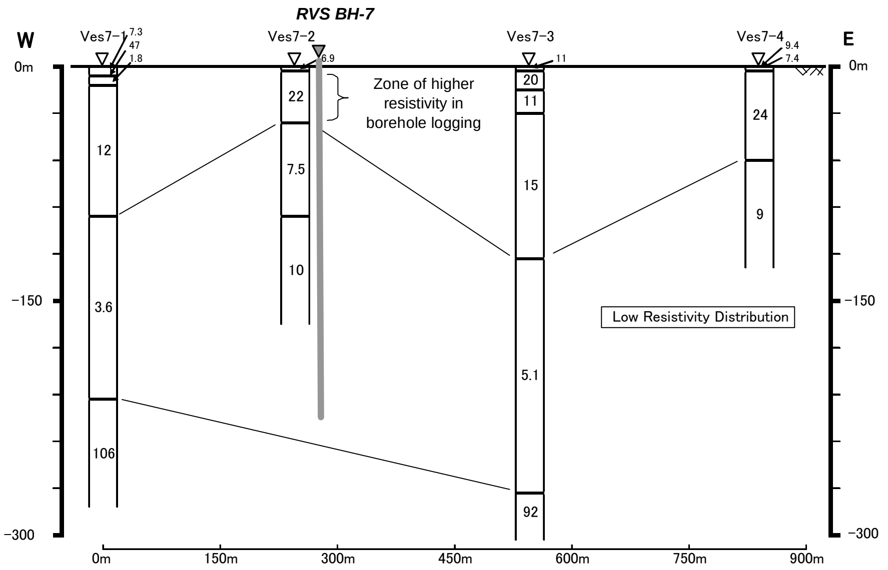


Figure 5.7: Resistivity Profile at Site No-7

i. Site No-8

The following figure illustrates the resistivity profile of a survey line that intersects survey point VES 8-5 at site No-8. The well (RVS BH-8) was drilled about 50m to the east of VES 8-5 on the extended survey line. The profile shows a 10 m thick low resistivity layer of 34 Ω-m at the surface. Below this are two layers of extremely low resistivity of 1 to 6 Ω-m up to around 110 m. These layers are underlain by a higher resistivity layer of 83 Ω-m. The zones of striking water during the drilling operation that are considered the top of aquifers do not correspond to the boundaries of the resistivity layers. The dry zone at the top of the borehole that may be detected as higher resistivity zone was interpreted much thinner in the resistivity profile. The sudden change in the resistivity value at around 110 m may, however, correspond to the top of the basalt lava in the geological log. This zone also showed relatively higher resistivity values in the borehole logging.

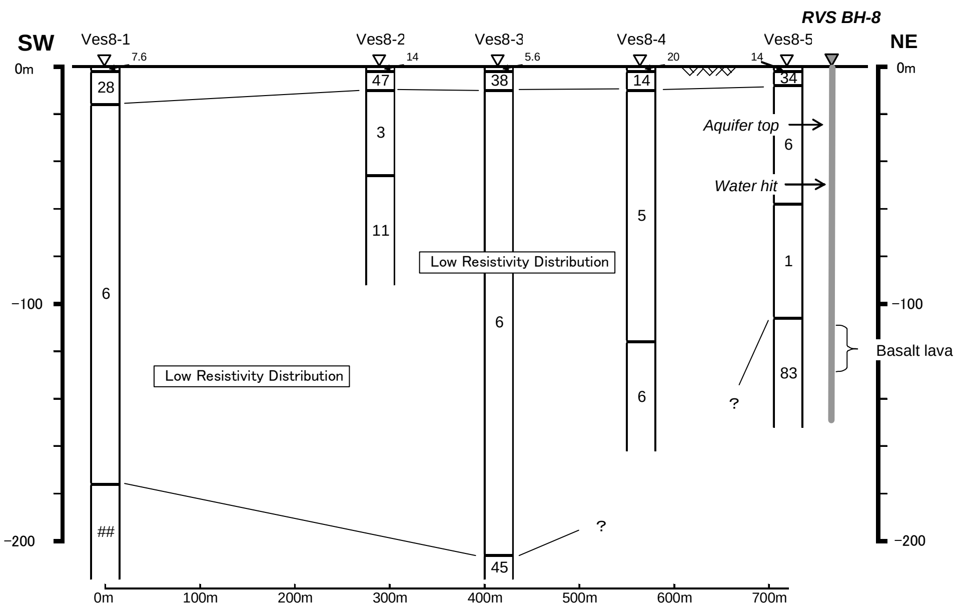


Figure 5.8: Resistivity Profile at Site No-8

j. Site No-9N

The geophysical survey at this newly selected site (alternative of Site No-9) was conducted with TEM (Transient Electro Magnetic) survey method. The analyzed resistivity profile along the line that intersects the drilling point No-9N was shown below. The borehole was drilled right beside survey point No-3. As can be seen in the figure, four layers of different resistivity values were recognized as a result of analysis. At the drilling point, major water was struck around 89 m and 100 m, and these were considered the major aquifer zone. The top depth of aquifer zone (89 m) is about 10 to 15 m below the boundary of first (9 - 38 ohm-m) and second (29 - 63 ohm-m) layers in the figure. As a result of the comparison with the geological log and this resistivity layer structure, the second resistivity layer seem to correspond to the aquifer zone. Although the resistivity values of the first layer is unusually low. The corresponding geological formation is dry tuff and pumice, which does not explain the low resistivity of the zone. The third and fourth layers on the figure have very low resistivity values. There is a every thick formation of damp clay below 130 m in the borehole. Thus, this zone may correspond to that clay formation. The TEM survey did not vary accurately locate the zone of aquifer but gave some indication of it at this site too

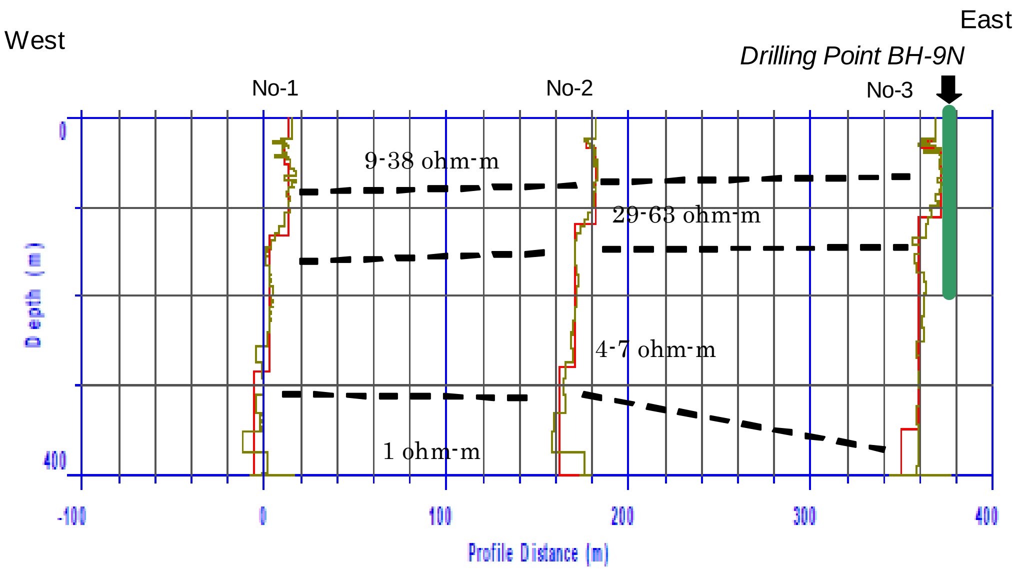


Figure 5.9: TEM Resistivity Profile at Site No-9N

k. Site No-10N

The geophysical survey at this newly selected site (alternative of Site No-10) was conducted with TEM (Transient Electro Magnetic) survey method. The analyzed resistivity profile along the line that intersects the drilling point No-10N was shown below. As can be seen in the figure, five layers of different resistivity values were recognized as a result of analysis. At the drilling point, major water was struck around 65 m and this is considered to be the top of the aquifer zone. This depth corresponds to the boundary of first (25-161 ohm-m) and second (75-114 ohm-m) layers. Although the difference in the labeled resistivity values is relatively small, at point No-6, the resistivity curve shows higher contrast than at points No-4 and 5. The TEM survey successfully located the zone of aquifer at this site too

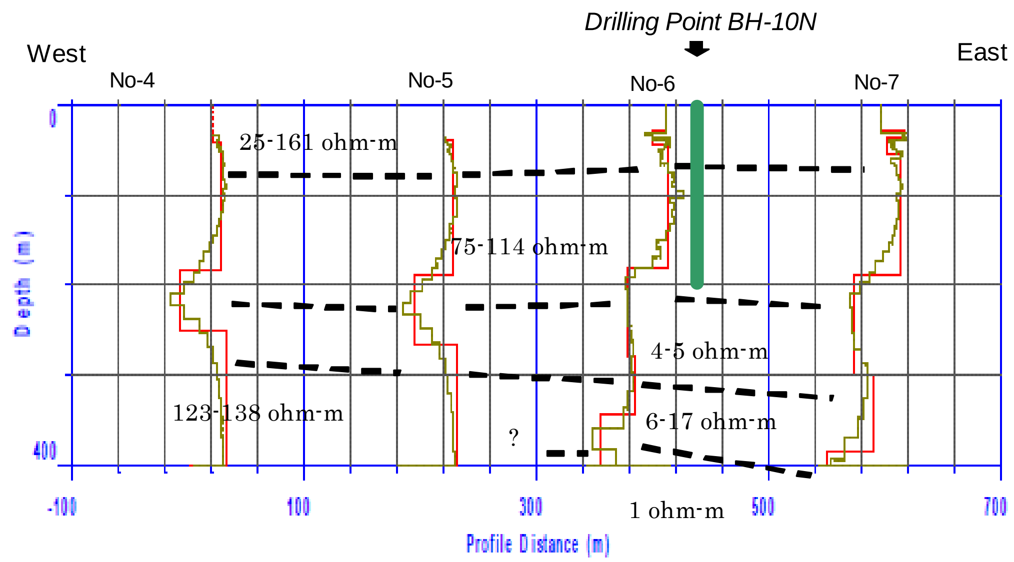


Figure 5.10: TEM Resistivity Profile at Site No-10N

5.3 Pumping test

5.3.1 Introduction

Two teams of pump test were employed to conduct pumping test at each well after completion. The last pumping test was finished in the beginning of August, 2011 at site No-6. The specifications of the pumping test are summarized in the table below and more detailed information of the pumping test can be found in Progress Report (1).

Table 5.6: Specification of Pumping Test

Test type	Specification and detail
Preliminary	At least 4 hours
Step drawdown	5 steps, 2 hours/each step
Continuous	24 hours, EC and pH measurement
Recovery	97% recovery or maximum 12 hours

The duration of the pumping test at each of the 10 observation wells is compiled below.

Table 5.7: Dates of Pumping Tests

Site	**No-1**	**No-2**	**No-3**	**No-4**	**No-5N**
Date	7, 8, 9, 10	31, 1, 2	21, 22, 23	15, 16, 17	NA
Month Year	*June 2010*	*May - June 2010*	*July 2010*	*November 2011*	*NA*
Site	**No-6**	**No-7**	**No-8**	**No-9N**	**No-10N**
Date	28, 29, 30	13, 15, 16, 17	27, 28, 29	4, 5, 6, 7	4, 5, 6, 7

Month Year	*October 2011*	*August 2011*	*August 2011*	June 2011	March 2011

* The pumping test is considered started with preliminary test and ended with recovery test

It should be noted that the wells were completed with screens pipes installed over most of available aquifer sections within the borehole because it was very difficult to distinguish different aquifers and also difficult to shut off the other possible water bearing zones in consideration of the skill level of the drilling contractor. Thus, the data obtained from the pumping test represent, in most cases, the combined effect of multiple aquifers and it is natural that that data plots show atypical curves and lines with a high degree of variation.

5.3.2 Preliminary test

The production capacity of each well was roughly assessed during the preliminary test by observing the drawdown in the well corresponding to changes in pumping rates. Then, pumping rates for the step drawdown test were determined based on the data.

5.3.3 Step-Drawdown test

The step drawdown test was conducted to determine the discharge for the continuous test and also to evaluate the efficiency of the well. The raw data of the pumping test is available in the Data book. The results of step drawdown tests are summarized in the table below and the graphs showing the drawdown plot are given in Figure 5.61 to Figure 5.68.

Table 5.8: Results of Step Drawdown Test

		No-1	**No-2**	**No-3**	**No-4**	**No-5N**	**No-6**	**No-7**	**No-8**	**No-9N**	**No-10N**
	SWL (-m)	47.35	92.20	172.38	7.70	Artesian	247.60	4.89	NA	43.41	24.50
Step 1	Discharge (L/s)	8.00	7.50	0.30	4.20		4.20	9.00		8.00	13.00
	Drawdown (m)	3.88	0.26	0.41	26.10		4.93	26.76		4.22	5.74
Step 2	Discharge (L/s)	9.00	8.00	0.60	5.20		4.40	11.00		10.00	14.50
	Drawdown (m)	4.34	0.53	1.42	33.39		5.13	35.47		5.32	6.71
Step 3	Discharge (L/s)	11.50	8.50	0.90	6.20		4.60	13.00		12.00	16.00
	Drawdown (m)	5.23	0.80	3.57	41.85		5.80	41.81		6.53	7.65
Step 4	Discharge (L/s)	14.00	9.20	1.20				15.00		14.00	17.50
	Drawdown (m)	6.03	1.12	7.07				48.21		7.73	8.91
Step 5	Discharge (L/s)	16.00	NA	1.50				17.00		16.00	19.00
	Drawdown (m)	7.25	NA	11.00				52.34		8.88	9.29

* SWL (Static Water Level) was measured from the top of casing/observation pipe

One objective of conducting a step-drawdown test is to evaluate the efficiency of the well. The evaluation is based on the theory that the total drawdown in a pumping well is a sum of drawdown caused by the head loss in the aquifer (aquifer loss) and head loss due to the well screen and packing material (well loss). It is generally expressed by the following formula.

$$s_w = BQ + CQ^2$$

where s_w is the drawdown in the pumping well, Q is the discharge, B is the coefficient for aquifer loss, and C is the coefficient for well loss.

The results of the analysis are discussed in the following sections.

a. Site No-1

The data was first plotted on a simple s_w – Q plot to visually inspect the effect of well loss. The result is in the following graph. At site no-1, the regression line drawn through the first four plots probably represents a linear relationship between the drawdown (s) and discharge (Q). At Q = 16 L/s, however, the plot starts to deviate from this linear trend. This is most probably the effect of well loss. In any case, the deviation at this larger discharge is as small as 0.5m and the well is considered very efficient.

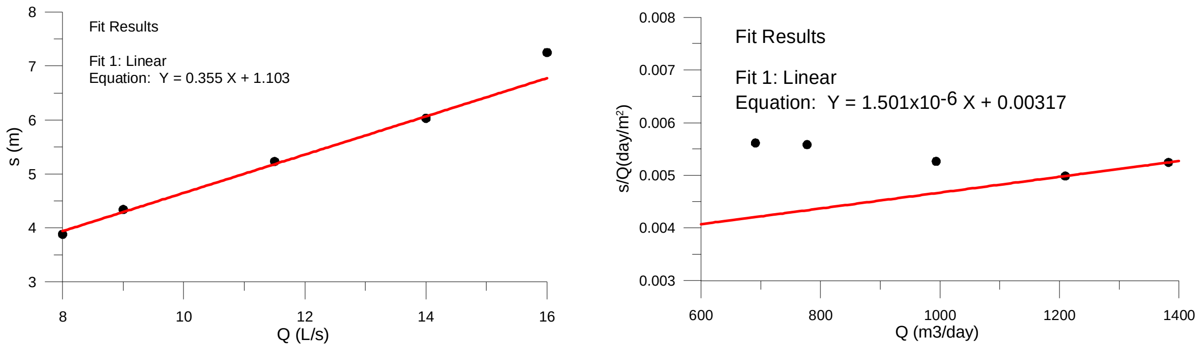


Figure 5.11: s-Q Plot (Left) and s/Q-Q Plot (Right) for Site No-1

Then the data is plotted on s_w/Q – Q graph to evaluate the effect of well loss. The plot turned out somewhat atypical probably due to measurement errors for the first few plots. Thus, the regression line was drawn using the last two plots. As a result the coefficients B and C for the equation were evaluated as follows.

$B = 0.00317, \quad C = 1.5 \times 10^{-6}$

For discharge Q = 14 L/s (1209.6m^3/day), the well efficiency (Ew) is then calculated to be

$Ew = Q/s \times B = (1209.6/6.03) \times 0.00317 \approx 0.64$ (64%)

Table 5.9: Results of Well Efficiency Analysis for No-1

No-1	sw(m)	Q(m^3/day)	Sc(m^2/day)	Ew(%)
Step 1	3.88	691.2	178.1	56%
Step 2	4.34	777.6	179.2	57%
Step 3	5.23	993.6	190.0	60%
Step 4	6.03	1209.6	200.6	64%
Step 5	7.25	1382.4	190.7	60%

b. Site No-2

The same analysis was performed using the data set from Site No-2. The resultant graphs are presented in the following:

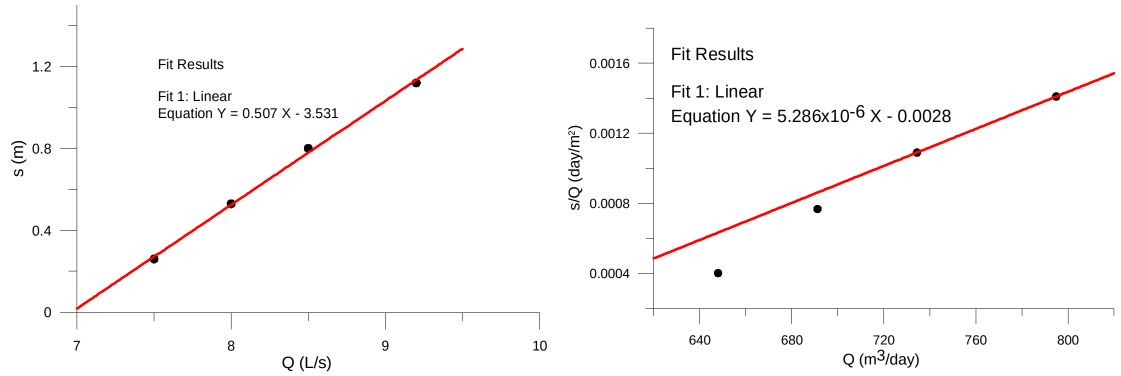


Figure 5.12: s-Q Plot (Left) and s/Q-Q Plot (Right) for Site No-2

At No-2 site, the aquifer potential was far over the capacity of the largest submersible pump available. Thus, only a small amount of drawdown (maximum 1.23 m) was created by the pumping test. This means that the test could not put sufficient stress to the aquifer. As a result, the s-Q plot is almost linear and the plots show no sign of deviation from the linearity. Deviation from this line may have occurred at higher discharges.

s/Q-Q plot evaluation indicates that C is as small as $5.3x10^{-6}$ and B is a small negative value. Normally the values are positive and this is considered because of the error resulting from the fact the aquifer was not stressed sufficiently. B would probably be a very small positive value without the errors.

This efficiency of over 100 percent theoretically makes no sense. However, we can tell that only 1.2 m drawdown at a discharge of 8.5 L/s indicates high potential of the well.

c. Site No-3

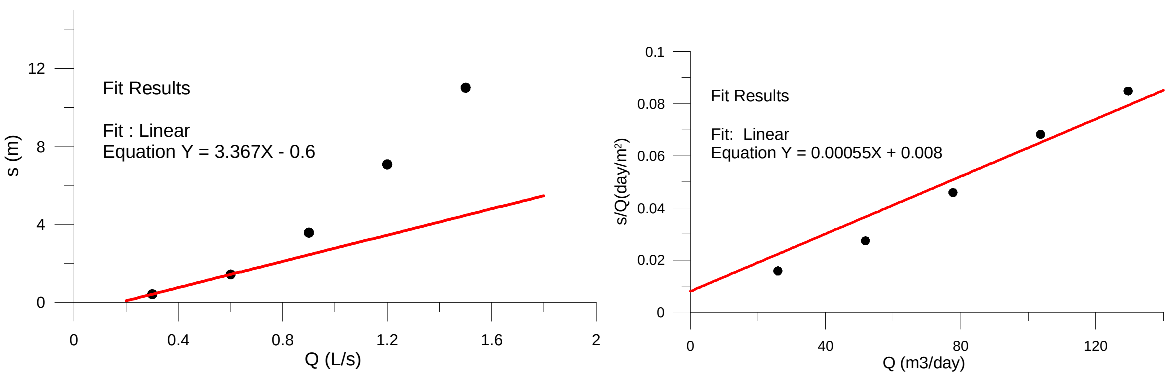


Figure 5.13: s-Q Plot (left) and s/Q-Q Plot (right) for Site No-3

At site No-3, the static water level is as low as 172 m and this made pumping at high rates practically impossible. On the other hand, the aquifer potential is also relatively low. Thus, reasonable amount of drawdown was created in spite of low pumping rates. The result shows that the s-Q plot clearly deviates from the straight line after the second step, showing possible effect of well loss.

On the s/Q-Q plot, the regression line was drawn using all the data points and the evaluation indicates that:

B = 0.008, C = 5.5×10^{-4}

The results are compiled in the table below. For discharge Q = 1.5 L/s (129.6 m^3/day), the largest pumping rate in the step test, the well efficiency (Ew) is calculated to be :

Ew = Q/s x B = (129.6 / 11) x 0.0088 ≈ 0.104 (10.4%)

The well efficiency of this borehole is very low. The result may have been affected by data error due to low pumping rates.

Table 5.10: Results of Well Efficiency Analysis for No-3

No-3	sw(m)	Q(m^3/day)	Sc(m^2/day)	Ew(%)
Step 1	0.41	25.92	63.2	56%
Step 2	1.42	51.84	36.5	32%
Step 3	3.57	77.76	21.8	19%
Step 4	7.07	103.68	14.7	13%
Step 5	11	129.6	11.8	10%

This efficiency of over 100 percent theoretically makes no sense. However, we can tell that only 1.2 m drawdown at a discharge of 8.5 L/s indicates high potential of the well.

d. Site No-4

Due to the limitation of the pump capacity, the test was conducted in three steps. The data was analyzed and the result shows that the s-Q plot clearly shows linear relation between s and Q, showing little effect of well loss.

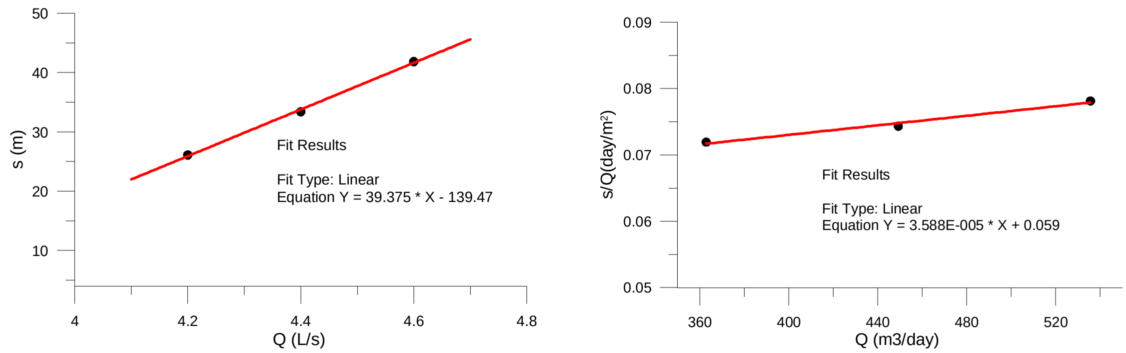


Figure 5.14: s-Q Plot (left) and s/Q-Q Plot (right) for Site No-4

On the s/Q-Q plot, the regression line was drawn using all the data points and the evaluation indicates that:

B = 0.059, C = 3.6×10^{-5}

The results are compiled in the table below. For discharge Q = 6.2 L/s (536 m^3/day), the largest pumping rate in the step test, the well efficiency (Ew) is calculated to be :

Ew = Q/s x B = (536 / 41.8) x 0.059 ≈ 0.756 (76%)

The well efficiency of this borehole is high

Table 5.11: Results of Well Efficiency Analysis for No-4

No-4	sw(m)	Q(m^3/day)	Sc(m^2/day)	Ew(%)
Step 1	26.76	363	13.6	80%
Step 2	35.47	449	12.7	75%
Step 3	41.81	536	12.8	76%

e. Site No-5N

Pumping test was not conducted at this site because the well turned out to be flowing artesian after development and also because the well was a hot spring of as high as 54 °C in temperature. The discharge measured in the draining ditch with a float indicated a flow rate of as large as 100 L/s.

f. Site No-6

Due to the limitation of the pump capacity, the test was conducted in three steps. The data was analyzed and the result shows that the s-Q plot shows moderately linear relation between s and Q, showing moderate effect of well loss. However, the data may carry some error due to small interval between the pumping rates.

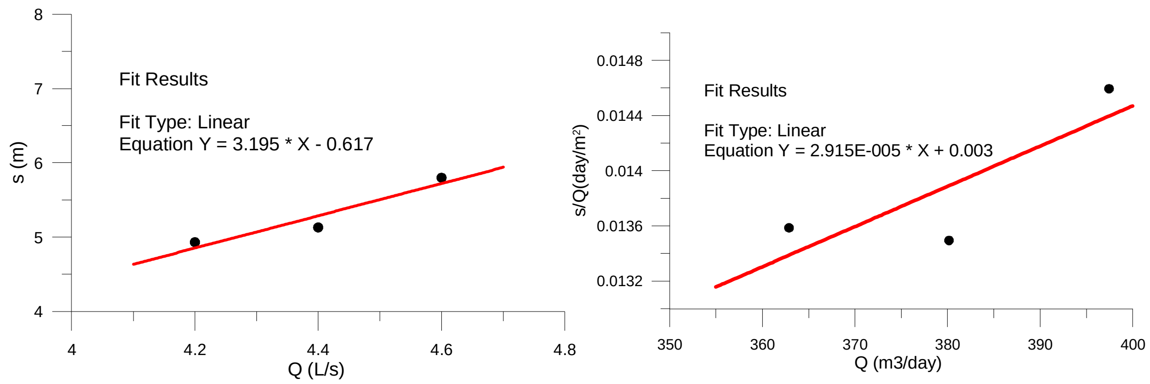


Figure 5.15: s-Q Plot (left) and s/Q-Q Plot (right) for Site No-6

On the s/Q-Q plot, the regression line was drawn using all the data points although the data points were not plotted in a straight line. The evaluation indicates that:

B = 0.003, C = 2.9 x 10^{-5}

The results are compiled in the table below. For discharge Q = 4.6 L/s (397 m^3/day), the largest pumping rate in the step test, the well efficiency (Ew) is calculated to be :

Ew = Q/s x B = (397 / 5.8) x 0.003 ≈ 0.205 (21%)

The well efficiency of this borehole is very low. The data, however, may carry some error due to the small interval in pumping rates that was difficult to measure accurately.

Table 5.12: Results of Well Efficiency Analysis for No-6

No-6	sw(m)	Q(m^3/day)	Sc(m^2/day)	Ew(%)
Step 1	4.93	363	73.6	22%
Step 2	5.13	380	74.1	22%
Step 3	5.8	397	68.5	21%

g. Site No-7

The step drawdown test was conducted in five steps. The data was analyzed and the result shows that the s-Q plot shows nearly linear relation between s and Q, showing little effect of well loss.

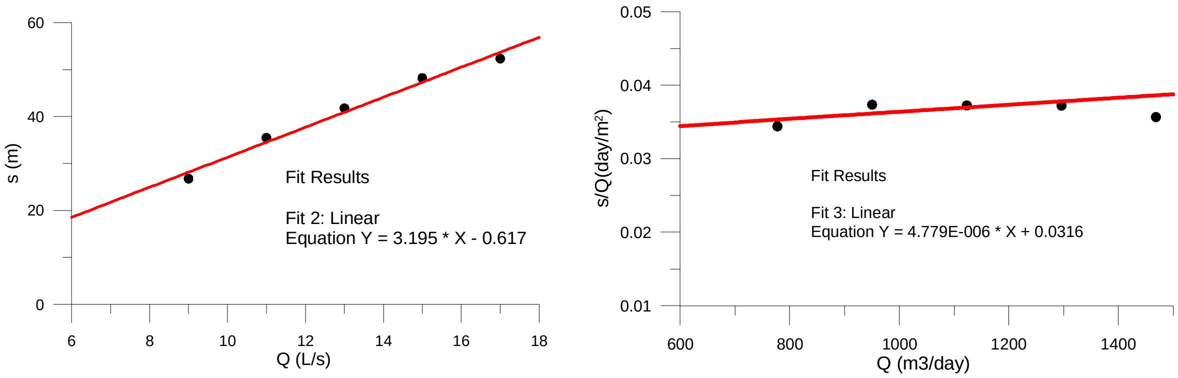


Figure 5.16: s-Q Plot (left) and s/Q-Q Plot (right) for Site No-7

On the s/Q-Q plot, the data points were not plotted in a straight line, with the last three points slightly lower than expected values. Thus, the regression line was drawn using all the data points. The evaluation indicates that:

B = 0.032, C = 4.8 x 10^{-6}

The results are compiled in the table below. For discharge Q = 17.0 L/s (1469 m^3/day), the largest pumping rate in the step test, the well efficiency (Ew) is calculated to be :

Ew = Q/s x B = (1469 / 52.34) x 0.032 ≈ 0.89 (89%)

The well efficiency of this borehole is very high.

Table 5.13: Results of Well Efficiency Analysis for No-7

No-7	sw(m)	Q(m^3/day)	Sc(m^2/day)	Ew(%)
Step 1	26.76	778	29.1	92%
Step 2	35.47	950	26.8	85%
Step 3	41.81	1123	26.9	85%
Step 4	48.21	1296	26.9	85%
Step 5	52.34	1469	28.1	89%

h. Site No-8

The step drawdown test was not conducted at this site because the aquifer was highly productive and a submersible pump that fitted in the 6-inch well and that had large enough capacity to cause meaningful amount of drawdown could not be found in the country.

i. Site No-9N

The data was first plotted on a simple s_w – Q plot to visually inspect the effect of well loss. The result is in the following graph. At site No-9N, the regression line drawn through the plots represents a typical linear relationship between the drawdown (s) and discharge (Q). No sign of the effect of well loss is recognized at this level of discharges.

Then the data is plotted on s_w/Q – Q graph to evaluate the effect of well loss. The plot formed a nearly straight line. Thus, the regression line was drawn using all the plots. As a result the coefficients B and C for the equation were evaluated as follows.

$$B = 0.0058, \quad C = 5.03 \times 10^{-7}$$

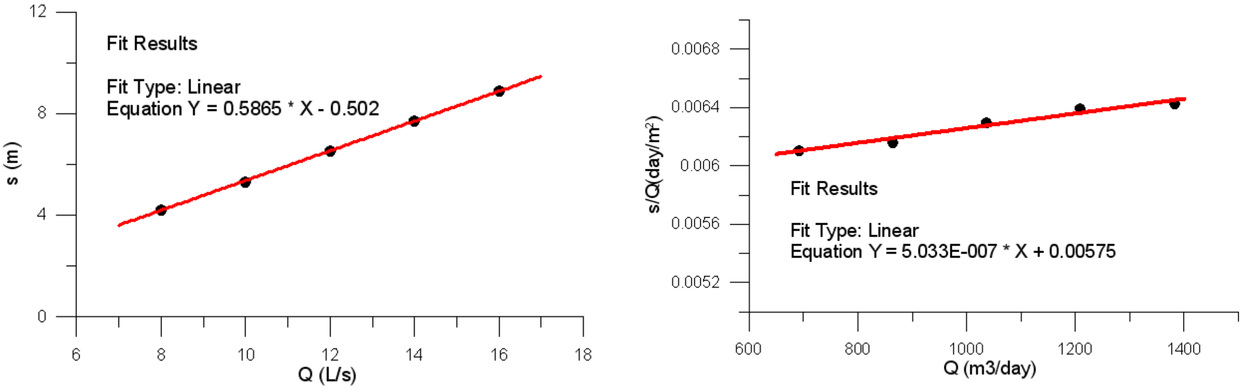


Figure 5.17: s-Q Plot (left) and s/Q-Q Plot (right) for Site No-9N

The results are compiled in the table below. For discharge Q = 16 L/s (1382.4 m^3/day), the largest pumping rate in the step test, the well efficiency (Ew) is calculated to be :

$$Ew = Q/s \times B = (1382.4 / 8.88) \times 0.0058 \approx 0.90\ (94\%)$$

The well efficiency of this borehole is very high.

Table 5.14: The results of Well Efficiency Analysis for No-9N

No-9N	sw(m)	Q(m^3/day)	Sc(m^2/day)	Ew(%)
Step 1	4.22	691.2	163.8	95%
Step 2	5.32	864	162.4	94%
Step 3	6.53	1036.8	158.8	92%
Step 4	7.73	1209.6	156.5	91%
Step 5	8.88	1382.4	155.7	90%

j. Site No-10N

The same analysis was performed using the data set from Site No-10N. The resultant graphs are presented in the following.

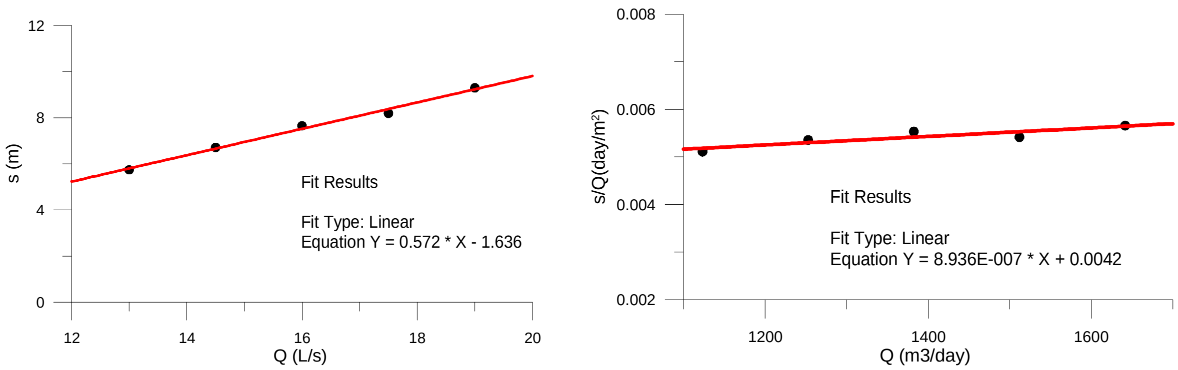


Figure 5.18: s-Q Plot (left) and s/Q-Q Plot (right) for Site No-10N

At Site No-10N, the s-Q plot is almost on a straight line and the plots show no sign of deviation from the linearity. Deviation from this line may have occurred at higher discharges.

s/Q-Q plot evaluation indicates that following values for the coefficients:

$$B = 0.0042, \quad C = 8.94 \times 10^{-7}$$

The results are compiled in the table below. For discharge Q = 19 L/s (1641.6 m^3/day), the largest pumping rate in the step test, the well efficiency (Ew) is calculated to be :

$$Ew = Q/s \times B = (1641.6 / 9.29) \times 0.0042 \approx 0.74 \ (74\%)$$

The well efficiency of this borehole is judged high.

Table 5.15: The results of Well Efficiency Analysis for No-10N

No-10N	sw(m)	Q(m^3/day)	Sc(m^2/day)	Ew(%)
Step 1	5.74	1123.2	195.7	82%
Step 2	6.71	1252.8	186.7	78%
Step 3	7.65	1382.4	180.7	76%
Step 4	8.19	1512	184.6	78%
Step 5	9.29	1641.6	176.7	74%

5.3.4 Continuous test

The results of continuous tests were plotted on time-drawdown graph and presented in Figure 5.60 to Figure 5.68. This data is commonly used to evaluate aquifer constants of Transmissivity (T), Hydraulic conductivity (K), and Storage coefficient (S). In this study, Cooper-Jacob method was employed to evaluate the parameters. In this analysis the data is plotted on a semi-log s (Y axis) – t (X axis) graph. Theoretically the data plots would form a straight line and that is fitted with a regression line to calculate the intersection of the x axis by the line to find “t_0” and one log cycle drawdown to find “Δs”.

a. Site No-1

The continuous pumping test was conducted for 24 hours with a discharge of 12 L/s. The result was analyzed on the following graph.

The plotted data starts deviating form the straight line after 10 minutes, indicating possible recharge from surrounding layers. The regression line is drawn thus, through the 2nd to 7th plots. The resultant formula of the regression line is shown on the figure. The hydrogeological parameters were calculated as follows.

$T = 4.36 \times 10^{-3}$ m^2/sec = 376.5 m^2/day	$S = 4.84 \times 10^{-8}$

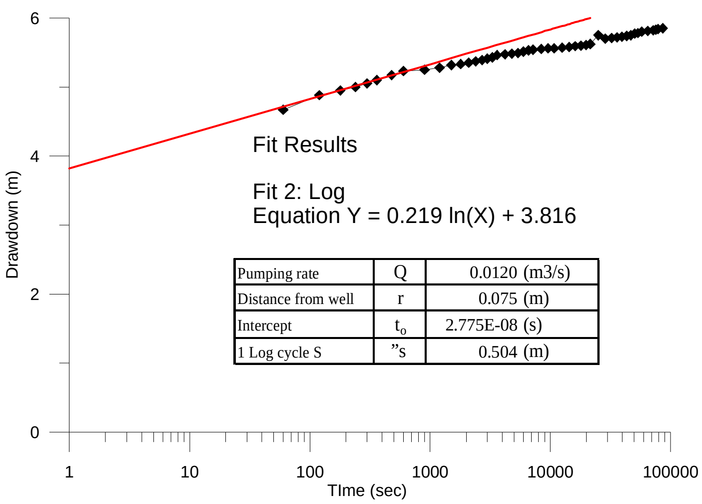


Figure 5.19: Cooper-Jacob Analysis of Data from Site No-1

If we assume the aquifer thickness is the same as the screened length of 30 m, the average hydraulic conductivity (K) of the aquifer is therefore estimated to be 1.45×10^{-2} cm/sec. The result suggests that it is a permeable aquifer.

b. Site No-2

The continuous pumping test was conducted for 24 hours with a discharge of 8.5 L/s. The result was analyzed on the following graph.

As mentioned in the preceding section, the test was not able to create sufficient drawdown to evaluate the aquifer capacity to a reasonable level. Nevertheless, the data was analyzed by Cooper-Jacob method.

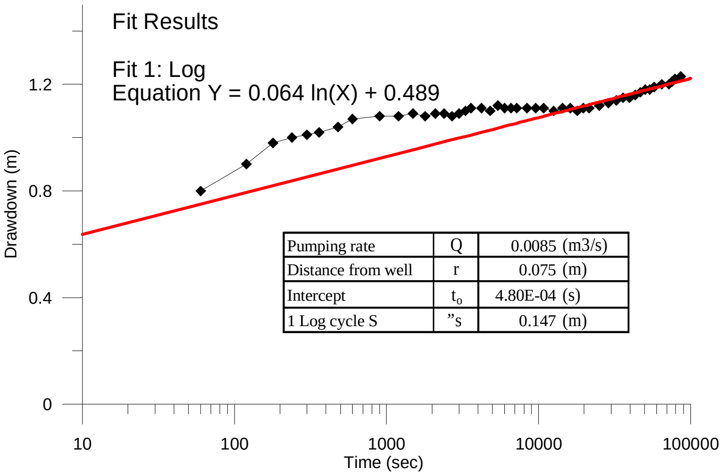


Figure 5.20: Cooper-Jacob Analysis of Data from Site No-2

The plotted data does not form a straight line but instead it seems to be made up of three data segments of different characteristics. Especially the middle section (500 – 1000 sec) seems to indicate possible recharge from surrounding layers. The regression line is drawn thus, through the third segment that is considered to represent actual aquifer capacity. The resultant formula of the regression line is shown on the figure. The Hydrogeological parameters were calculated as follows.

T = 1.06 x 10^{-2} m^2/sec = 914.4 m^2/day	S = 2.03 x 10^{-3}

If we assume the aquifer thickness is the same as the screened length of 30 m, the average hydraulic conductivity (K) of the aquifer is therefore estimated to be 3.53 x 10^{-2} cm/sec. The result suggests that it is a permeable aquifer.

c. Site No-3

The continuous pumping test was conducted for 24 hours with a discharge of 1.0 L/s. The result was analyzed on the following graph.

The test was not able to create sufficient drawdown to evaluate the aquifer capacity to a reasonable level due to the low static water level. Nevertheless, the data was analyzed by Cooper-Jacob method.

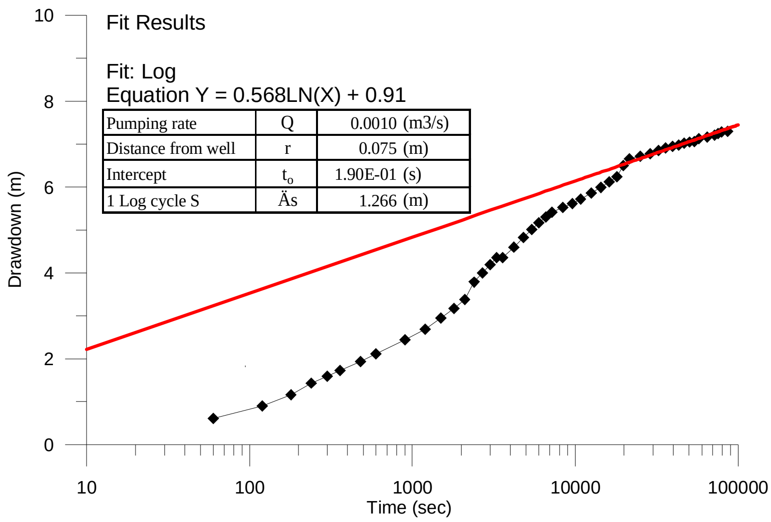


Figure 5.21: Cooper-Jacob Analysis of Data from Site No-3

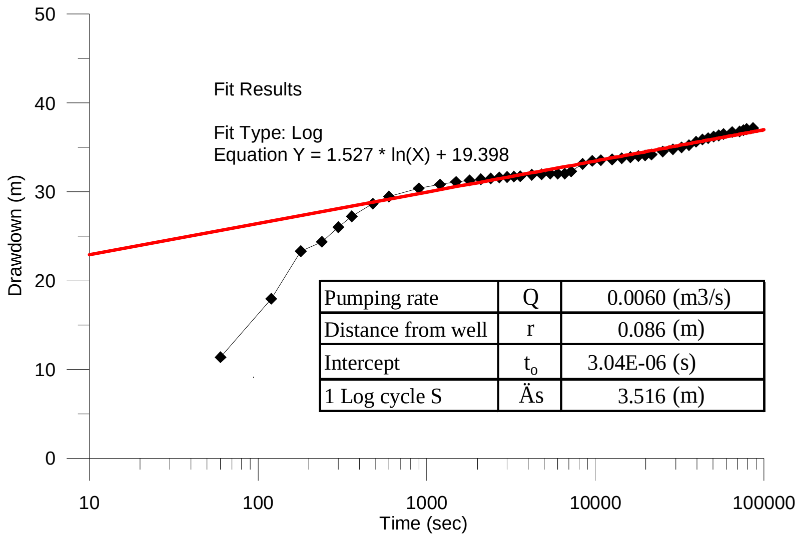
The plotted data does not form a straight line but instead it seems to be made up of several data segments of different characteristics. Since the last segments after t = 20000 sec, seemed to be stable and to be free from initial variation and thus, most reasonably represent the characteristics of the well, . the regression line was drawn through this segment. The resultant formula of the regression line is shown on the figure. The Hydrogeological parameters were calculated as follows.

$T = 1.5 \times 10^{-4}\ m^2/sec = 13\ m^2/day$	$S = 1.1 \times 10^{-2}$

If we assume that the aquifer thickness is the same as the screened length of 48 m, the average hydraulic conductivity (K) of the aquifer is therefore estimated to be 3.0×10^{-4} cm/sec. The result suggests that the aquifer has low permeability and is semi-confined.

d. Site No-4

The continuous pumping test was conducted for 24 hours with a discharge of 6.0 L/s. The result was analyzed on the following graph.



Pumping rate	Q	0.0060 (m3/s)
Distance from well	r	0.086 (m)
Intercept	t_0	3.04E-06 (s)
1 Log cycle S	Äs	3.516 (m)

Figure 5.22: Cooper-Jacob Analysis of Data from Site No-4

The plotted data forms a straight line except for the first six data points that deviate from the line. The regression line was, thus, drawn without these six data points. The resultant formula of the regression line is shown on the figure. The Hydrogeological parameters were calculated as follows.

$T = 3.1 \times 10^{-4}$ m²/sec = 27 m²/day	$S = 2.9 \times 10^{-7}$

If we assume that the aquifer thickness is the same as the screened length of 56 m, the average hydraulic conductivity (K) of the aquifer is therefore estimated to be 5.6×10^{-4} cm/sec. The result suggests that the aquifer has low permeability.

e. Site No-5N

The pumping test was not conducted for this well because the well was flowing artesian.

f. Site No-6

The continuous pumping test was conducted for 24 hours with a discharge of 4.6 L/s. The result was analyzed on the following graph.

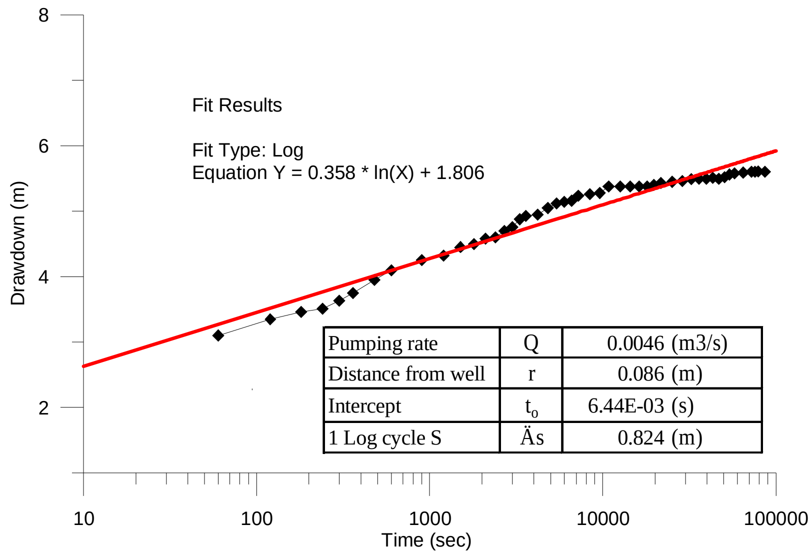


Figure 5.23: Cooper-Jacob Analysis of Data from Site No-6

The plotted data does not exactly form a straight line but rather a series of slightly bending line segments. However, since the degree of bending was not significant, the regression line was drawn using all the data points. The resultant formula of the regression line is shown on the figure. The Hydrogeological parameters were calculated as follows.

$T = 1.0 \times 10^{-3}$ m^2/sec = 88 m^2/day	$S = 2.0 \times 10^{-3}$

If we assume that the aquifer thickness is the same as the screened length of 66 m, the average hydraulic conductivity (K) of the aquifer is therefore estimated to be 1.6×10^{-3} cm/sec. The result suggests that the aquifer has moderate permeability.

g. Site No-7

The continuous pumping test was conducted for 24 hours with a discharge of 16 L/s. The result was analyzed on the following graph.

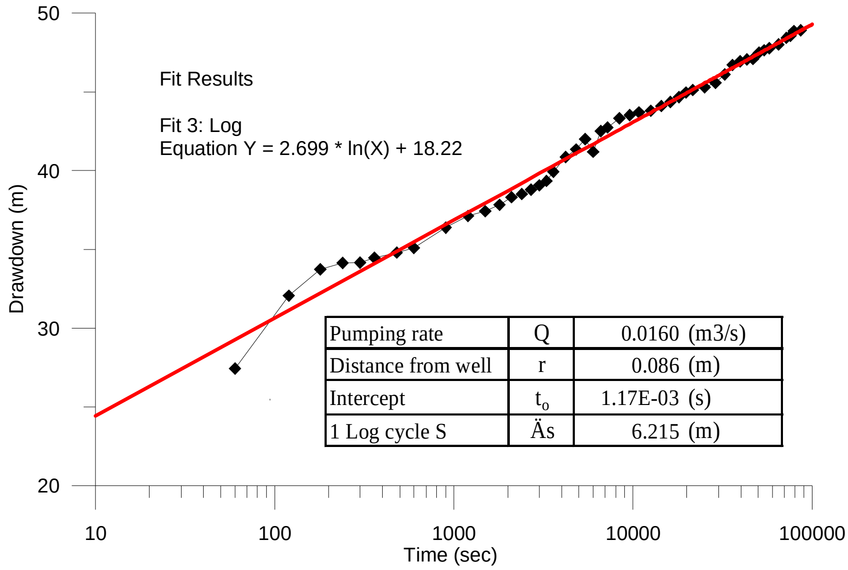


Figure 5.24: Cooper-Jacob Analysis of Data from Site No-7

The plotted data forms a quasi-straight line with some minor bumps and dents. The regression line is drawn thus, through the entire data plots. The resultant formula of the regression line is shown on the figure. The hydrogeological parameters were calculated as follows.

$T = 4.7 \times 10^{-3}$ m^2/sec = 40.7 m^2/day	$S = 1.7 \times 10^{-4}$

If we assume the aquifer thickness is the same as the screened length of 60 m, the average hydraulic conductivity (K) of the aquifer is therefore estimated to be 7.9 x 10^{-4} cm/sec. The result suggests that it is a moderately permeable confined aquifer.

h. Site No-8

The continuous pumping test was conducted for nine hours with a discharge of 26 L/s. The result was analyzed on the following graph.

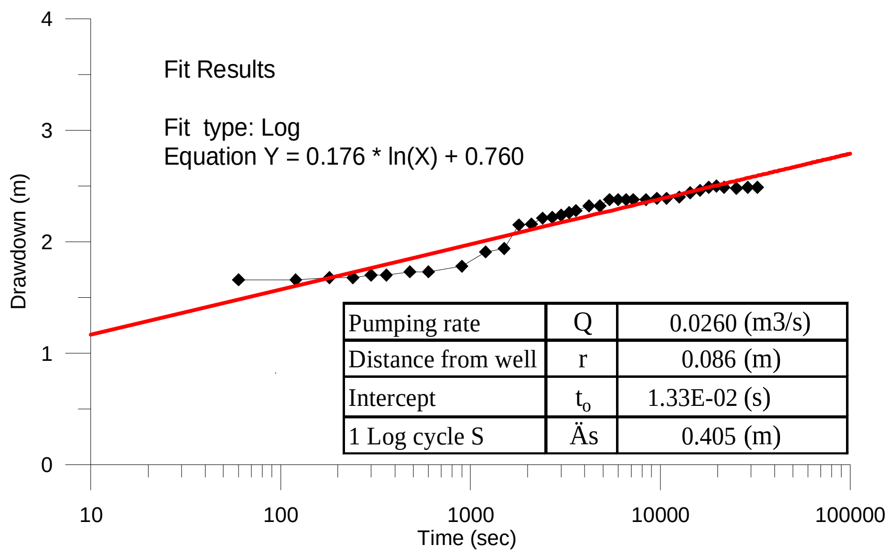


Figure 5.25: Cooper-Jacob Analysis of Data from Site No-8

The plotted data forms a quasi-straight line with a minor bump and a dent. The regression line is drawn thus, through the entire data plots. The resultant formula of the regression line is shown on the figure. The hydrogeological parameters were calculated as follows.

T = 1.2 x 10^{-2} m^2/sec = 1015 m^2/day	S = 4.8 x 10^{-2}

If we assume the aquifer thickness is the same as the screened length of 60 m, the average hydraulic conductivity (K) of the aquifer is therefore estimated to be 2.0 x 10^{-2} cm/sec. The result suggests that it is a permeable aquifer.

i. Site No-9N

The continuous pumping test was conducted for 24 hours with a discharge of 16 L/s. The result was analyzed on the following graph.

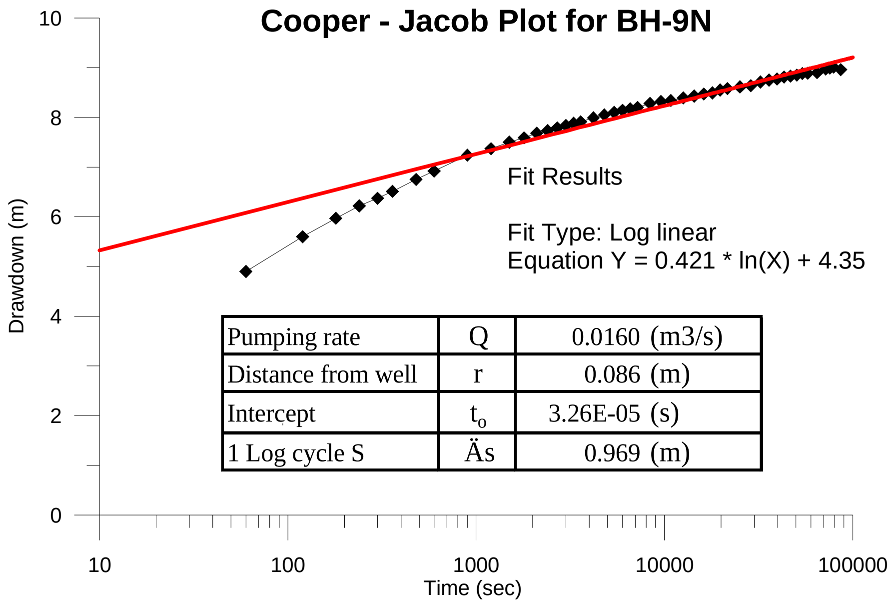


Figure 5.26: Cooper-Jacob Analysis of Data from Site No-9N

The plotted data for the 10 minutes deviates form the straight line, indicating possible error due to borehole storage effect. The regression line is drawn thus, through the 9^{th} to the last plot. The resultant formula of the regression line is shown on the figure. The hydrogeological parameters were calculated as follows.

T = 3.02 x 10^{-3} m^2/sec = 261.1 m^2/day	S = 2.99 x 10^{-5}

If we assume the aquifer thickness is the same as the screened length of 18 m, the average hydraulic conductivity (K) of the aquifer is therefore estimated to be 1.68 x 10^{-2} cm/sec. The result suggests that it is a permeable aquifer.

j. Site No-10N

The continuous pumping test was conducted for 24 hours with a discharge of 18.5 L/s. The result was analyzed on the following graph.

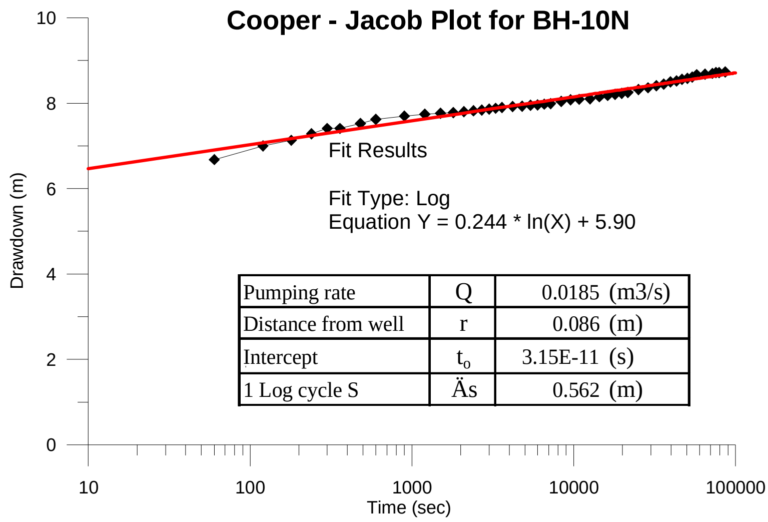


Figure 5.27: Cooper-Jacob Analysis of Data from Site No-10N

The plotted data forms a straight line although it is a little wavy. The regression line was drawn thus, through the entire segment of the data that is considered to represent actual aquifer capacity. The resultant formula of the regression line is shown on the figure. The Hydrogeological parameters were calculated as follows.

$T = 6.02 \times 10^{-2}\ m^2/sec = 520.6\ m^2/day$	$S = 5.78 \times 10^{-11}$

The calculated value of S is much smaller than the usual range of S for confined aquifer although estimation of S value usually carries higher degree of error margin. If we assume the aquifer thickness is the same as the screened length of borehole of 66 m, the average hydraulic conductivity (K) of the aquifer is therefore estimated to be 9.13 x 10^{-3} cm/sec. The result suggests that it is a reasonably permeable aquifer.

5.3.5 Recovery test

The recovery of water level in the borehole was observed immediately after the pump was stopped after 24 hours of operation. Transmissivity (T) can be estimated using this data. The raw data is given in the data book and the time-drawdown plot is shown in Figure 5.60 to Figure 5.68.

a. Site No-1

The well was pumped for 24 hours at a constant rate of 12 L/s and the maximum drawdown observed was 5.85m. After the pump was stopped the water level in the well recovered to the original level within 60 minutes. The data was plotted on s' – t/t' graph where s' is the residual drawdown, t is the time since the pump was started, and t' is the time after the pump was stopped. Theoretically the plots should form a straight line but several points on the right deviates from the line, especially the right most plot of the first reading after the pump stopped. This is probably due to measurement error because of quick rise of water level. Thus, this right most plot was ignored and the regression line was drawn through the rest of the data.

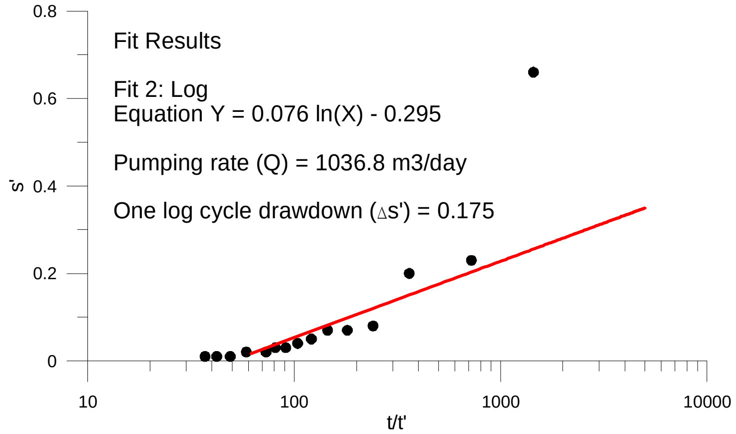


Figure 5.28: Analysis of Recovery Test Data at Site No-1

From the graph, one log cycle of residual drawdown Δs' is calculated to be 0.175 m. With discharge (Q) = 1037m^3/day during the constant test, transmissivity (T) is calculated to be:

$$T = \frac{2.30Q}{4\pi\Delta s'} = (2.3 \times 1037) / (4 \times 3.14 \times 0.175) \approx 1084 \text{ m}^2\text{/day}$$

b. Site No-2

The well was pumped for 24 hours at a constant rate of 8.5 L/s and the maximum drawdown observed was 1.23m. After the pump was stopped the water level in the well recovered close to the original water level after 410 minutes. The data was plotted on s' – t/t' graph and transmissivity was calculated in the same way as explained above.

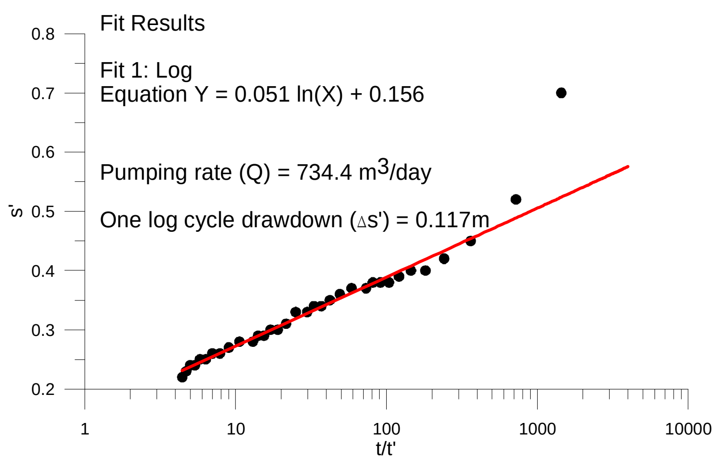


Figure 5.29: Analysis of Recovery Test Data at Site No-2

As a result, transmissivity was evaluated to be as follows:

$$T = (2.3 \times 734) / (4 \times 3.14 \times 0.117) \approx 1149 \text{ m}^2\text{/day}$$

c. Site No-3

The well was pumped for 24 hours at a constant rate of 1 L/s and the maximum drawdown observed was 7.3 m. After the pump was stopped, 90 % of the drawdown in the well was recovered within three hours. The data was plotted on s' – t/t' graph. The first seven data plots show some variation and the last seven data points deviate from the linear trend of the entire data set. Thus, the regression line was drawn to follow the general trend of the data plots.

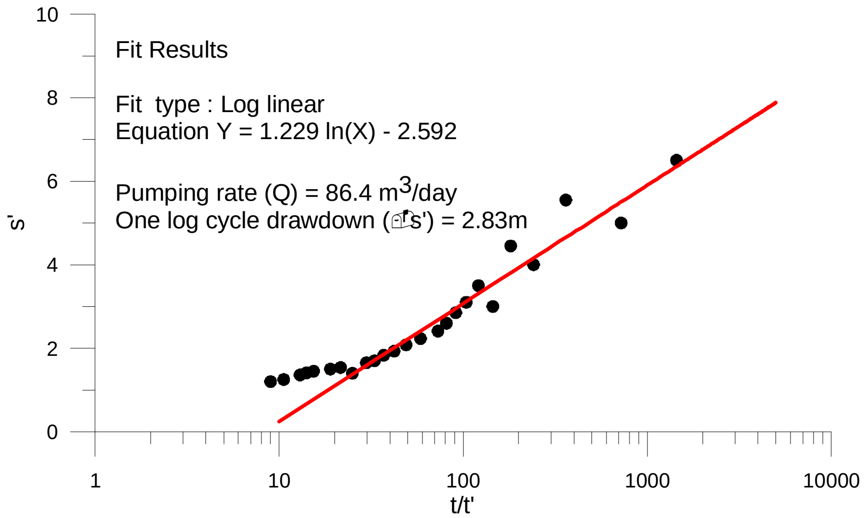


Figure 5.30: Analysis of Recovery Test Data at Site No-3

From the graph, one log cycle of residual drawdown Δs' is calculated to be 2.83 m. With discharge (Q) = 86.4 m^3/day during the constant test, transmissivity (T) is calculated to be:

$$T = \frac{2.30Q}{4\pi\Delta s'} = (2.3 \times 86.4) / (4 \times 3.14 \times 2.83) \approx 5.6 \text{ m}^2/\text{day}$$

d. Site No-4

The well was pumped for 24 hours at a constant rate of 6 L/s and the maximum drawdown observed was 37.2 m. After the pump was stopped, approximately 97 % of the drawdown in the well was recovered within only six minutes. After that, the rate of recovery significantly slowed down. The data was plotted on s' – t/t' graph. The plots displayed two distinctive line segments. The first three data plots (t/t' over 200) show significant deviation from the rest of the plots and have a steep slope. On the other hand the rest of the data plots have gentle slope, indicating the existence of two aquifers of different characteristics. Since the first three data plots were considered non-essential, the regression line was drawn through the remaining data plots on the left half of the graph below.

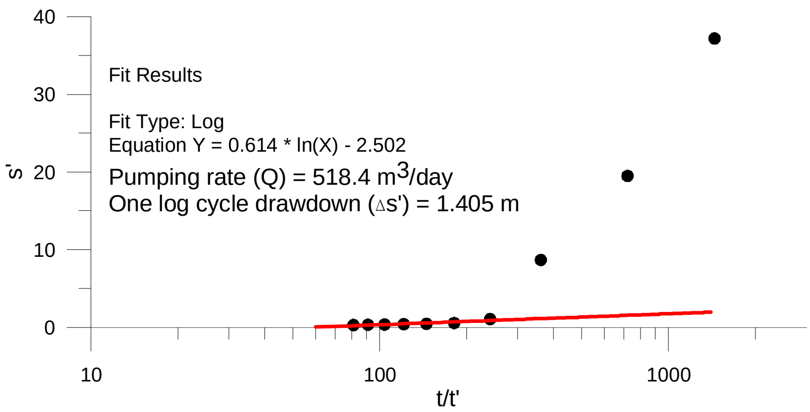


Figure 5.31: Analysis of Recovery Test Data at Site No-4

From the graph, one log cycle of residual drawdown Δs' is calculated to be 1.4 m. With discharge (Q) = 518 m^3/day during the constant test, transmissivity (T) is calculated to be:

$$T = \frac{2.30Q}{4\pi\Delta s'} = (2.3 \text{ x } 518) / (4 \text{ x } 3.14 \text{ x } 1.4) \approx 68 \text{ m}^2\text{/day}$$

e. Site No-5

The pumping test was not conducted because the well was flowing artesian.

f. Site No-6

The well was pumped for 24 hours at a constant rate of 4.6 L/s and the maximum drawdown observed was 5.6 m. After the pump was stopped, 88 % of the drawdown in the well was recovered within 12 minutes. The data was plotted on s' – t/t' graph. The first six data plots show some variation, especially the first one (right most plot). Thus, the regression line was drawn to follow the general trend of the remaining data plots that form a line segment.

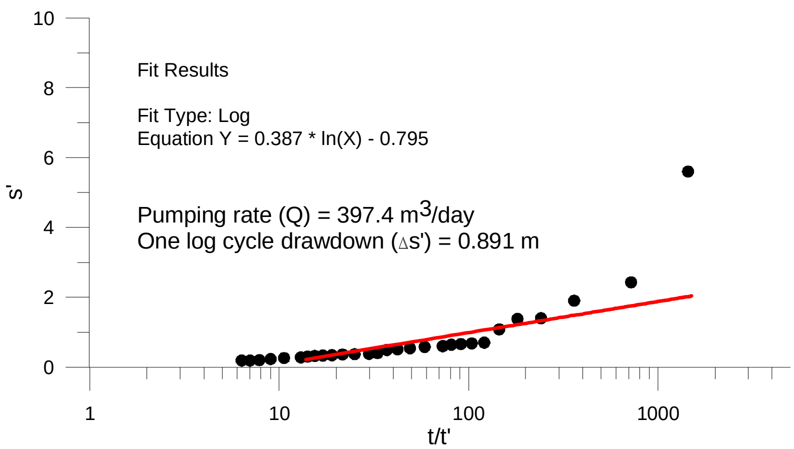


Figure 5.32: Analysis of Recovery Test Data at Site No-6

From the graph, one log cycle of residual drawdown Δs' is calculated to be 0.89 m. With discharge (Q) = 397 m^3/day during the constant test, transmissivity (T) is calculated to be:

$$T = \frac{2.30Q}{4\pi\Delta s'} = (2.3 \text{ x } 397) / (4 \text{ x } 3.14 \text{ x } 0.89) \approx 82 \text{ m}^2\text{/day}$$

g. Site No-7

The well was pumped for 24 hours at a constant rate of 16 L/s and the maximum drawdown observed was 48.9 m. The water level recovery was observed 12 hours after the pump was stopped and approximately 91 % of the drawdown in the well was recovered. The data was plotted on s' – t/t' graph. The data plots form a straight line. Thus, the regression line was drawn to follow the general trend of the remaining data plots that form a line segment.

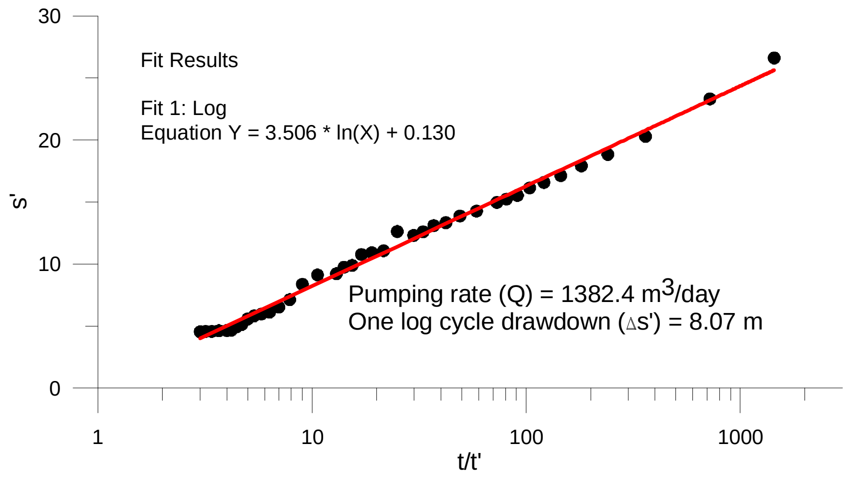


Figure 5.33: Analysis of Recovery Test Data at Site No-7

From the graph, one log cycle of residual drawdown Δs' is calculated to be 8.07 m. With discharge (Q) = 1382 m^3/day during the constant test, transmissivity (T) is calculated to be:

$$T = \frac{2.30Q}{4\pi\Delta s'} = (2.3 \text{ x } 1382) / (4 \text{ x } 3.14 \text{ x } 8.07) \approx 31 \text{ m}^2\text{/day}$$

h. Site No-8

The well was pumped for nine hours at a constant rate of 26 L/s and the maximum drawdown observed was as small as 2.49 m. The water level recovery was observed 5.5 hours after the pump was stopped and within this time, approximately 97 % of the drawdown in the well was recovered. The data was plotted on s' – t/t' graph. The data plots form a straight line. Thus, the regression line was drawn to follow the general trend of the entire data plots.

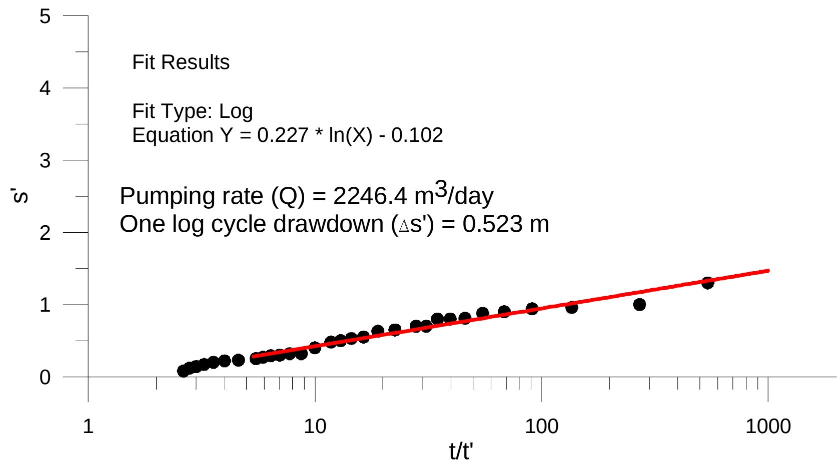


Figure 5.34: Analysis of Recovery Test Data at Site No-8

From the graph, one log cycle of residual drawdown Δs' is calculated to be 0.523 m. With discharge (Q) = 2246 m^3/day during the constant test, transmissivity (T) is calculated to be:

$$T = \frac{2.30Q}{4\pi\Delta s'} = (2.3 \times 2246) / (4 \times 3.14 \times 0.523) \approx 786 \ m^2/day$$

i. Site No-9N

The well was pumped for 24 hours at a constant rate of 16 L/s and the maximum drawdown observed was 8.96m. After the pump was stopped, 90% of the drawdown in the well recovered within 60 minutes.

The data was plotted on s' – t/t' graph where s' is the residual drawdown, t is the time since the pump was started, and t' is the time after the pump was stopped. The result is shown in the Figure below. Theoretically the plots should form a straight line and most points, in this case, were plotted on a straight line.

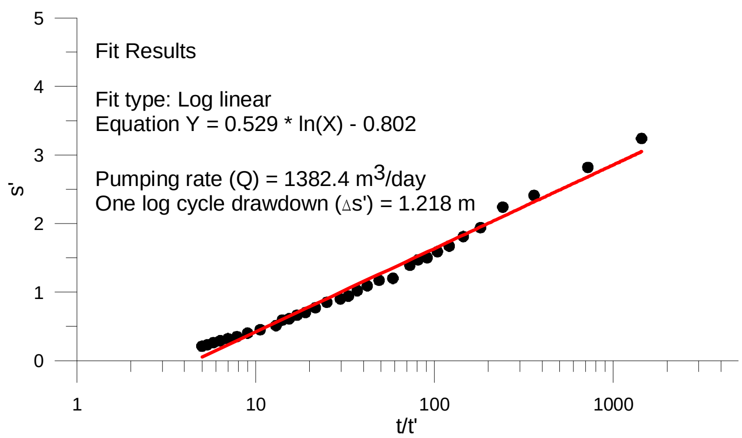


Figure 5.35: Recovery Analysis of Data from Site No-9N

From the graph, one log cycle of residual drawdown Δs' is calculated to be 1.218 m. With discharge (Q) = 1382 m^3/day during the continuous test, Transmissivity (T) is calculated to be:

$$T = \frac{2.30Q}{4\pi\Delta s'} = (2.3 \times 1382) / (4 \times 3.14 \times 1.218) \approx 208 \text{ m}^2\text{/day}$$

The value is close to the one calculated under the analysis of continuous pump test data.

j. Site No-10N

The well was pumped for 24 hours at a constant rate of 18.5 L/s and the maximum drawdown observed was 8.73m. After the pump was stopped, 90 % of the drawdown in the well recovered within only six (6) minutes. The data was plotted on s' – t/t' graph and transmissivity was calculated in the same way as explained above.

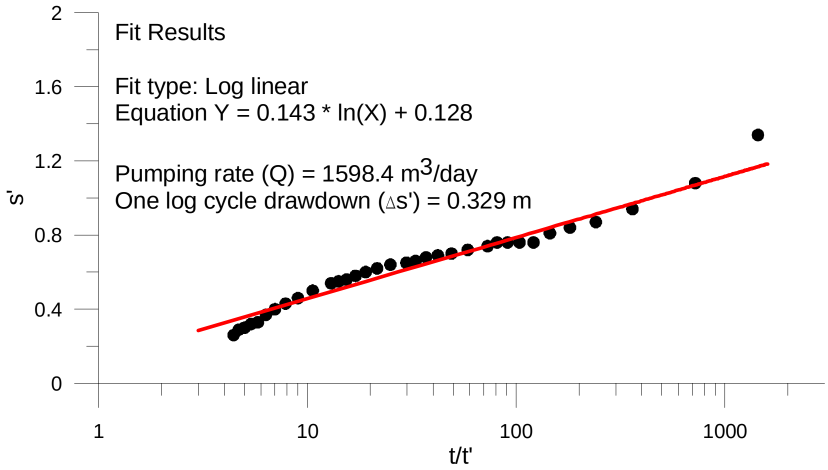


Figure 5.36: Recovery Analysis of Data from Site No-10N

As a result, transmissivity was evaluated to be:

$$T = (2.3 \times 1598) / (4 \times 3.14 \times 0.329) \approx 889 \text{ m}^2\text{/day}$$

This value is a little bigger than the one found under the analysis of continuous pump test data.

5.4 Groundwater level monitoring

5.4.1 Outline

Groundwater level observation is one of the most basic and essential activities necessary to investigate the groundwater regime of a given area. However, in spite of its importance, little work has been done to regularly measure the water level of any wells in the study area. Consequently there is practically no data available on long-term groundwater level changes for the study area.

In response to this situation, automatic water level recorders (WLR) were installed at each of the completed observation wells in this study in order to obtain long-term ground water level record. The recorded data will be used to:

1) help clarify groundwater level fluctuation and movement and to

2) provide essential data for calibration in groundwater modeling that is to be conducted in the second year.

A set of automatic water level recorders was installed at each of the 10 observations wells completed in this the study. The method of measurements and setup of the WLRs are described in the following sections.

5.4.2 Methodology

A self-contained pressure gauge designed to measure water pressure (water level recorder) and atmospheric pressure (barometer) was employed to automatically record the water level in the well. The device is a small metallic rod (see the photo), which contains battery for powers supply and a memory for data storage. It is designed to periodically measure and record absolute pressure of the water/air where it is placed along with the temperature. The water level recorder (water pressure gauge) was hung by a thin wire within the well casing approximately 10m below the static water level. The barometer (air pressure gauge) of the same build was also placed besides the casing within the metal protection housing as illustrated in Figure 5.69.

The water level data recorded by these devices was regularly downloaded to check the data. Water level measurement was also conducted manually by a dip meter at the time of installation and data retrieval (where the device was pulled out of water to be connected to a computer and lowered back into the borehole).

Since the device records absolute pressure of the water column in the well, the data retrieved from the device (measured in meters) was first compensated for the change in atmospheric pressure at the well head that was recorded by the barometer. Then the dip meter measurement data was used to calibrate the recorded data to obtain the actual fluctuation of the water level in the well. The devices were programmed to record the data every one hour, at exact hours such as 12:00, 13:00 etc. The detailed settings of the device are given in Table 5.22.

Figure 5.37: WLR employed (OYO S&DL mini) and wire

5.4.3 Technology transfer on the groundwater level recording

Training on the use and installation of WLRs was organized twice in the second year of the study as summarized in the following table. Technicians and engineers who are expected to engage in the groundwater monitoring activities were invited from the Ministry and from zonal water offices where the observations wells were drilled under this project.

Table 5.16: The Summary of Training on Groundwater Monitoring

	Date	Site	Participants	Training
1st	4 and 5 July, 2011	Meki area RVBH - 2	MoWE: 2 persons ZWMEO: 5 persons SPWMEO: 1 person	Lecture on the concept of ground water level and its monitoring. Practice of data retrieval and mock practice of WLR installation.
2nd	15 to 18 September, 2011	Arbaminch area RVBH -7 and 8	WRB: 1 person ZWMEO: 1 person SPWMEO: 1 person	Installation of WLRs in the borehole. Mock practice for data retrieval from WLR.

* ZWMEO: Zonal Water and Energy Office, SPWMEO: Special Woreda Water and Energy Office

The first training session was organized and instructed by the Japanese consultant who was in charge of well drilling. The participants came from the zonal water offices of East Arsi, Arsi, Walayta, Shidama, West Showa zones and Alaba special woreda. In addition, two persons from the Ministry participated. A lecture was given on how the system works and also how to set up the WLRs. The participants learned how to program the device by actually programming the devices using their computers. After the lecture, the participants went to the actual installation sites and practiced how to pull out from and install the device in the well.

The second session was organized and instructed by the Local consultant who had worked and had prior training on WLR installation and data retrieval by the Japanese consultant. The participants came from Gamo Gofa zone and Derashe woreda water offices, and also a hydrogeologist from the regional water resources bureau (WRB) participated in the training. They learned how to install WLRs through actual installation practice. Also they learned how to take the WLRs out and download the data from the device.

As a result of these two training sessions, all the zones and special woredas that have an observation well drilled in their territories, in addition to the relevant department in the ministry, acquired knowledge and skill in handling WRLs and now they are able to continue the monitoring work on their own. Keys to the wells were also handed over to each and all woreda water offices concerned.

5.4.4 Water level monitoring results

The water level data was retrieved from the following four (4) observation wells in the beginning of June 2011. The outline of the data and the wells is given in the following table.

Table 5.17: Outline of the Data and Well

Well name	RVS BH-1	RVS BH-2	RVS BH-3	RVS BH-10N
Duration	1 Jul. 2010 – 5 Jun. 2011	30 Jun. 2010 – 4 Jan. 2011	29 Jul. 2010 – 6 Jan. 2011	12 Mar. 2011 – 8 Jun. 2011
Data period	339 days	343 days	315 days	88 days
SWL (m)*	47.02	92.02	172.06	25.36
Data interval	1 hour	1 hour	1 hour	1 hour
Pipe stickup**	0.33 m	0.44 m	0.45 m	0.5

* Stick up measured from the top of the casing pipe during pump test, ** Measured from the concrete base

The water level (piezometric level) data was measured from the top of observation/casing pipes and was compensated for the barometric change that was recorded at the top of each observation well. The long term (all available period) and short term (beginning and ending three days) water level changes for each observation well are graphed in Figure 5.70 to Figure 5.73.

a. RVS BH-1

In Figure 5.70, the short term data shows clear pattern of daily fluctuation: the water level generally shows two distinctive peaks at around 4:00 and 15:00. On the other hand, it hits bottoms at around 10:00 and 23:00. The range of fluctuation is two to three centimeters. The water temperature is stable throughout a day at around 30 ^{o}C.

The daily average water level data was represented by the 6:00 o’clock data to plot the long term water level change of nearly one year. In the graph at the bottom of the figure, the water level is on the slight increase up to the end of November and then, levels off at around 47.01 m. From the end of December, it starts to gently decrease toward the beginning of May and hits the bottom in mid May and seems to rise again. The range of fluctuation is only 10 cm. In this area of north of Abaya lake, most rain occurs in the months of March to June. Thus, this trend does not immediately correspond to the amount of precipitation. However, it is likely that the increase is due to recharge by annual precipitation somewhere up-gradient. In that case, the recorded water levels clearly show annual fluctuation pattern.

b. RVS BH-2

At this site also, the short term data shows clear pattern of daily fluctuation: the water level generally shows two distinctive peaks at around 3:00 and 16:00 as can be seen in Figure 5.71. On the other hand, it hits bottoms at around 11:00 and 23:00. The range of daily fluctuation is two to three (2 to 3) centimeters. The water temperature is stable throughout a day at around 32 ^{o}C.

The daily water level data was represented by the 6:00 o’clock data to plot the long term water level change of nearly one year. In the graph at the bottom of the figure, the water level is on the slight increase up until early December and then, seems to stabilize at around 92.03 m. There also seems to be a sudden shift of averaged water level in the beginning of October. The water level keeps increasing gently towards the beginning of March and levels off until the end of April. Then, it starts to gently decline toward the end of June. The sign of water level picking up in June is not observed in this data. The range of increase is as small as 8 cm but the day-to-day fluctuation is larger compared with RVS BH-1. In Meki area, most rain occurred in the months of July to September in 2010. Thus, this trend does not immediately reflect the amount of precipitation. However, it is likely that the increase is due to recharge by annual precipitation somewhere up-gradient and this recharge, although with significant time lag, seem to cause this annual fluctuation pattern of the water level.

c. RVS BH-3

Figure 5.72 shows a clear daily fluctuation pattern at this site: the water level generally shows two distinctive peaks at around 3:00 and 18:00. On the other hand, it hits bottoms at around 10:00 and 23:00. The range of daily fluctuation is within four (4) centimeters. The water temperature is stable throughout a day at around 30 ^oC.

The daily water level data was represented by the 6:00 o'clock data to plot the long term water level change of about 10 months. In the bottom long term graph, the water level is relatively stable at around 172.09 m with remarkable fluctuation until mid October and then, abruptly shifts to a higher level of 172.14 m. This level of water level is maintained with fluctuation until the beginning of January and again suddenly drops by around five centimeters. Then it stabilizes at around 174.7 m and maintains that level for the following 5 months. The range of increase is as small as 10 cm but the day-to-day fluctuation is larger compared with RVS BH-1. In Sheshemene area, most rain occurred in the months of February to May and October has very small precipitation in 2010. Thus, this trend does not immediately reflect the amount of precipitation. However, it is likely that the increase is due to recharge by annual precipitation somewhere up-gradient. In that case, the recorded water level shows sudden increase and decrease instead of gentle changes observed in the other boreholes. This may be due to special conditions in the recharge area and of the aquifer.

d. RVS BH-10N

The short term graphs in Figure 5.73 shows a clear daily fluctuation pattern at this site: the water level generally shows two distinctive peaks at around 3:00 and 16:00 in the 3-day data of March but this daily fluctuation pattern somehow become less clear and peaks also shift in June data. The range of daily fluctuation is within two (2) centimeters. The water temperature is stable throughout a day at around 25.9 ^oC.

The daily water level data was represented by the 6:00 o'clock data to plot the long term water level change of about three months. In the bottom long term graph, the water level is relatively stable at around 25.93 m for the first half a month and starts gentle decline until mid May and then, shows rather rapid increase towards the end of May. However after hitting a peak of 25..91 m at the beginning of June, it starts decreasing again. The range of increase is no more than 6 cm. In this area (Ogolcho), most rain occurs in May to September and especially July to September account for more than 50% of annual rain. Thus, this trend does not immediately reflect the amount of precipitation. Therefore the water level is likely to increase after June as observed in other boreholes.

e. The other wells and overall observation

The other wells were completed after June 2011 and the water level monitoring data was not collected from these wells. As a whole, the groundwater levels (piezometric levels) in all the boreholes, except for No-10N, show periodic change throughout a year although the degree of change is merely within 15cm. In general, the water levels tend to rise during the dry season and culminate around December, peak of dry season, and gradually decrease toward

June. This is because the water in confined aquifers that do not have immediate recharge of water from the overlying layers and circulation of such groundwater is generally slow. However, the ground water levels still show slight seasonal fluctuation pattern that is probably caused by recharge from precipitation in somewhere distant recharge area.

5.5 Challenges in well drilling in Rift Valley Area

This section presents the drilling problems experienced during this study and discusses possible counter-measures that may be employed in future drilling projects in the Rift Valley area.

The Rift Valley Lakes Basin is generally said to be a difficult area for drilling. The subsurface geology is variant and unpredictable. In most cases, drillers encounter succession of layers of hard rock (such as ignimbrite and rhyolite) and unconsolidated formations such as pumice and tuff. Some of the hard rocks are highly consolidated and take a lot of time to drill through by the mud rotary system and such rocks in many cases develop a network of open joints/fracture and, thus, sudden mud loss during the drilling operation is common if mud rotary system is used. On the other hand, one of the common unconsolidated formations is pumice tuff. This is very porous and also collapsible and sometimes makes air drilling difficult because application of high pressure air disturbs the borehole wall around the drill bit. In some areas, highly permeable sand and gravel layers occur as a major aquifer and such formations are highly collapsible making borehole logging and casing installation difficult. These collapsible formations are difficult to drill without proper protection of borehole wall by the use of properly controlled drill fluid or by the use of work casing, especially when drilling by the DTH.

At Site No-2, the drilling was originally planned up to 250m. However due to persistent collapsing of borehole wall, especially within the aquifer and due to unexpected sudden mud loss, the crew was forced to terminate drilling at a shallower depth of 172m because it was found technically beyond the capacity of the local driller to drill deeper. These conditions also affect installation of casing and even borehole logging. As a matter of fact, logging could not be done to the bottom of borehole at Site No-3. Also it took a considerable effort to install casing pipes at this site.

The lessons learned in this study should be utilized in for future drilling work where the target depth goes as deep as 400m. Since there is no perfect solution to these problems, the study team will employ the following strategy to perform the drilling work better in the second year of the study.

- Sufficient basic drilling materials (water and bentonite) should be prepared on site
- Application of slow but safe drilling method
- Use of more drill collar to apply down-force on the bit
- Use of longer surface work casing

5.5.1 Record of drilling problems faced during the study

a. Technical problems

The following table summarizes the problems encountered during the drilling work. The three major problems of drilling in the study area are a) drill bit jamming, b) circulation loss, and c) formation collapsing in borehole. Other non-essential problems such as machine troubles and bad weather condition usually add to these problems in actual field drilling work.

Table 5.18: Major Drilling Problems Encountered at Each Site

Site No.	Problem type	Detail	Counter measure
No-2	Circulation loss Collapsing soil	Large amount of mud loss occurred in the pumice sand formation below 127m.. Collapsing of borehole wall made it difficult to apply high air pressure and to install casing and screen pipes.	Use of bentonite and natural soil balls thrown into the borehole to seal the leaky section. Drilled through the casing pipe to install the casing.
No-3	Collapsing soil	Extensive collapsing of borehole wall occurred in the top 70m.	Surface work casing was applied to the section
No-4	Bit jamming High water pressure	Drill bit jamming occurred in the blocky basalt layer around 150m and the bit was lost. High water pressure due to shallow water level made it difficult to work efficiently with DTH system that uses a compressor.	Attempt to fish out the drill bit was made but failed. Another well had to be drilled beside the it. The drilling was changed to mud rotary method.
No-5N and 5	Bit jamming Hot water spring	Drill bit jamming occurred in the blocky basalt layer around 40m (at No-5N). Hot water of about 50°C started flowing out during development. It made it impossible to conduct pumping test.	Drilled with larger diameter bit and installed surface work casing to cover the jamming section. The spring flow rate was measured in a ditch and the protection fence was set up around the well.
No-10N	Circulation loss	An extensive and successive circulation loss occurred below 140m. Drilling had to be continued and the cutting sample was not recovered.	Several attempts to seal the leaky section were made but failed.

b. Operational problems

Although there are some special ways to technically solve these problems raised above in some countries, it is generally difficult both technically and financially to cope with the problems, especially in developing courtiers. Therefore in Ethiopia, the drilling companies often discuss with their clients and negotiate amendment of contracts when such problems occur. Also, both the drilling companies and the clients in principle conduct drilling projects only for the purpose of water supply and thus, drilling work is sometimes terminated when they get sufficient water from the borehole before reaching the planned depth. In other words, they are not used to conduct drilling work or contracts that dictate strict observation of technical specifications such as collecting samples regularly for the purpose of an academic study. Also, as far as the study team observed, the drillers tend to drill as quickly as possible regardless of the type of formation that they are drilling. In addition, most drillers operate preferably or exclusively in either mud rotary or DTH method and they can not switch to more appropriate method quickly in response to the drilling condition. This kind of situation hampers fostering of the drilling sector and technical skills of the technicians and engineers in the sector.

5.5.2 Possible counter measures

a. Bit jamming

This problem occurred in two different conditions: 1) the drilling bit got caught between relatively large pieces of rock that were protruding from the borehole wall in the section of blocky or fractured hard volcanic rocks, and 2) the bit was buried in a pile of cuttings or formation materials that fell off the borehole wall.

Once the drill bit gets jammed, there is no other ways than to pull up the bit with some force. Drillers usually have the know-how to release the bit through experience. However, some drill rig operators recklessly applied sudden force to give a quick turning motion to the bit in an effort to release the bit. Then that action led to detachment of the drill bit, which happened twice. The followings are the measures to avoid bit jamming.

- Careful and slow drilling practice to avoid unnecessary quick motion of the bit
- Use of surface casing to cover the problematic section
- Use of mud rotary drilling to prevent wall collapse

b. Circulation loss

This problem occurred when there was a very permeable zone in the borehole wall such as open fracture zones in welded tuff, scoriatic and breccia formations and also highly porous zones in soft sand and especially in pumice layers. When it happened in the study area, the drill fluid stopped flowing back to the ground and then, a few cubic meters of mud in the mud pit was lost usually within 10 to 15 minutes. The detailed record of mud loss at each site is given in Table 5.23. In some cases, the mud loss occurred at an upper section that had been already drilled a few days before. This indicates that the section was properly sealed by drill mud at first but its sealing effect was weakened due to a change in drilling condition or some accidents during the drilling operation. The following measures can be taken to cope with the problem.

- Use of thickened mud as drill fluid or use of drill mud additives
- Use of concentrated mud or mud dough in the borehole to seal the leakage section
- Switch to DTH method
- Cement grouting of the leakage section (requires some skill)
- Use of surface/work casing to cover the permeable section
- Use of other coarser sealing materials such as chaffs or saw dust

c. Collapsing formation

This problem usually occurs when drilling with air in unconsolidated pyroclastic sediments or derived formations (pumice sand). In the study area, the problem was outstanding in the permeable pumice sand section that yields a large amount of water at site No-2. Also, in many cases such collapse of borehole wall occurred during the downtime after the drilling work was suspended for some reason. The following measures are recommended.

- Avoid use of excessive air pressure or rough motion of drill bit in boreholes
- Minimize the down-time as much as possible and keep filling the borehole with mud if the suspension of drilling is unavoidable.
- Use of surface/work casing to protect the problematic section
- Use of mud rotary drilling method if drilled by DTH
- Thickening of drilling fluid

d. Operational issues

As mentioned earlier, the most fundamental and most effective (in terms of cost as well) way of avoiding most of these problems is try to secure the borehole wall as the drilling progresses. This requires close observation of the drilling samples to assess the nature of the formation that is drilled, and also proper adjustment of air pressure applied in the borehole and drill mud density. This and other related problems have to be solved through providing training to drill rig operators and drilling companies from both public and private sectors. EWTEC may be one of the organizations that can give such training. Drill rig operators are especially expected to lean the theoretical aspect of drilling technique and hydrogeology.

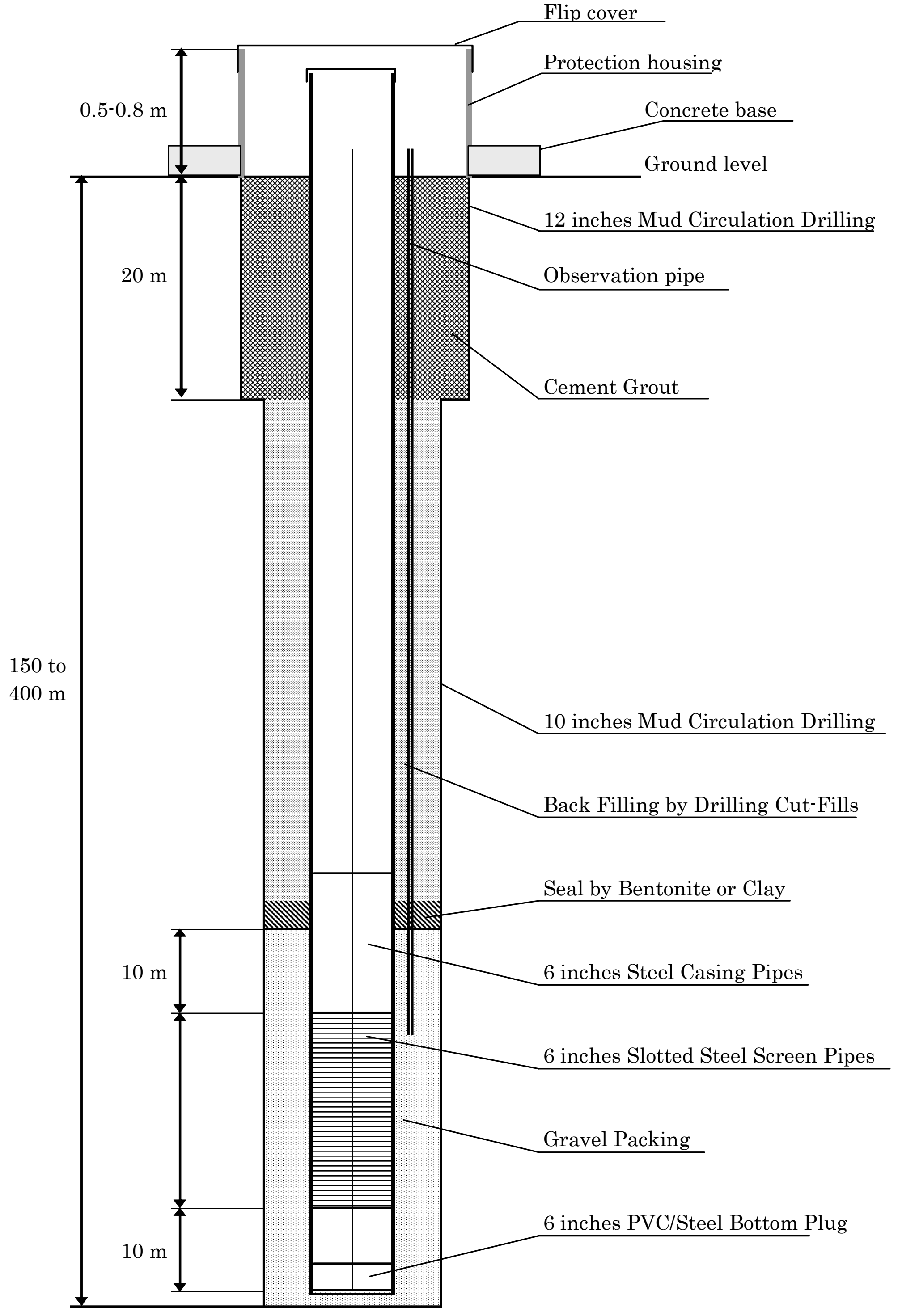


Figure 5.38	Specification of Observation Well
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

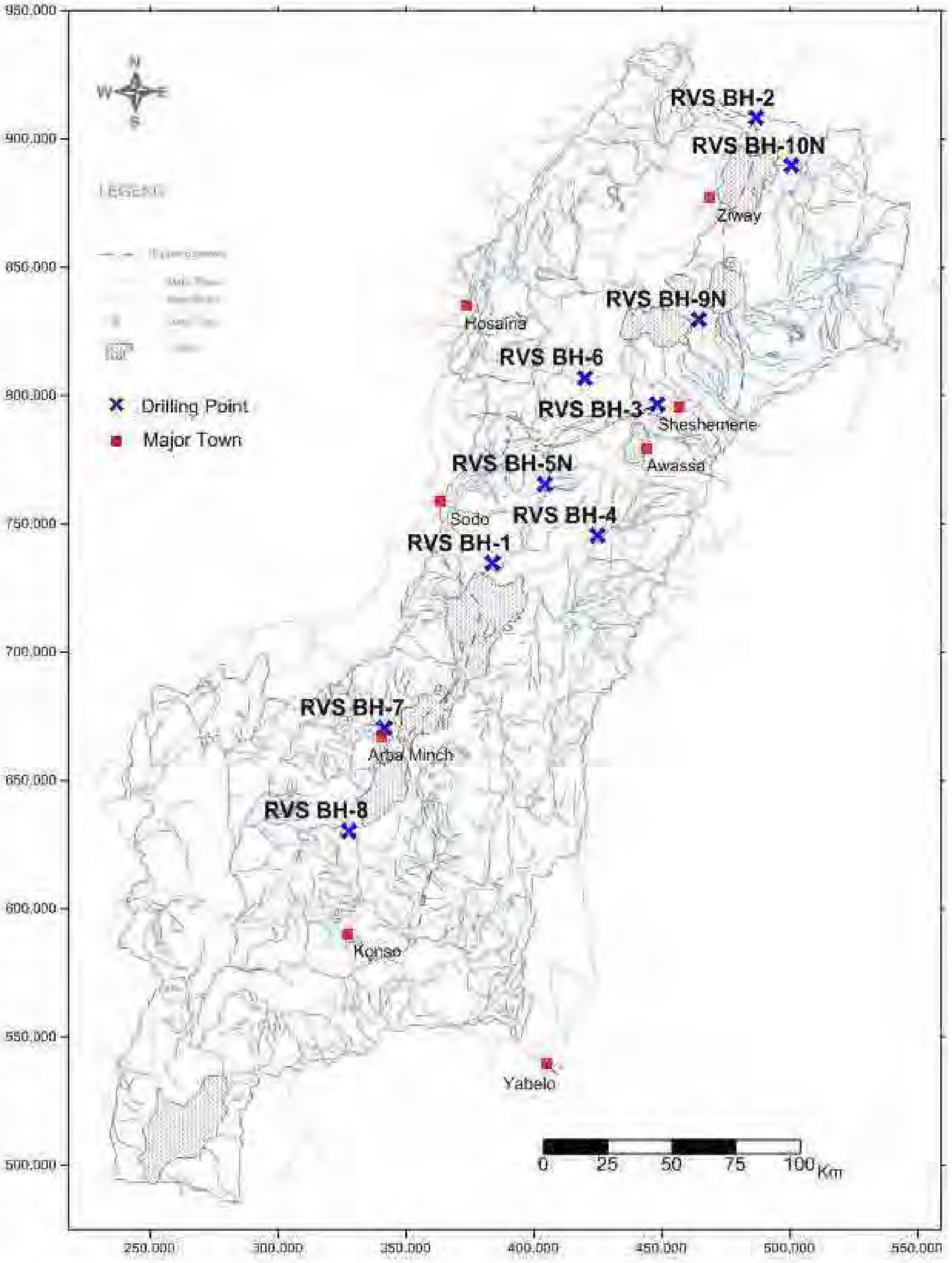
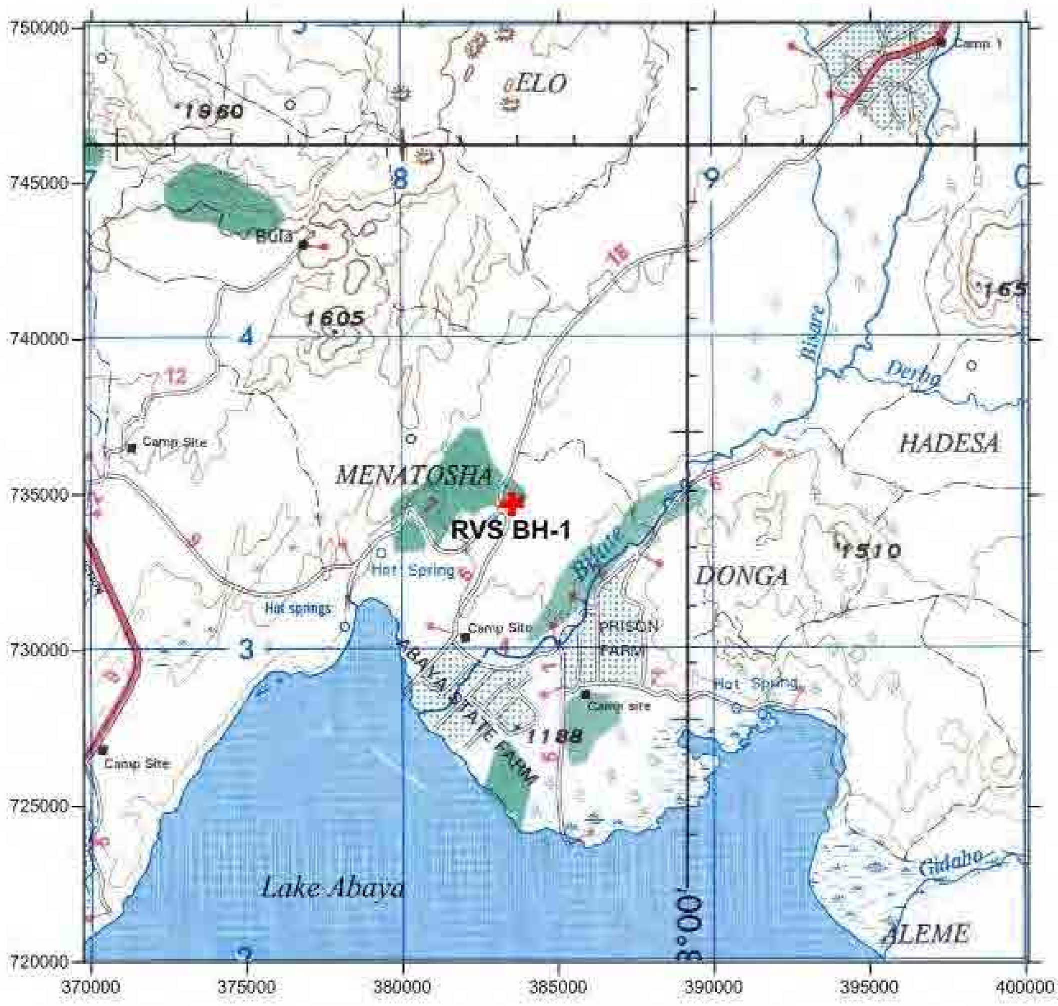


Figure 5.39	Location of Observation Wells

THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

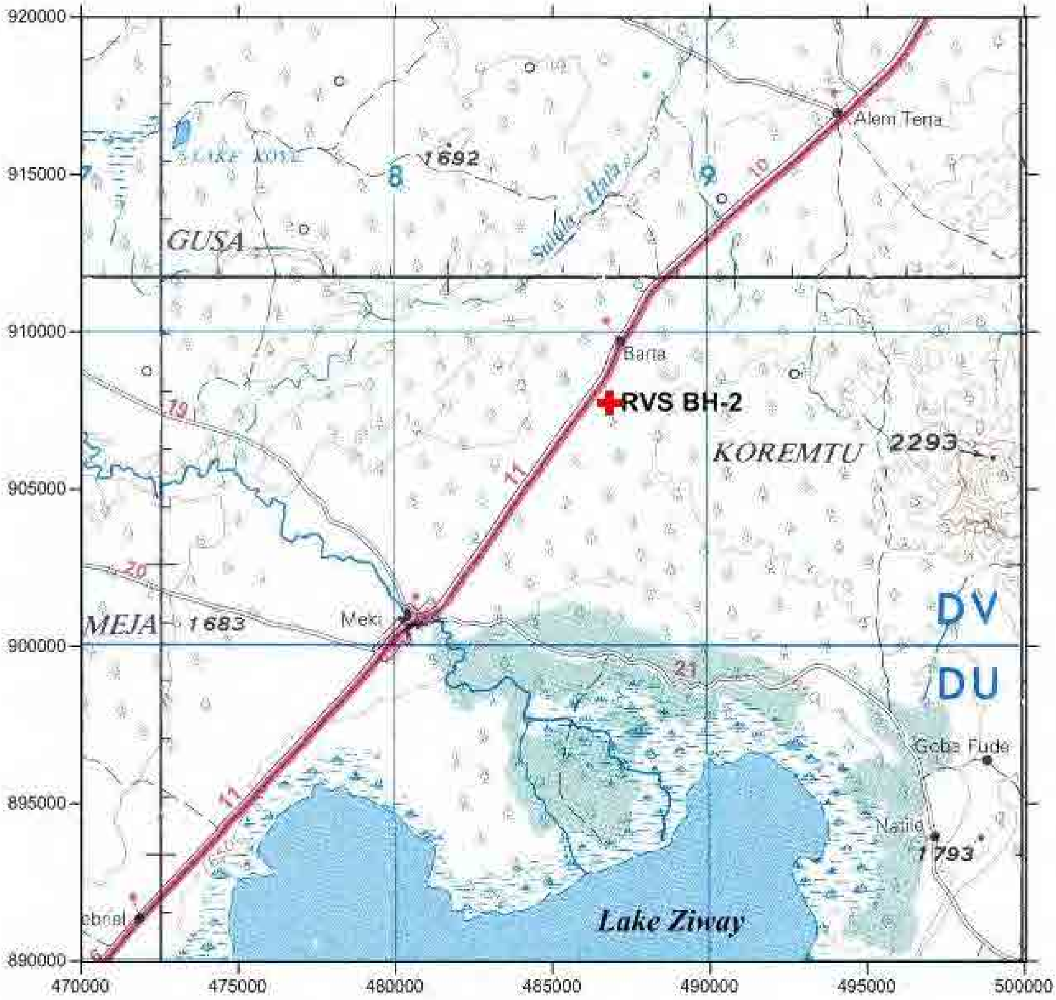


Site Information

Site No.	RVS BH-1		Remarks
GPS coord.*	383508 E	734719 N	- At junction of three roads, 20m off the road - Access to the site is difficult in rainy season - 1.5 hours from Sodo, 2.5 hours from Awassa
Region	SNNPRS		
Zone	Walayta		
Woreda	Humbo-Tebela		
Kebele	Abaya Chokane		

* UTM Zone 37, Datum Adindan

Figure 5.40	Location of Observation Well (RVS BH - 1)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

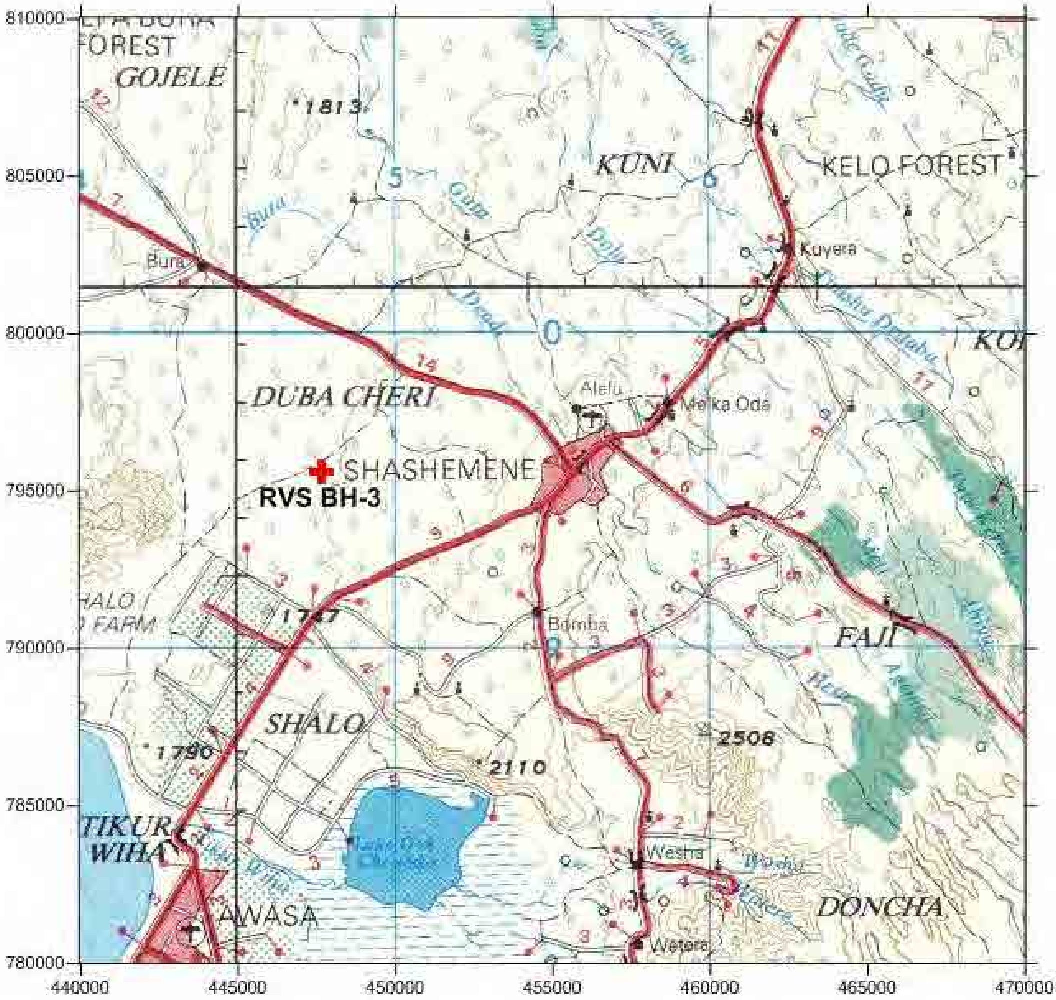


Site Information

Site No.	RVS BH-2		Remarks
GPS coord.*	486788 E	907743 N	- Located in a flat crop field, 200m off the paved road - Access to the site is difficult after heavy rain - 15 minutes from Meki town
Region	Oromia		
Zone	East Showa		
Woreda	Bora		
Kebele	Barta Sami		

*UTM Zone 37, Datum Adindan

Figure 5.41	Location of Observation Well (RVS BH - 2)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

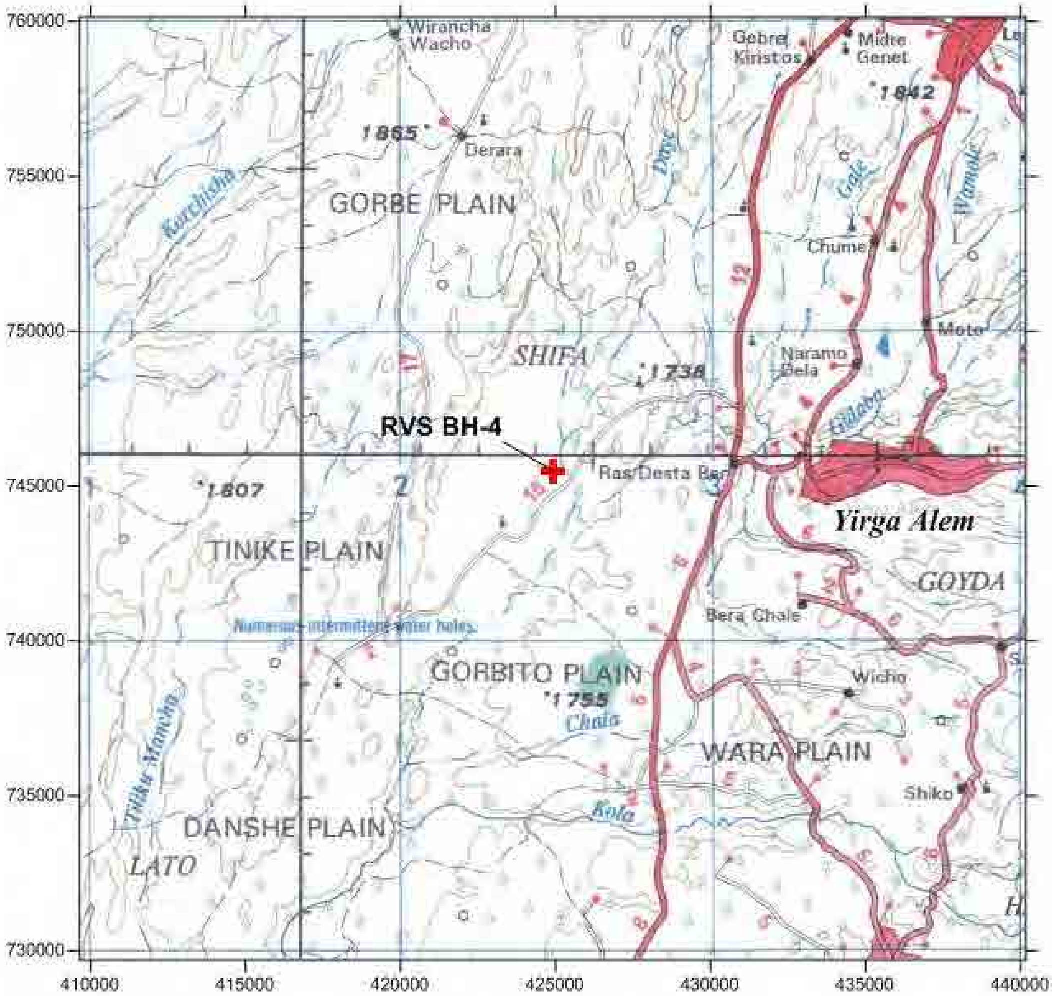


Site Information

Site No.	RVS BH-3		Remarks
GPS coord.*	447623 E	795610 N	- Located in a flat crop field, a few km off the paved road - Access to the site is difficult after heavy rain - Many small paths to get to the site - 25 minutes from Sheshemene town
Region	Oromia		
Zone	West Arsi		
Woreda	Sheshemene		
Kebele	Meja Dema		

*UTM Zone 37, Datum Adindan

Figure 5.42	Location of Observation Well (RVS BH - 3)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

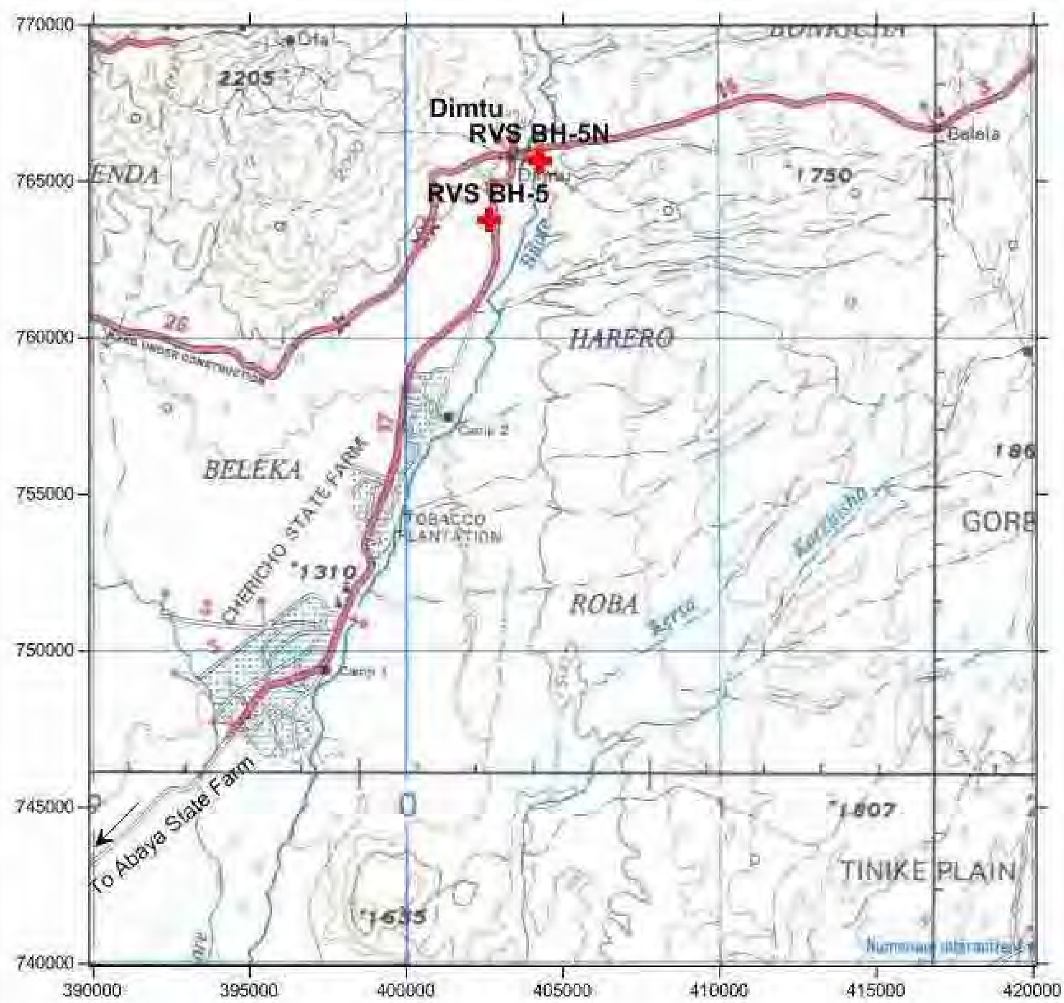


Site Information

Site No.	RVS BH-4		Remarks
GPS coord.*	424918 E	745467 N	- About 300m off the main gravel road - Next to a primary school - Access to the site is difficult in rainy season - 1 hour from Hawassa
Region	SNNPRS		
Zone	Sidama		
Woreda	Loka Abaya		
Kebele	Chancho		

* UTM Zone 37, Datum Adindan

Figure 5.43	Location of Observation Well (RVS BH - 4)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

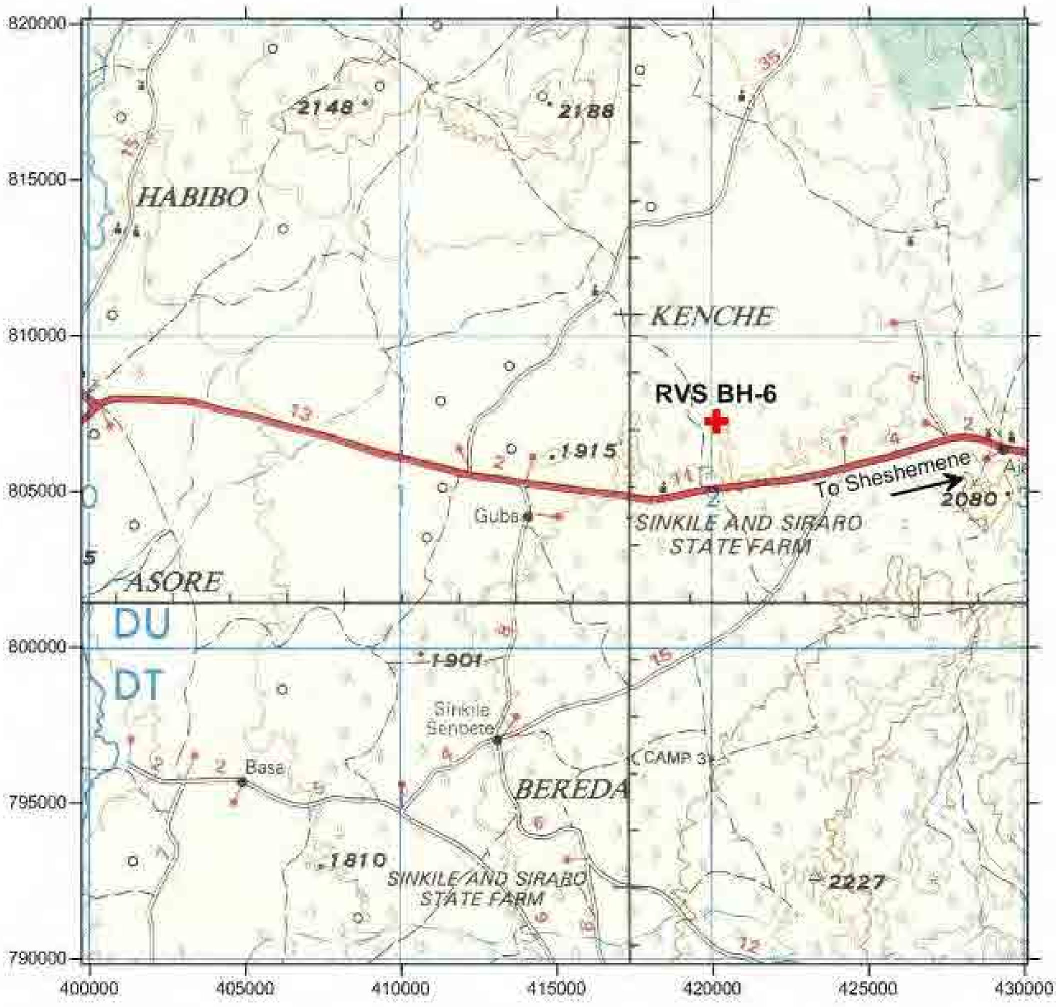


Site Information

Site No.	RVS BH-5N		Remarks
GPS coord.*	404286 E	765682 N	- Located on the left bank of Bilate river, 300m off the gravel road to Awassa - Access to the site is reletively easy after gravel was layed out on the muddy section - 5 minutes from Dimtu town, 2 hours from Hawassa - The land is considered not to belong any regions nor to woredas due to political reasons
Region	NA(Oromiya/SNNPRS)		
Zone	NA		
Woreda	NA		
Kebele	NA		

* UTM Zone 37, Datum Adindan

Figure 5.44	Location of Observation Well (RVS BH – 5N)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



Site Information

Site No.	RVS BH-6		Remarks
GPS coord.*	420139 E	707171 N	- Located in a gently sloping crop field, a few km off the paved road to Alaba - Close to regional boarder - Access to the site is difficult after heavy rain - 1 hour from Sheshemene town
Region	SNNPRS		
Zone	N/A		
Woreda	Alaba Special		
Kebele	Yeye Alaba		

* UTM Zone 37, Datum Adindan

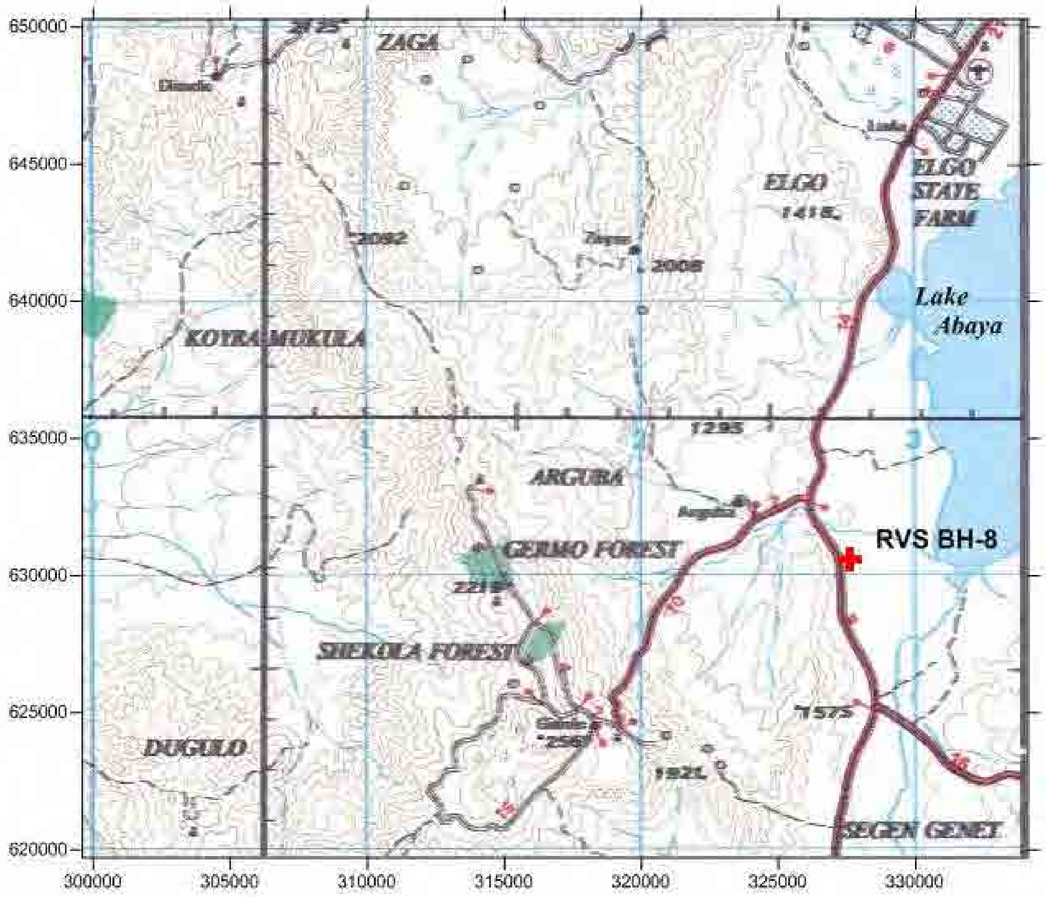
Figure 5.45	Location of Observation Well (RVS BH – 6)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

Site Information

Site No.	RVS BH-7		Remarks
GPS coord.*	341712 E	670506 N	- Located 300m off the asphalt road, in front of Arbaminch Univ. - Access to the site is difficult in rainy season - 15 min from Arbaminch town
Region	SNNPRS		
Zone	Gamo gofa		
Woreda	Arbaminch Zuria		
Kebele	Weze		

* UTM Zone 37, Datum Adindan

Figure 5.46	Location of Observation Well (RVS BH – 7)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



Site Information

Site No.	RVS BH-8		Remarks
GPS coord.*	327946 E	630717 N	- Located in a flat crop field near a river - 200m off the flat gravel road - Access to the site is difficult after heavy rain - 30 minutes from Gidole town
Region	SNNPRS		
Zone	N/A		
Woreda	Derashe special		
Kebele	Walesa / Kolta		

* UTM Zone 37, Datum Adindan

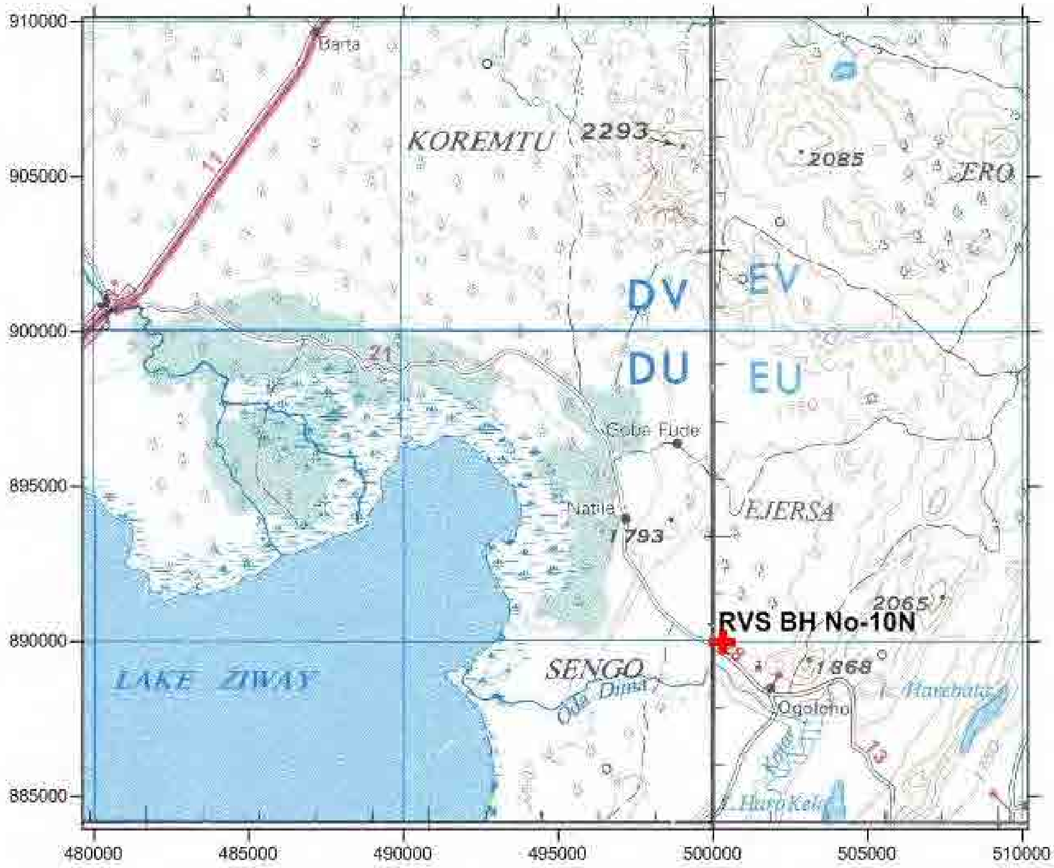
Figure 5.47	Location of Observation Well (RVS BH – 8)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

Site Information

Site No.	RVS BH-9N		Remarks
GPS coord.*	464826 E	829769 N	- Located in a flat crop field, 200 m off the paved road - Access to the site is not difficult even after rain - 40 minutes from Sheshemene town
Region	Oromia		
Zone	West Arsi		
Woreda	Arsi Negele		
Kebele	Hadda Bosso		

* UTM Zone 37, Datum Adindan

Figure 5.48	Location of Observation Well (RVS BH – 9N)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



Site Information

Site No.	RVS BH-10N		Remarks
GPS coord.*	500516 E	889860 N	- Located in a flat crop field, 300 m off the main gravel road to Ogolcho town - Access to the site is difficult after heavy rain - 50 minutes from Meki and 1 hour from Acela town
Region	Oromia		
Zone	Arsi		
Woreda	Ziway Dugda		
Kebele	Ubo Bericca		

* UTM Zone 37, Datum Adindan

Figure 5.49	Location of Observation Well (RVS BH – 10N)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

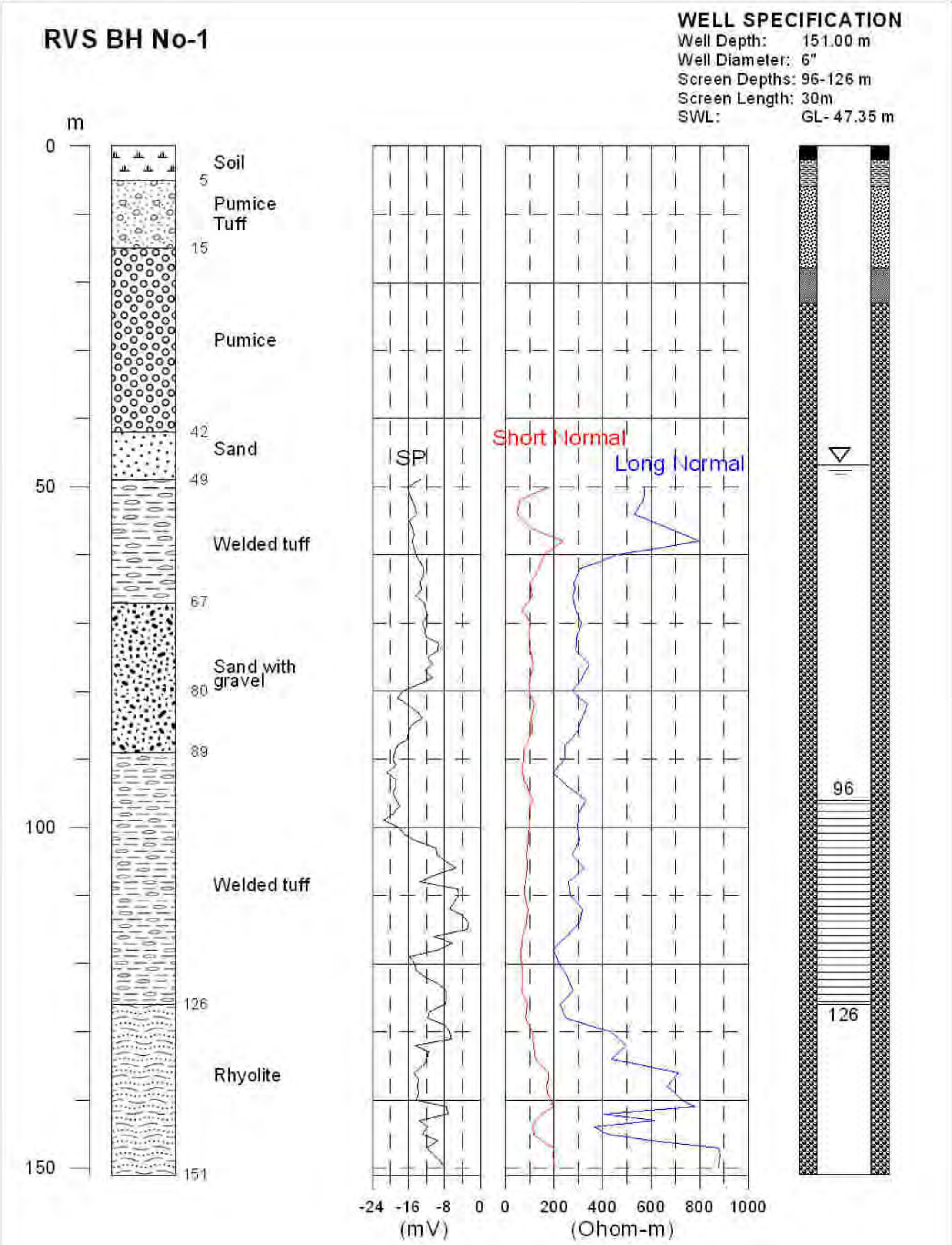


Figure 5.50	Drilling Log of Borehole (RVS BH-1)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

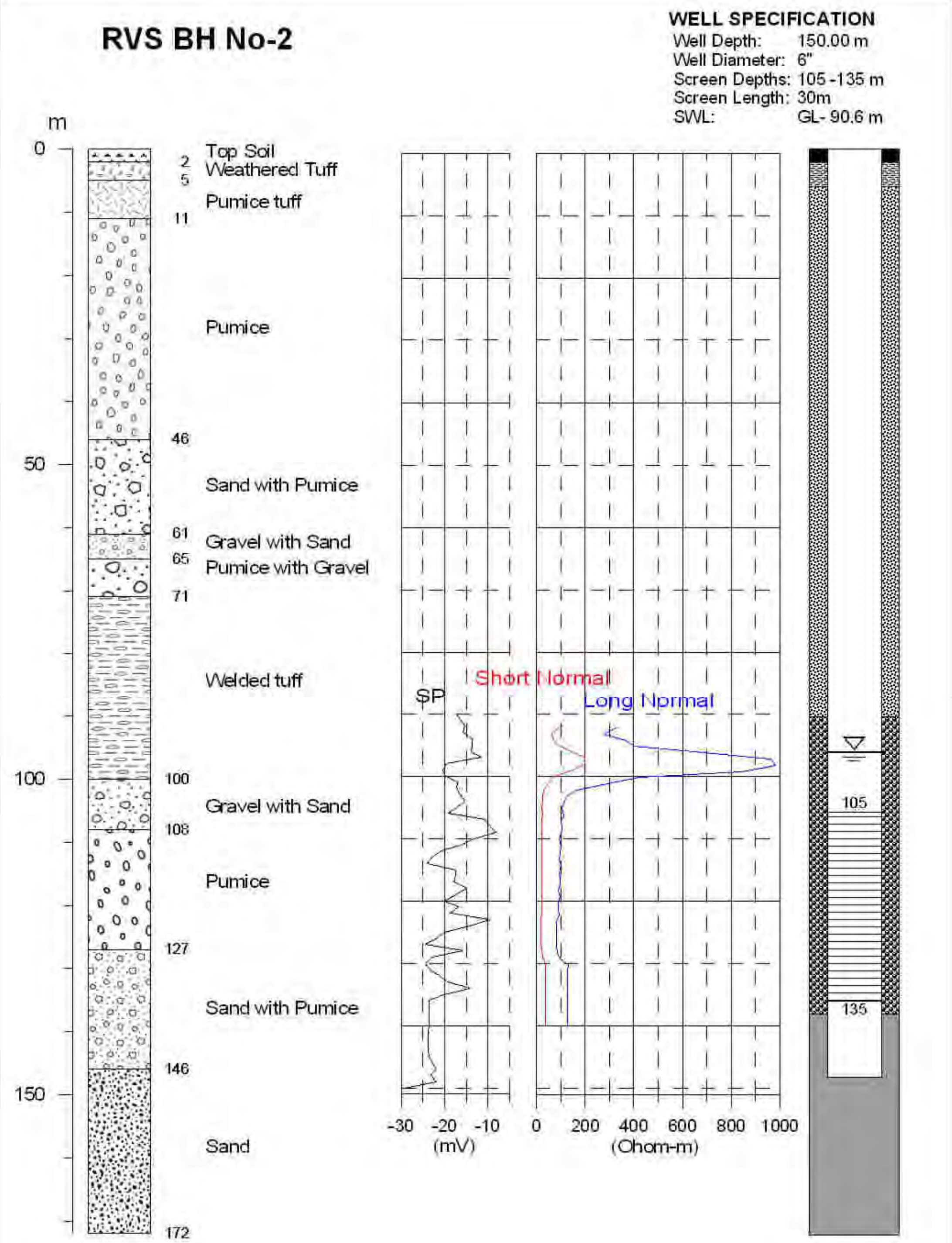


Figure 5.51	Drilling Log of Borehole (RVS BH-2)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

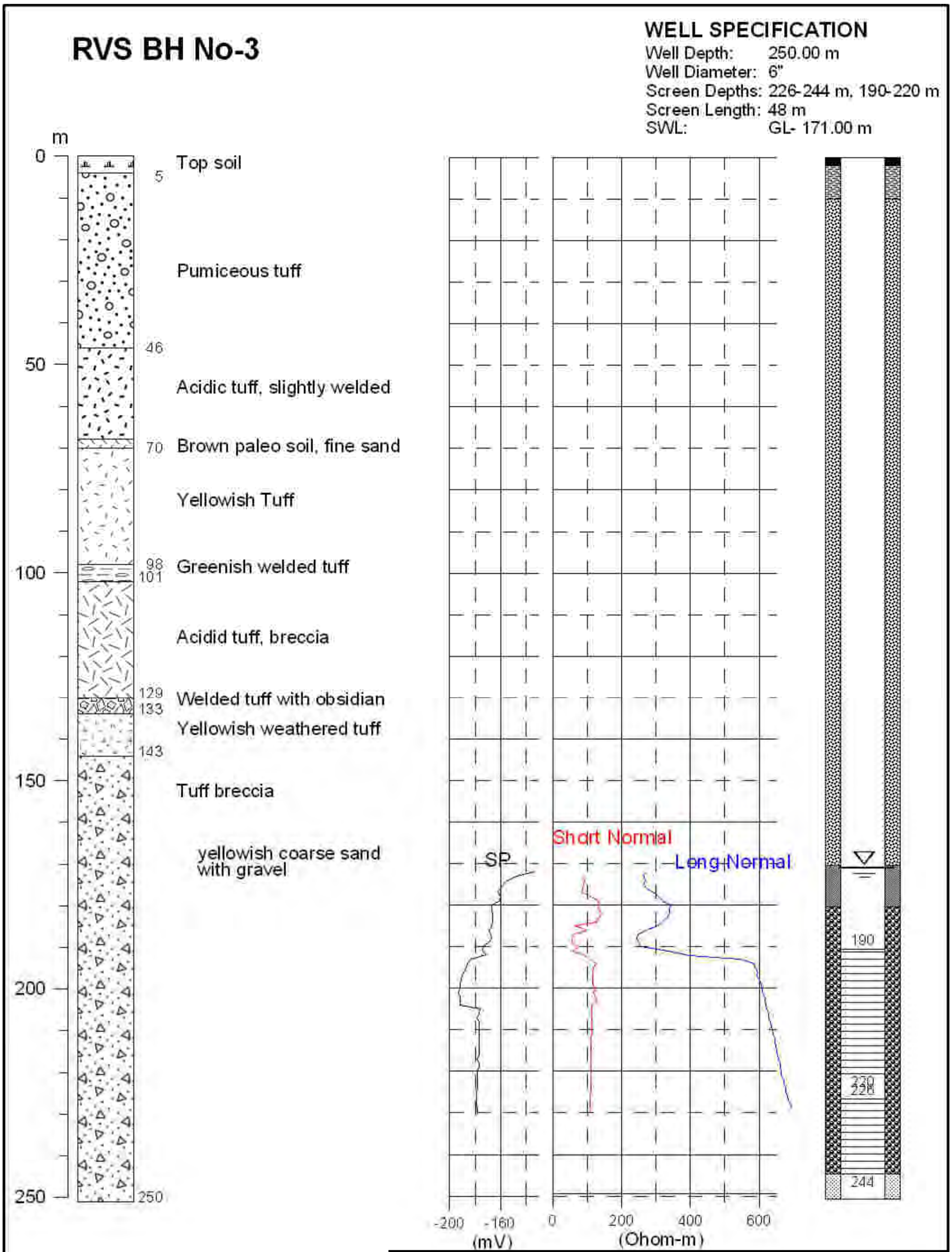


Figure 5.52	Drilling Log of Borehole (RVS BH-3)

THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

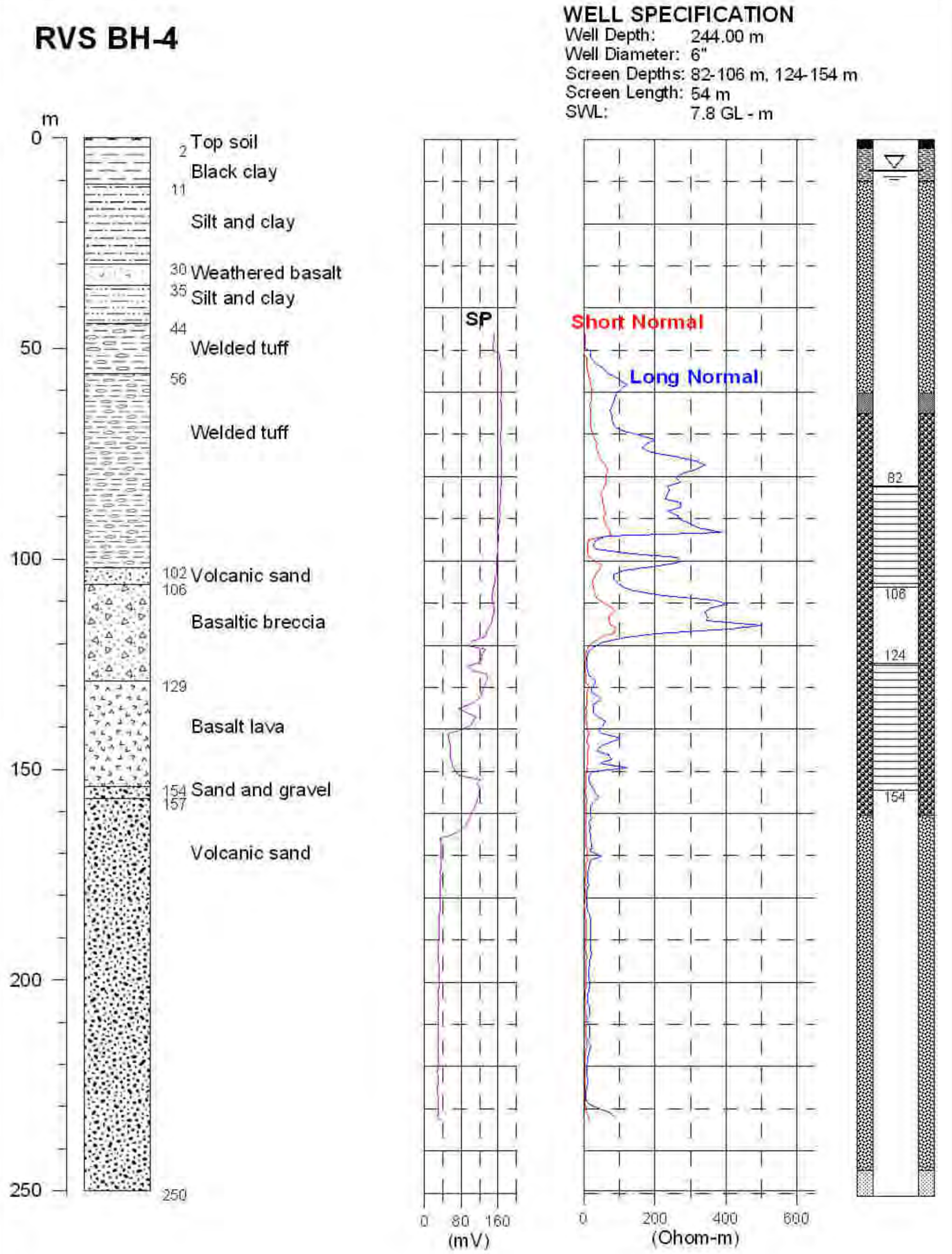


Figure 5.53	Drilling Log of Borehole (RVS BH-4)

THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

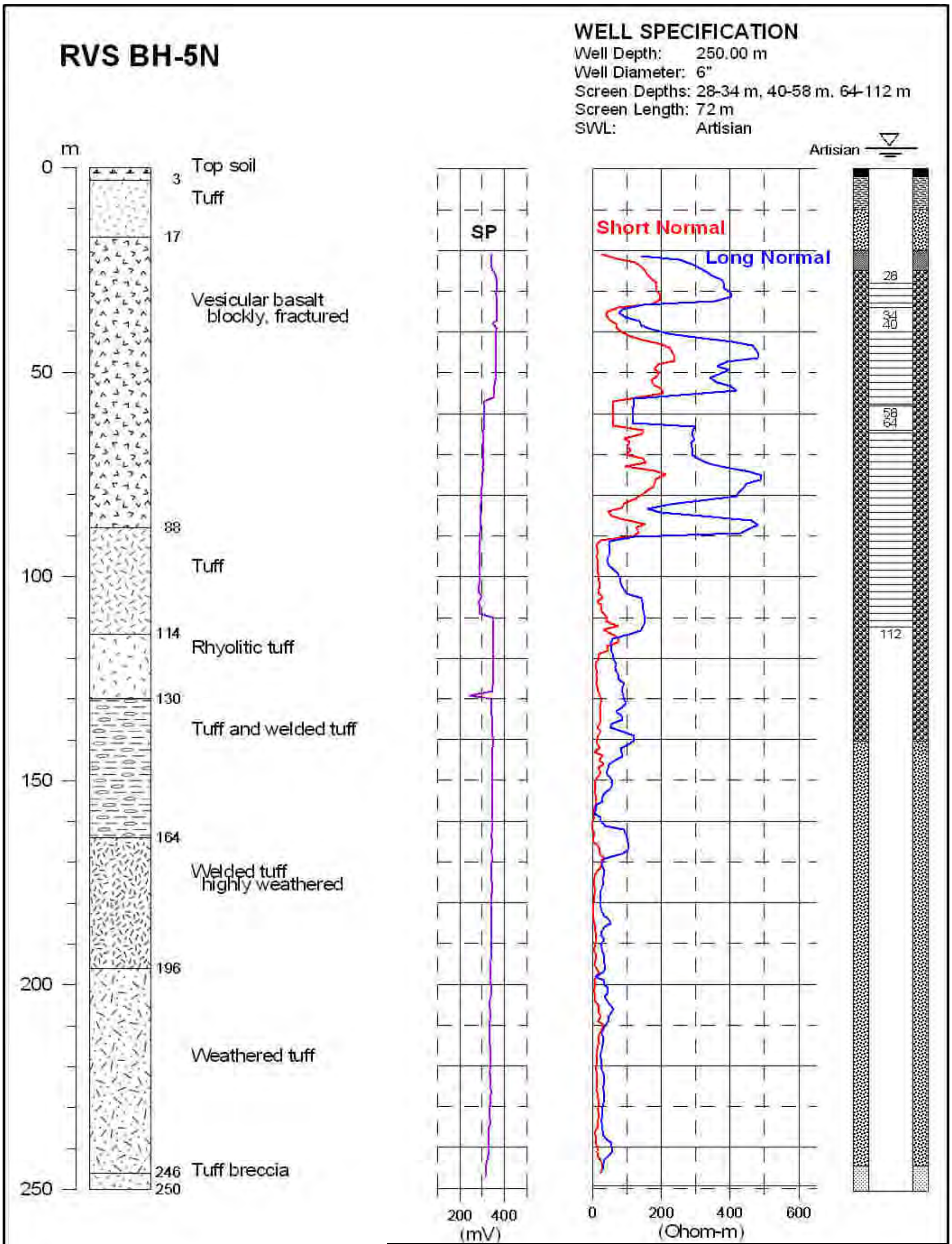


Figure 5.54	Drilling Log of Borehole (RVS BH-5N)

THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

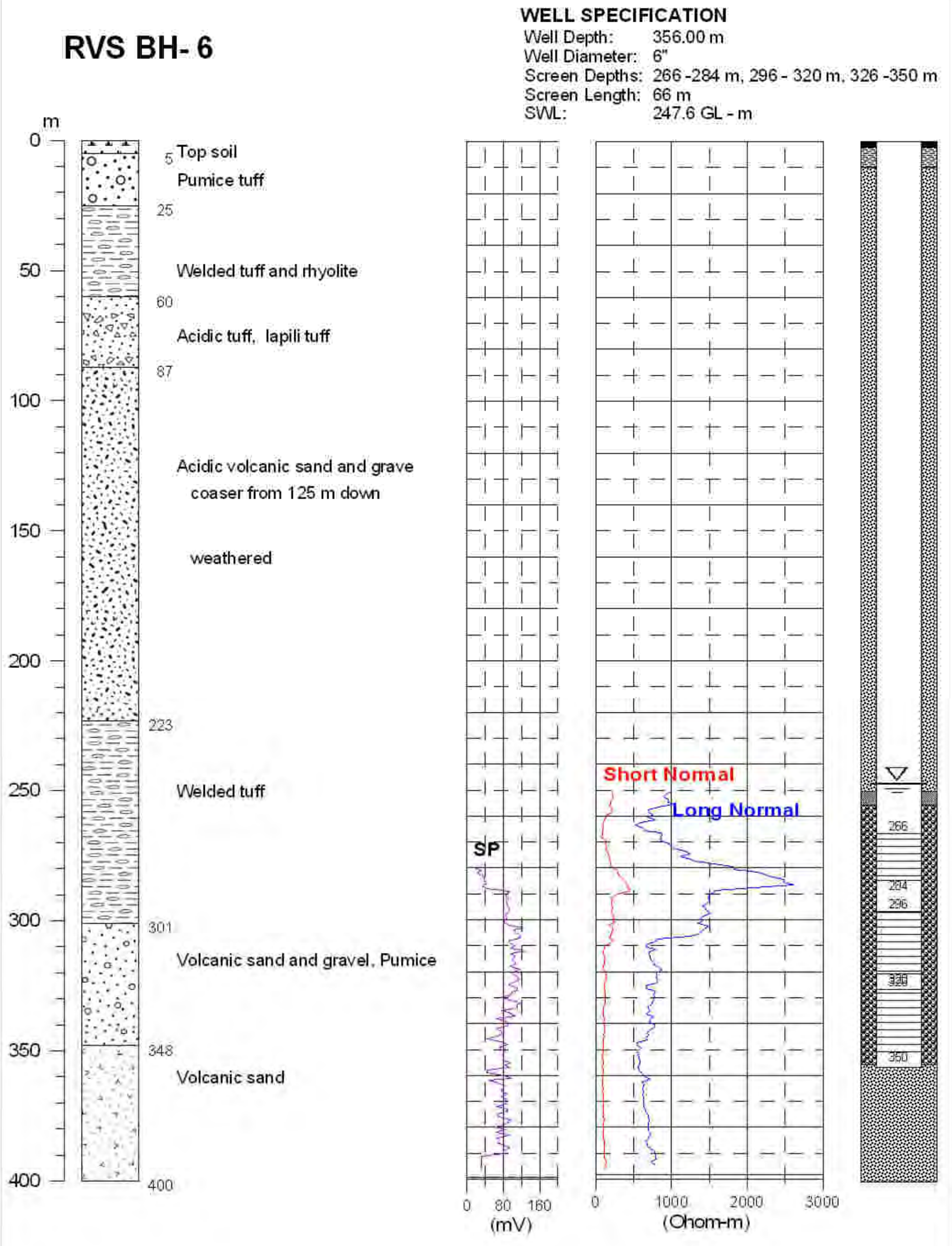


Figure 5.55	Drilling Log of Borehole (RVS BH-6)

THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

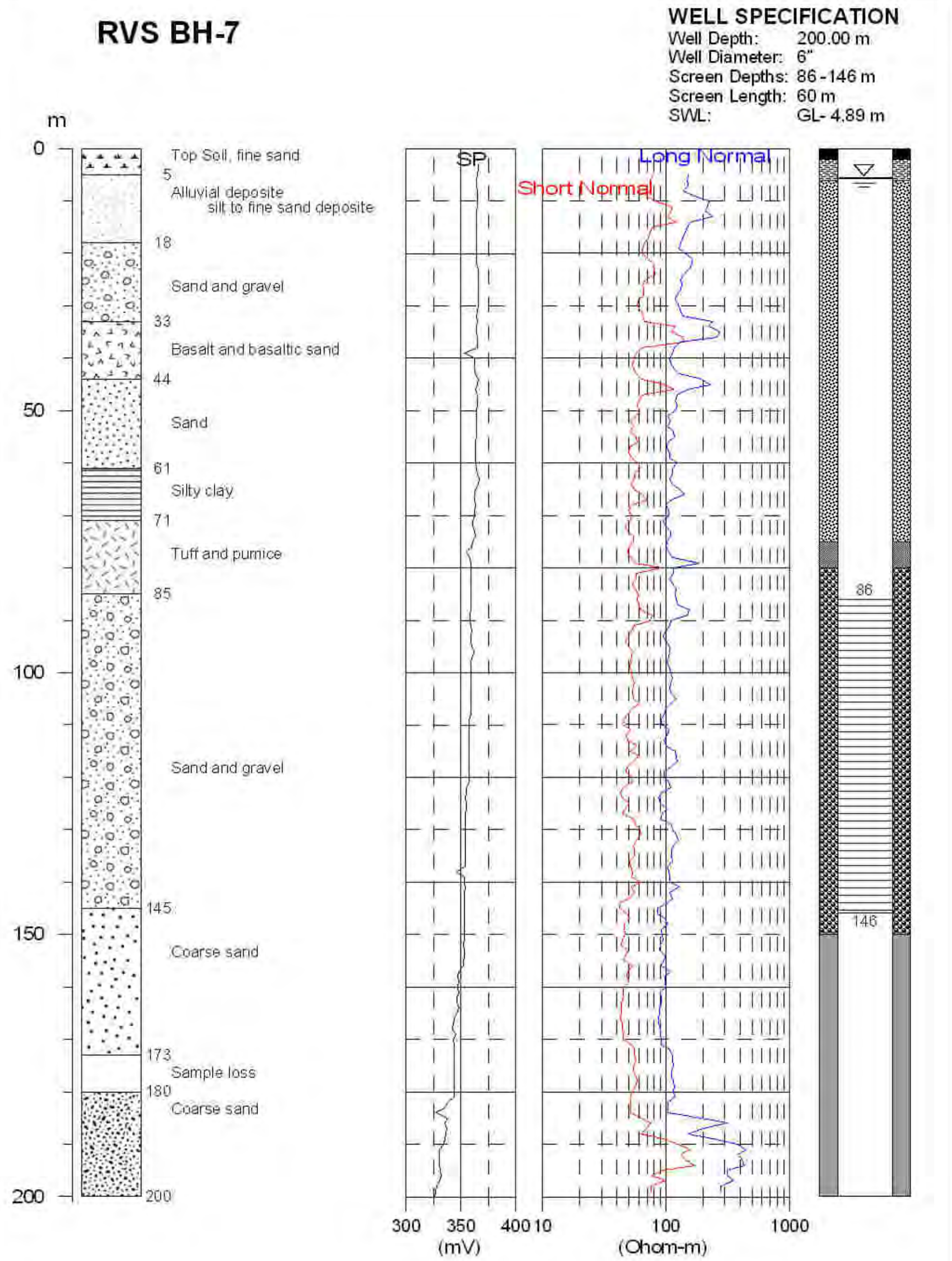


Figure 5.56	Drilling Log of Borehole (RVS BH-7)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

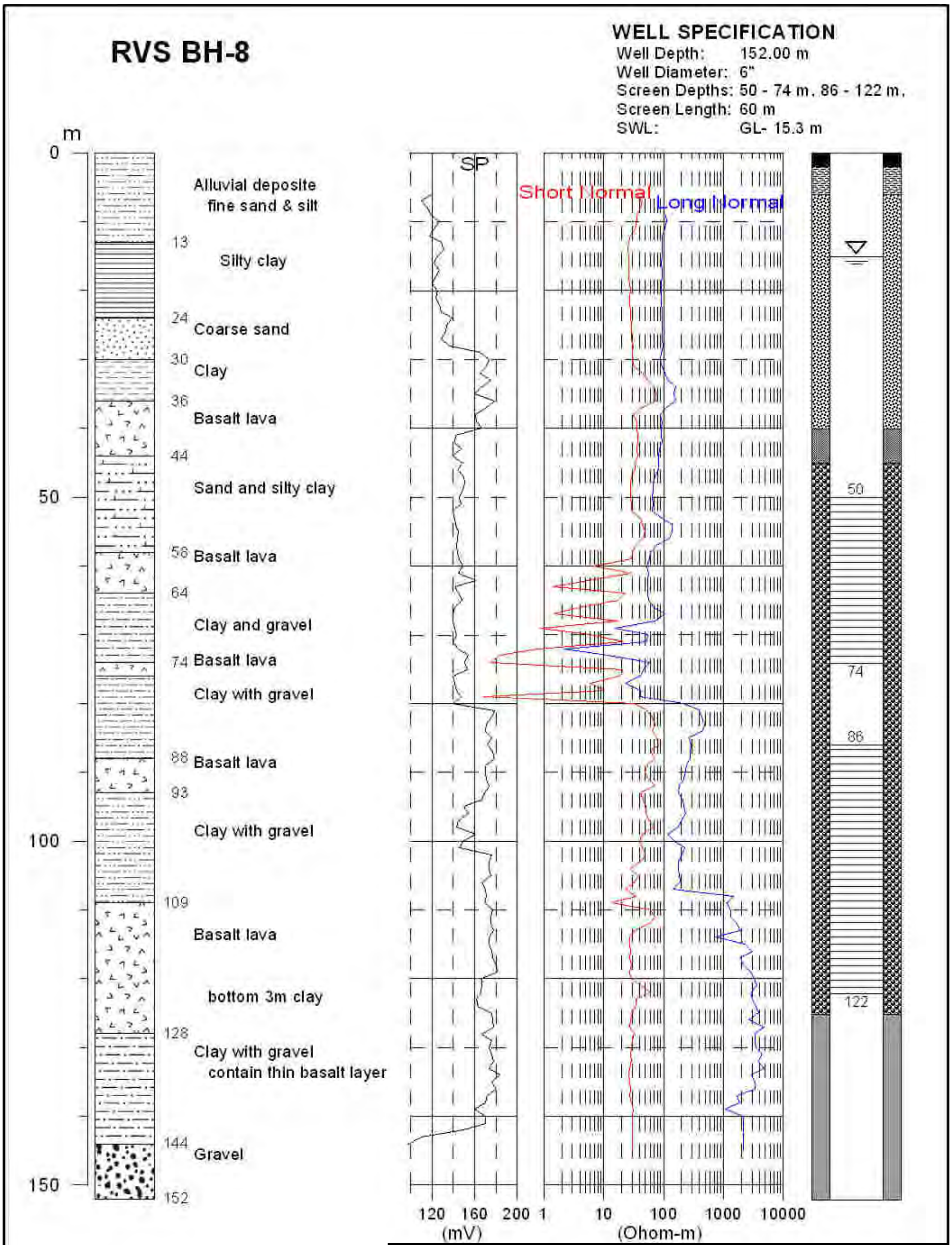


Figure 5.57	Drilling Log of Borehole (RVS BH-8)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

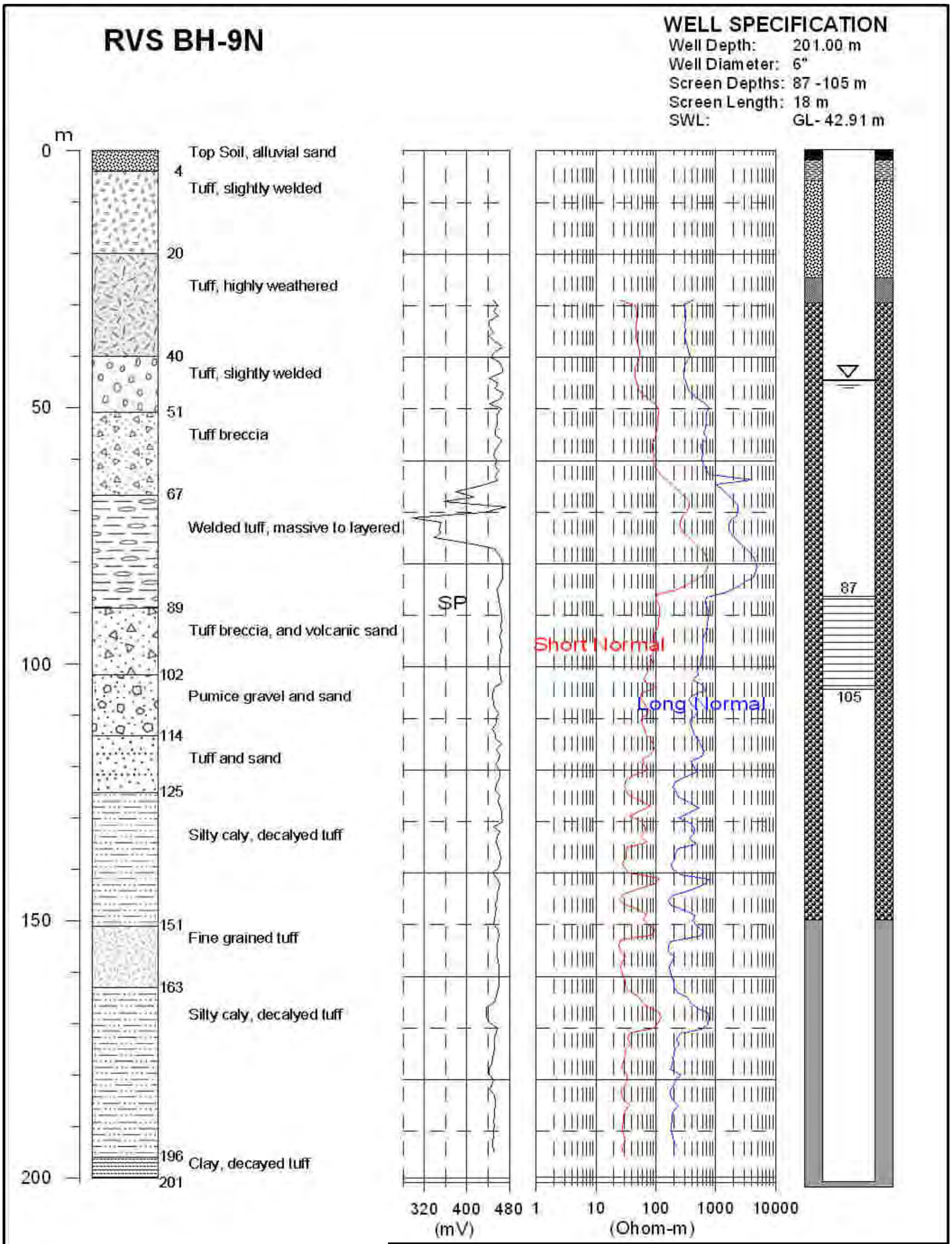


Figure 5.58	Drilling Log of Borehole (RVS BH-9N)

THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

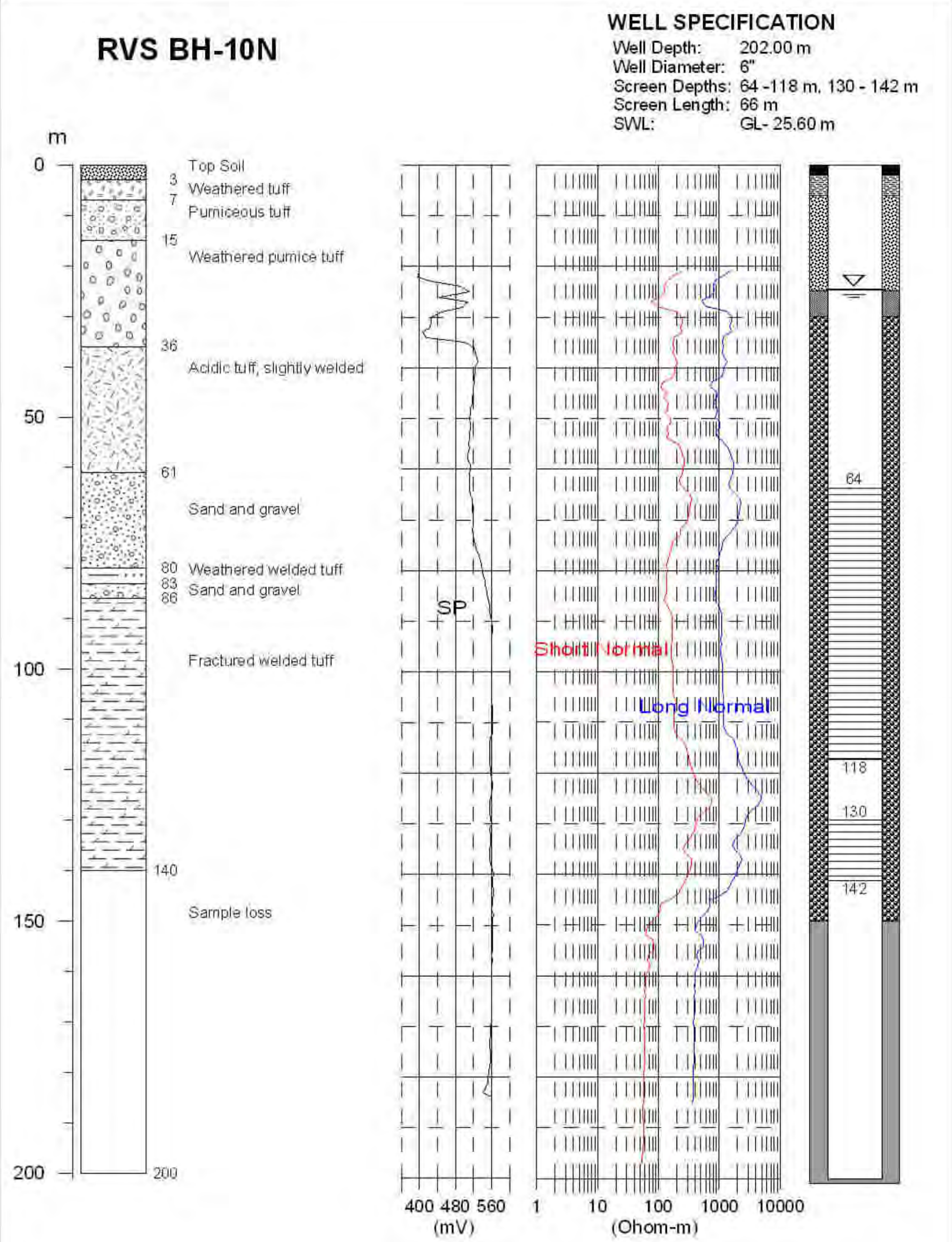
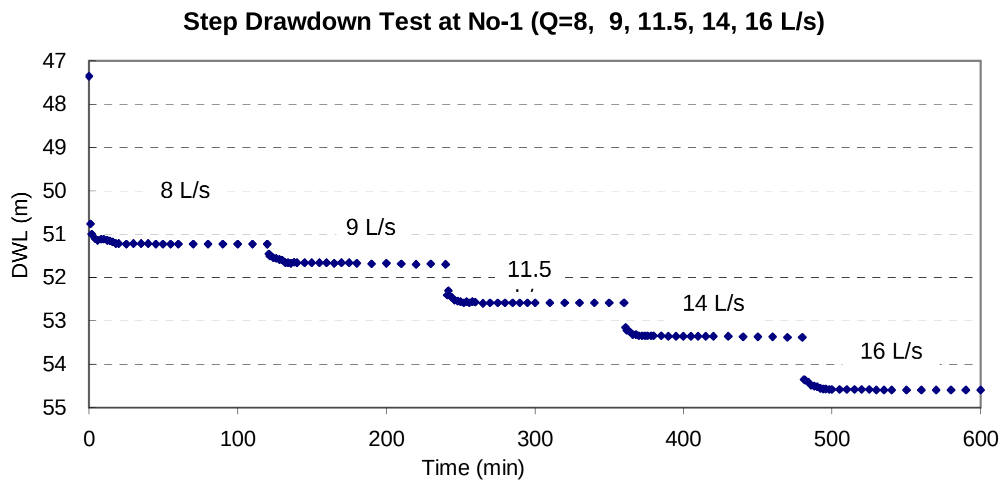
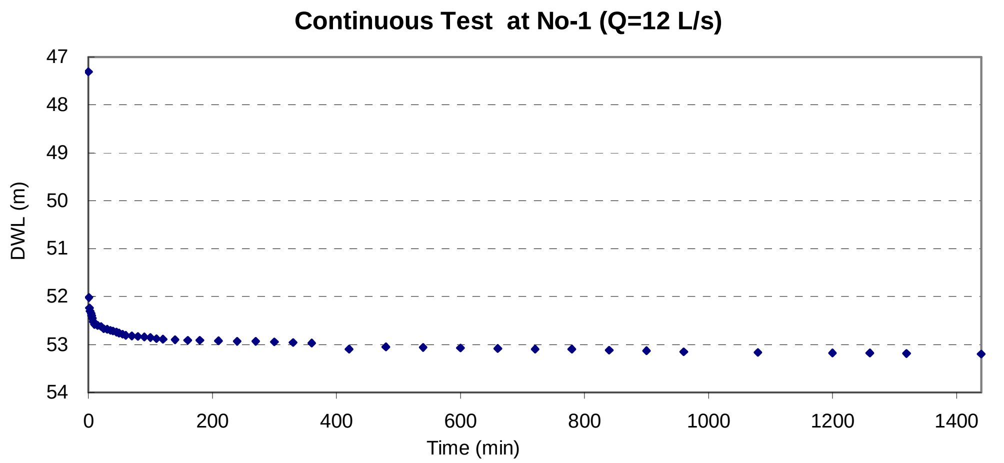


Figure 5.59	Drilling Log of Borehole (RVS BH-10N)

THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)





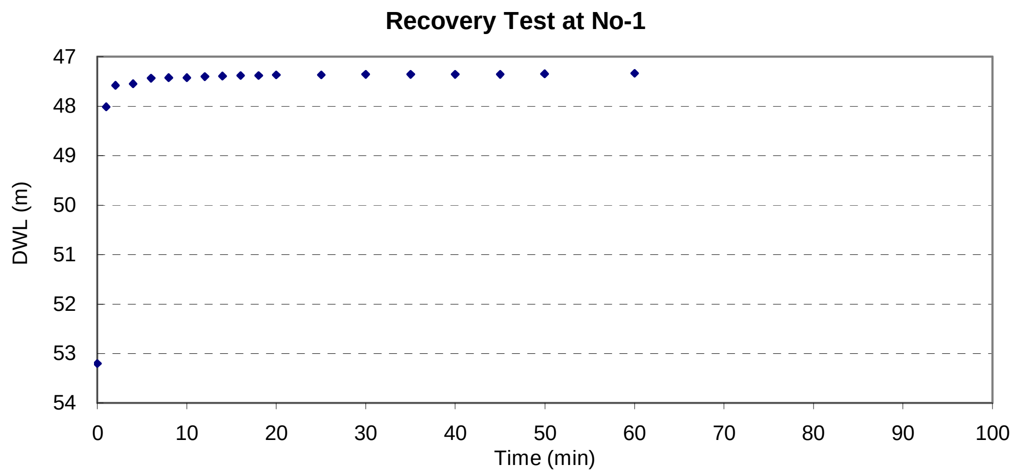


Figure 5.60	Pumping Test Result (RVS BH-1)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

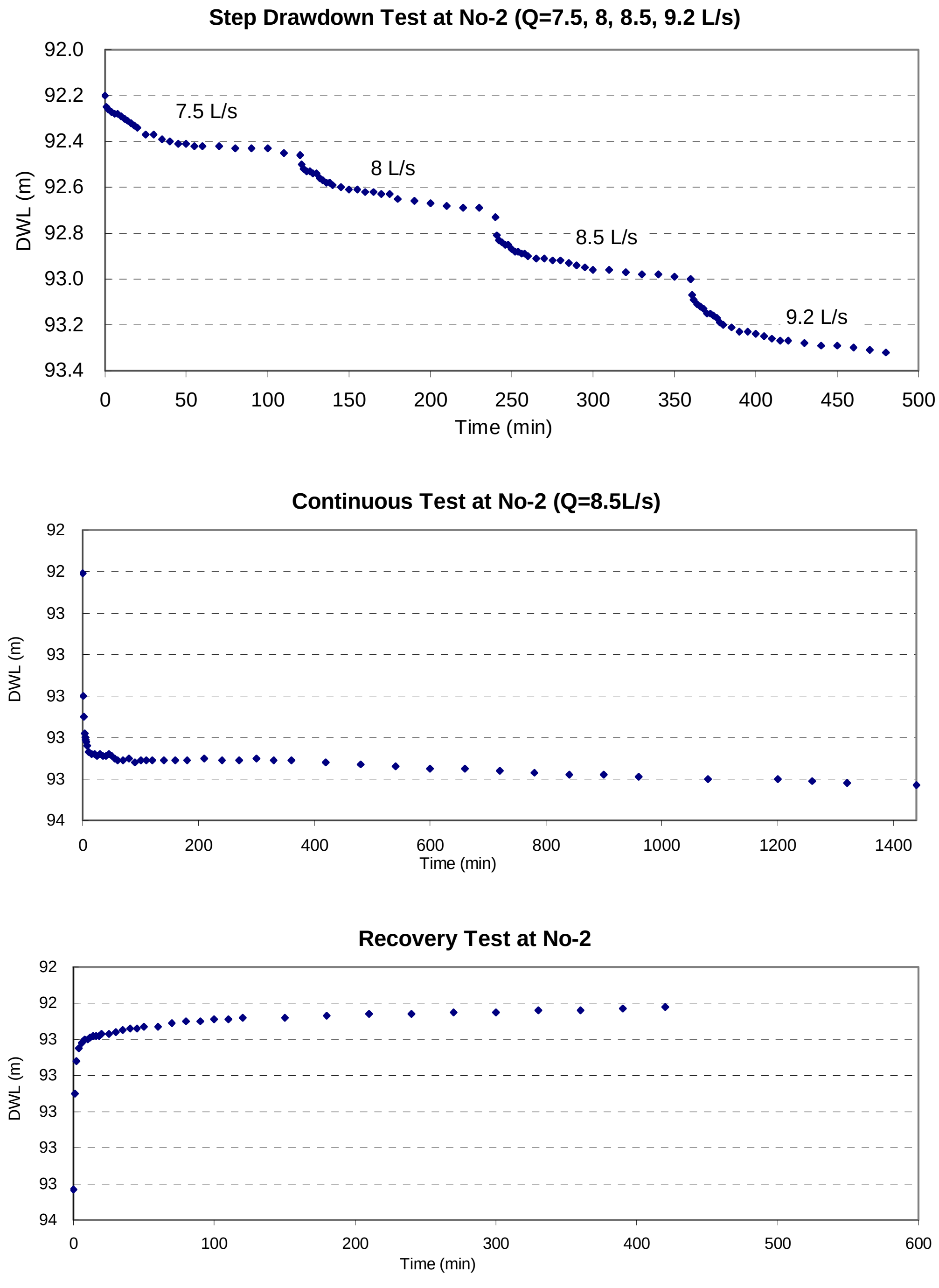


Figure 5.61	Pumping Test Result (RVS BH-2)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

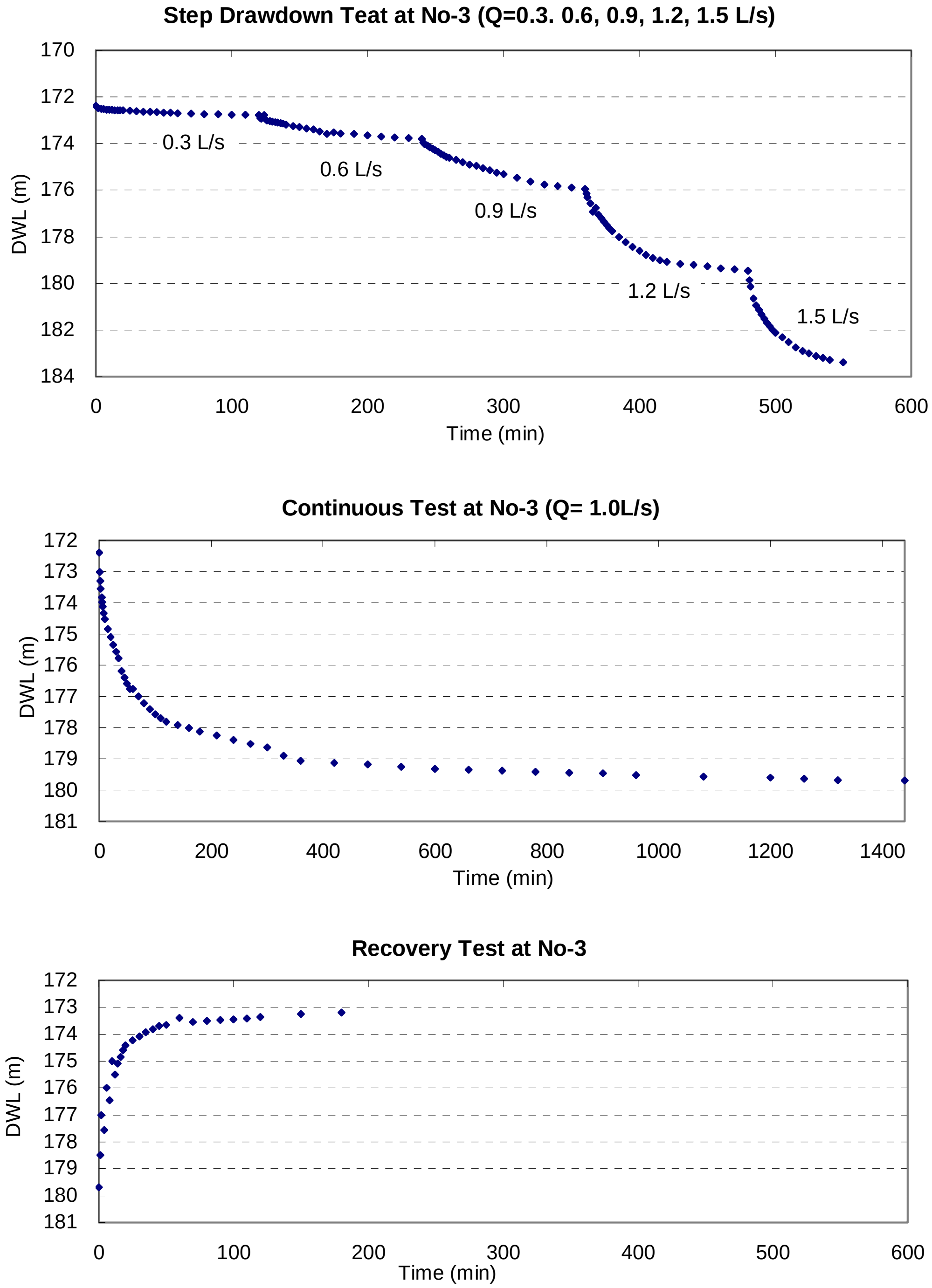


Figure 5.62	Pumping Test Result (RVS BH-3)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

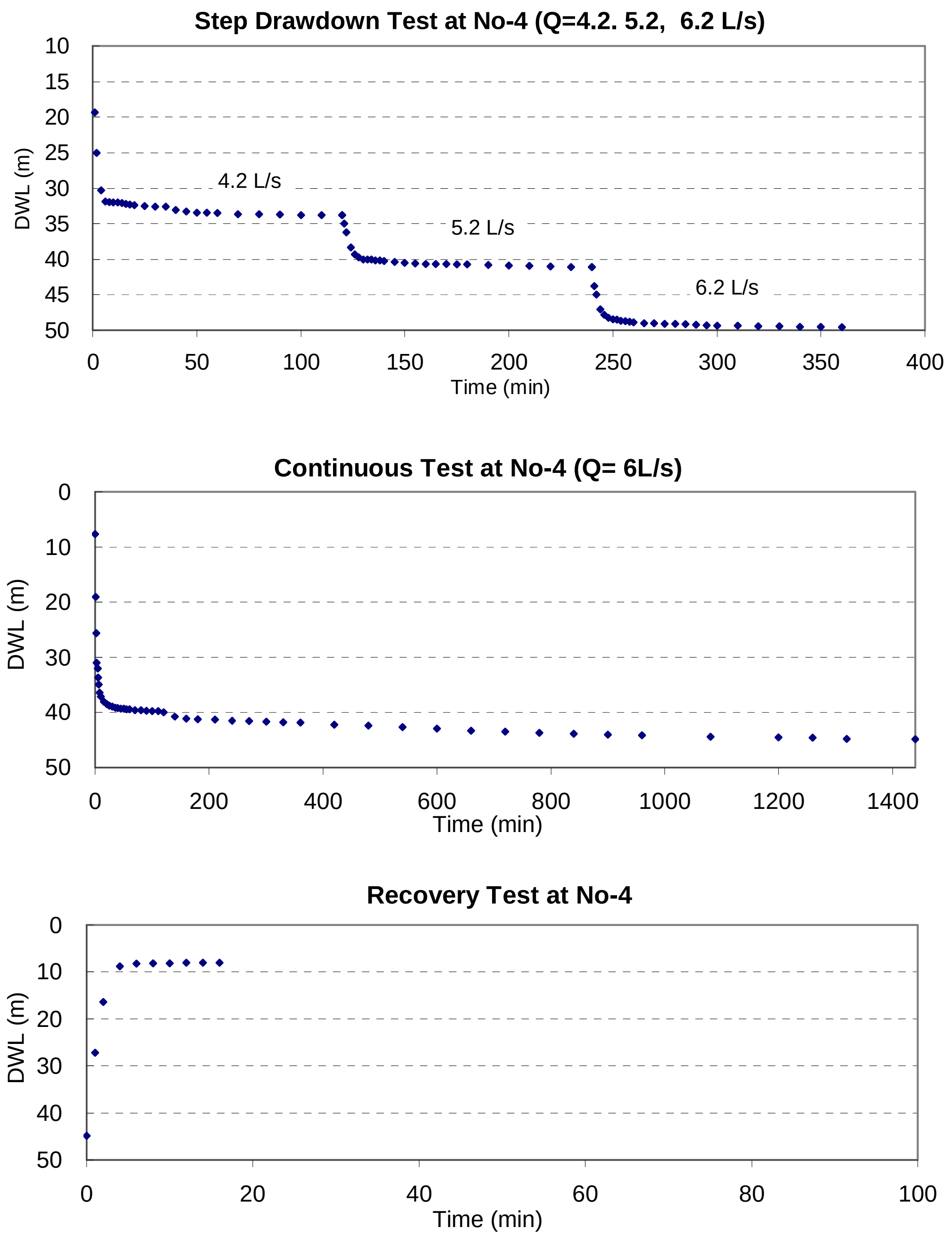
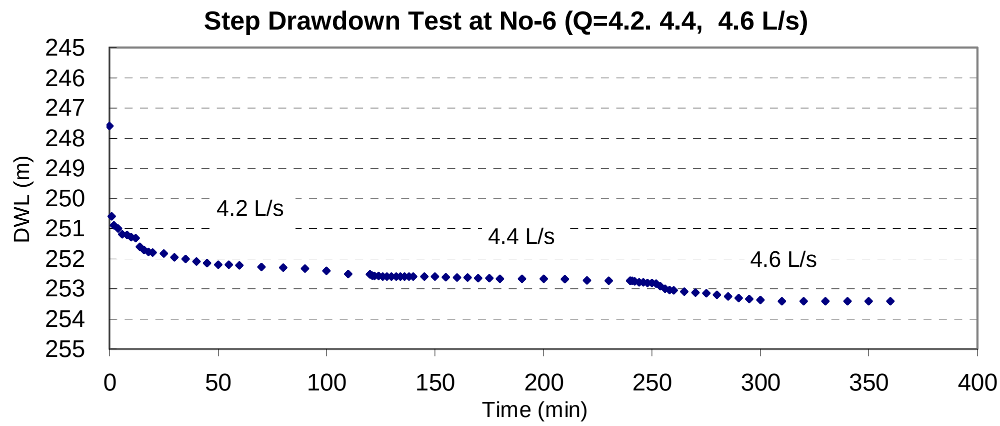
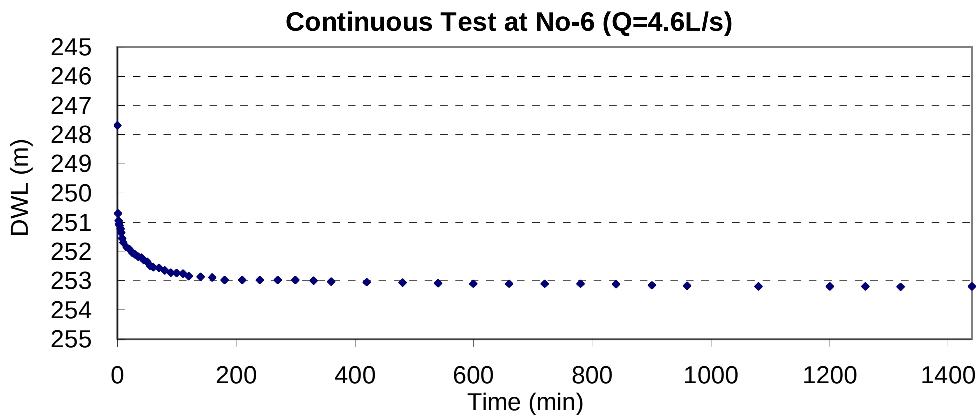


Figure 5.63	Pumping Test Result (RVS BH-4)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	





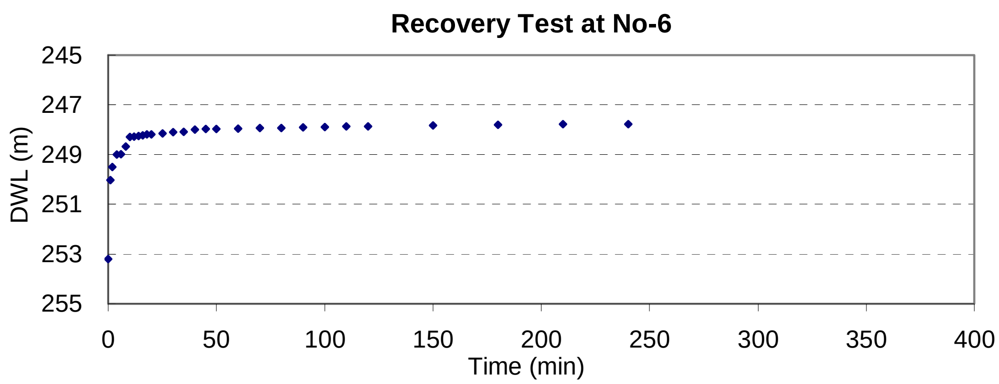


Figure 5.64	Pumping Test Result (RVS BH-6)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

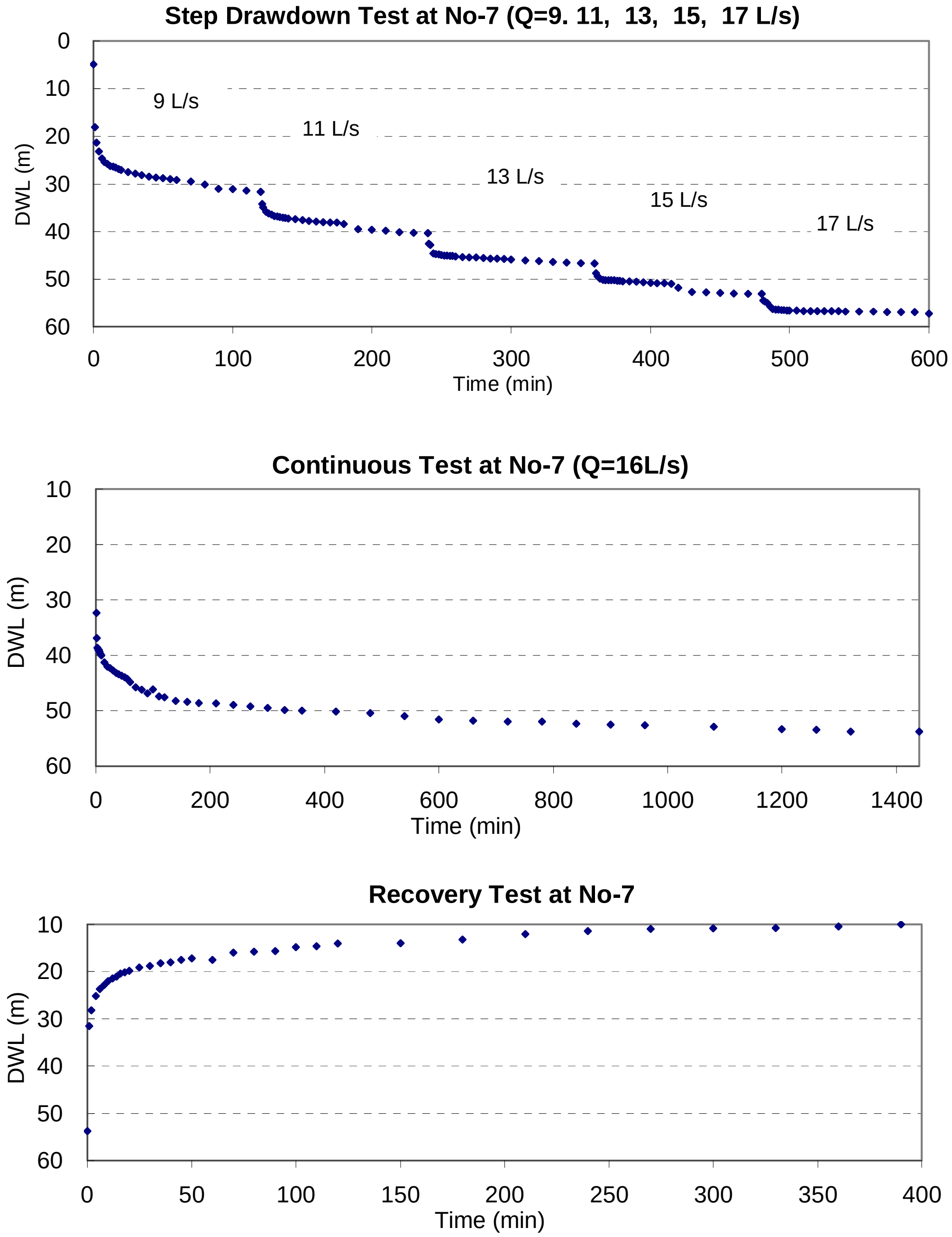


Figure 5.65	Pumping Test Result (RVS BH-7)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

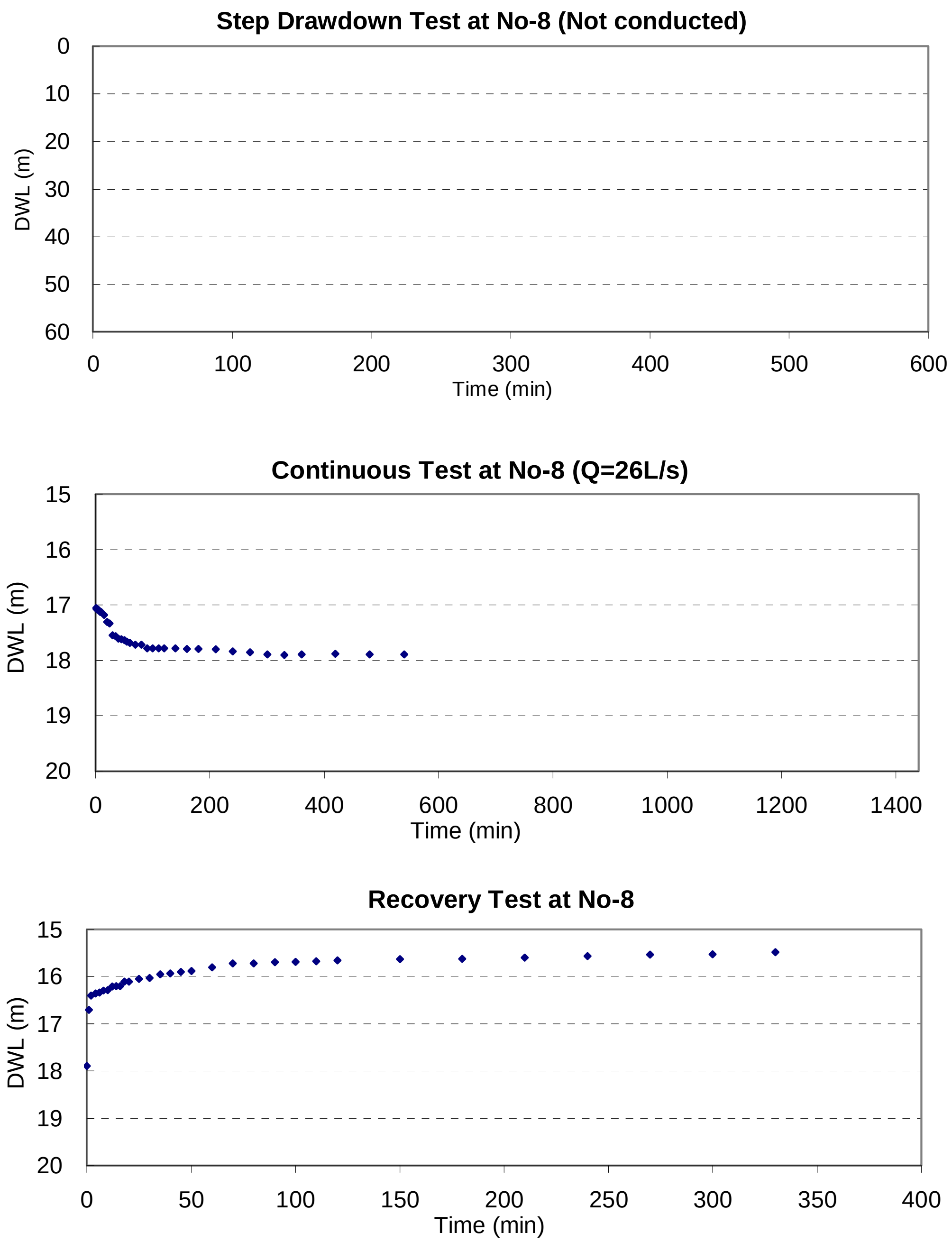


Figure 5.66	Pumping Test Result (RVS BH-8)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

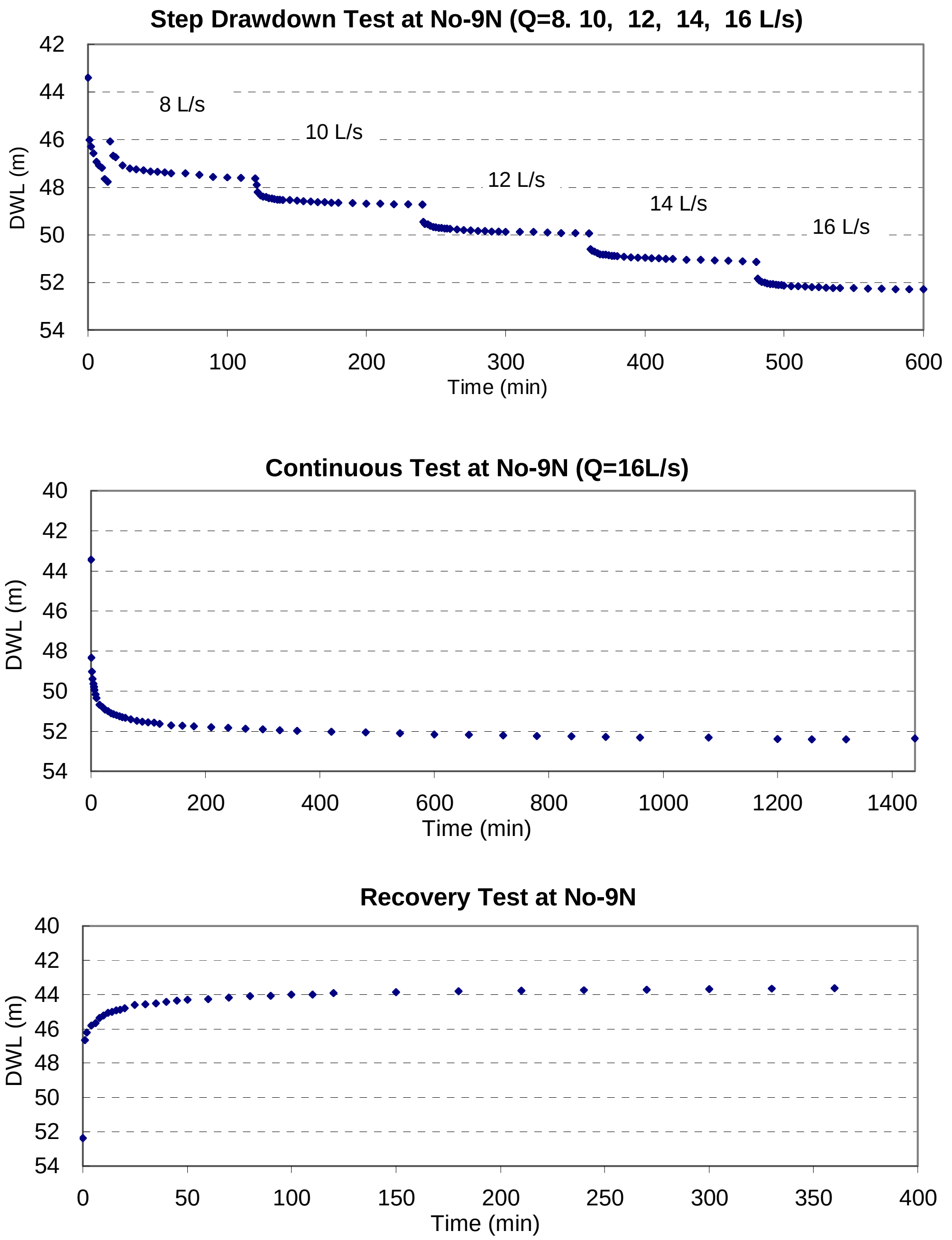


Figure 5.67	Pumping Test Result (RVS BH-9N)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

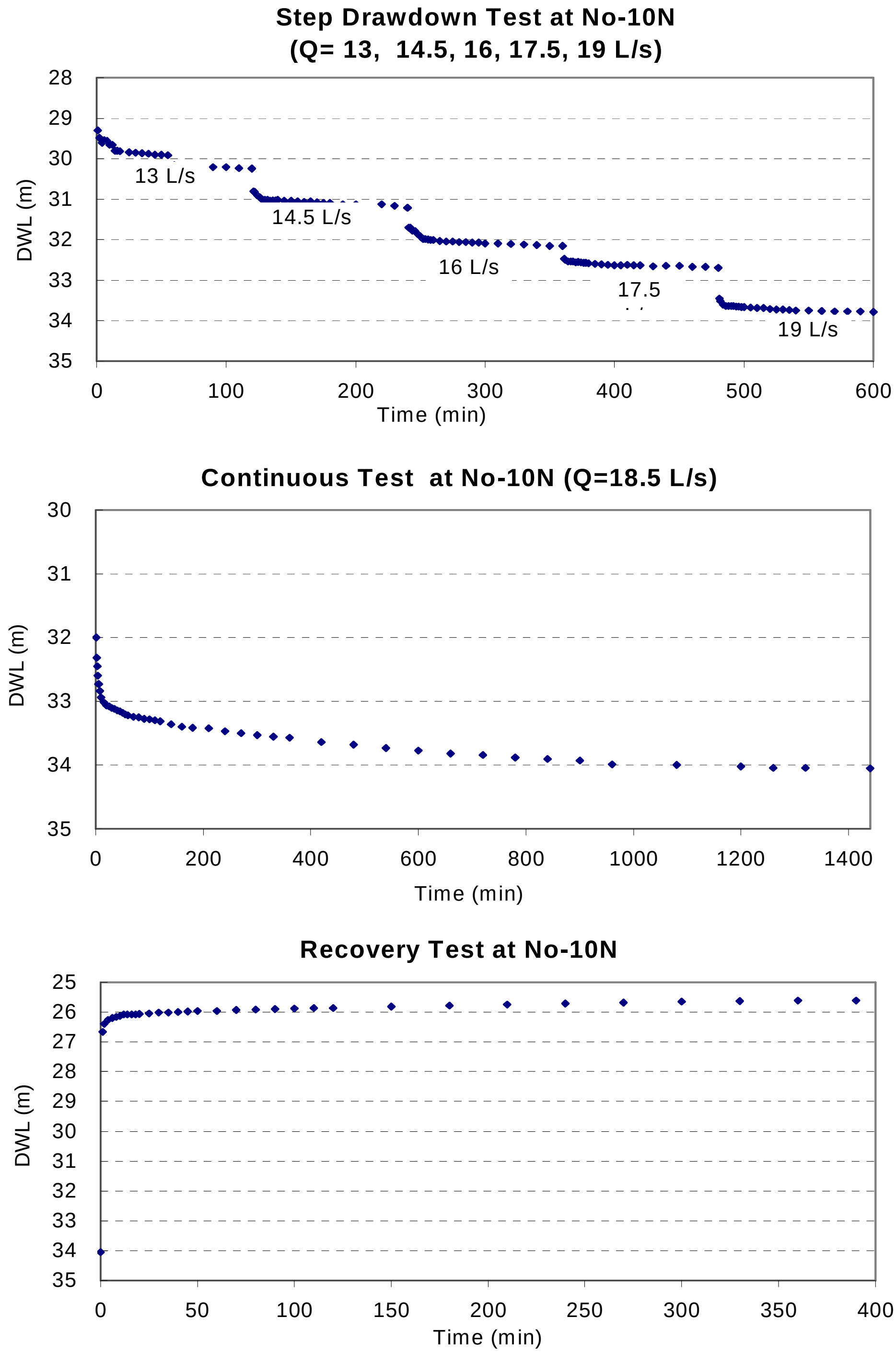


Figure 5.68	Pumping Test Result (RVS BH-10N)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

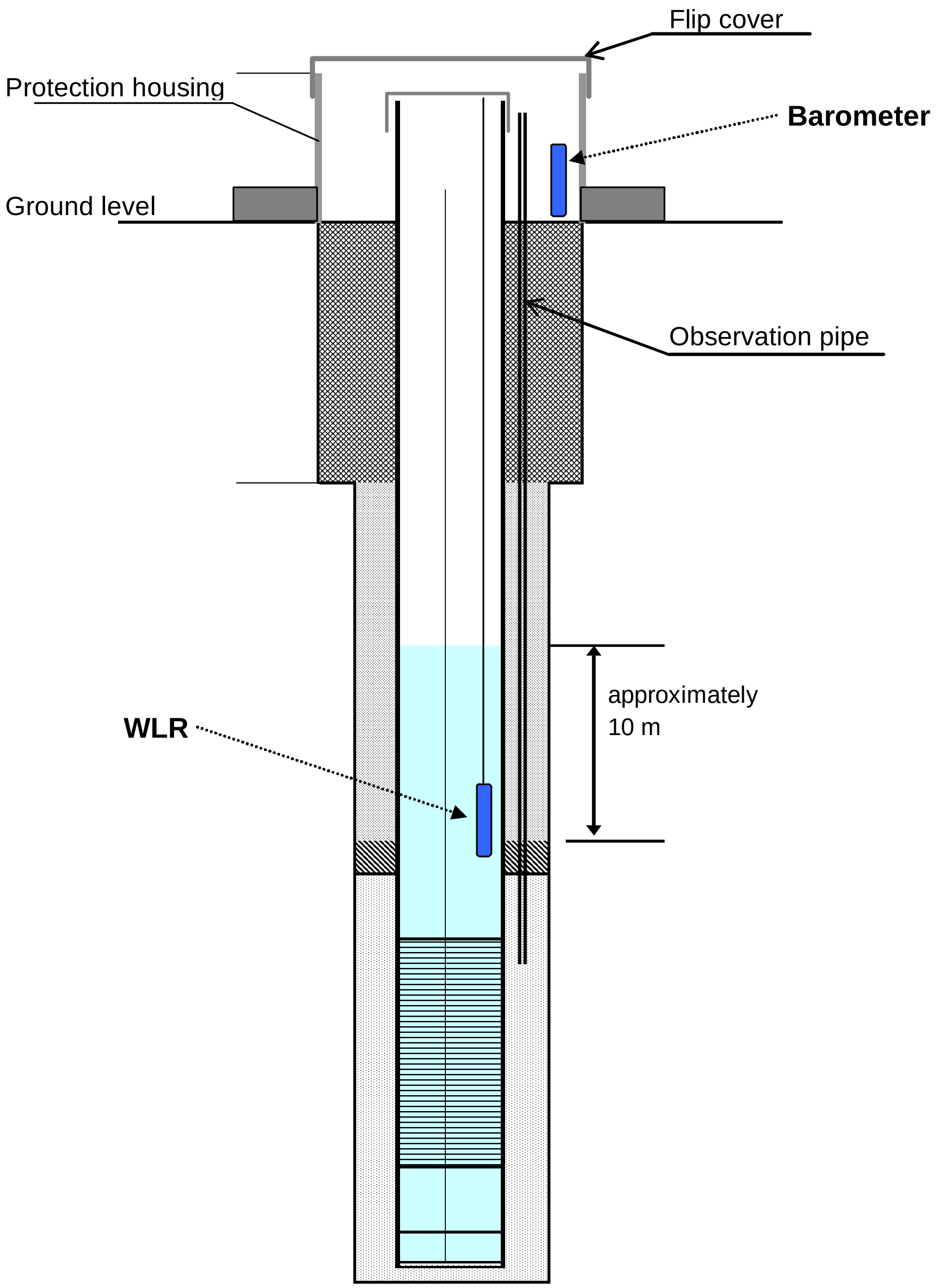
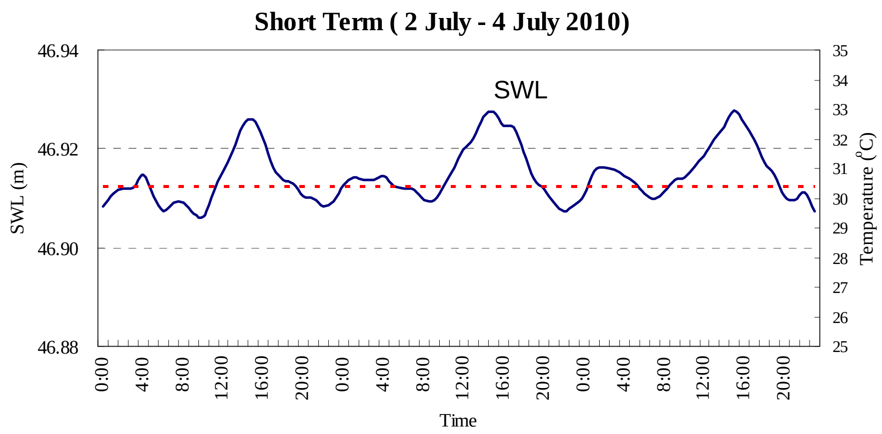
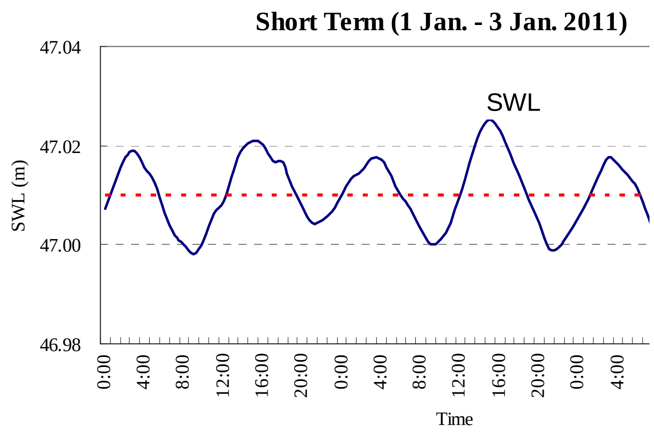


Figure 5.69	Schematic of Setup of Automatic Water Level Recorder (WLR)
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	





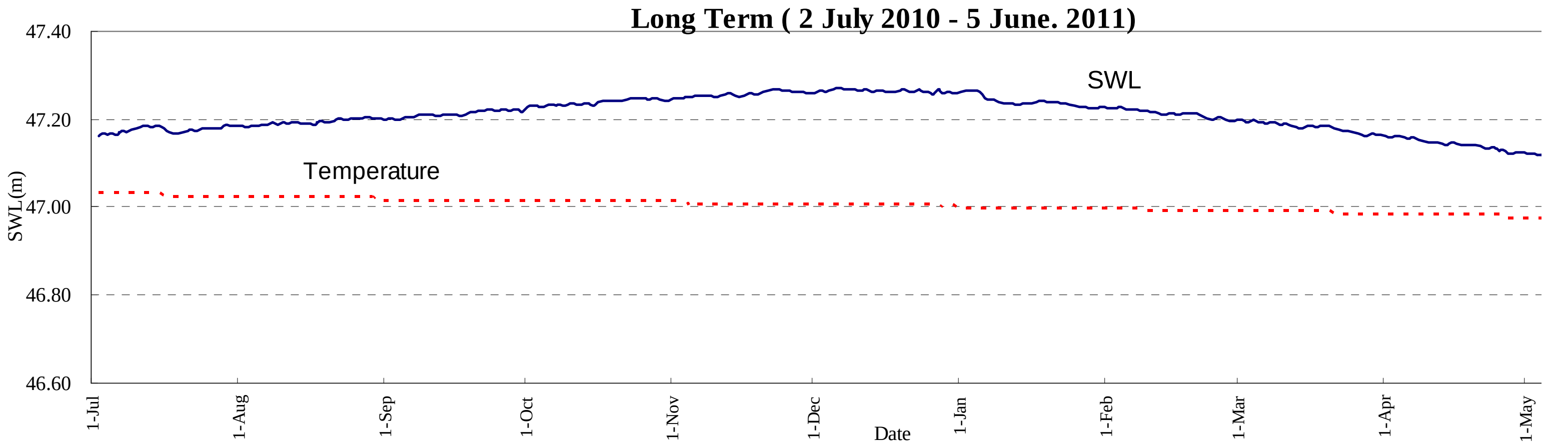


Figure 5.70	Groundwater Level Fluctuation in RVS BH -1
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

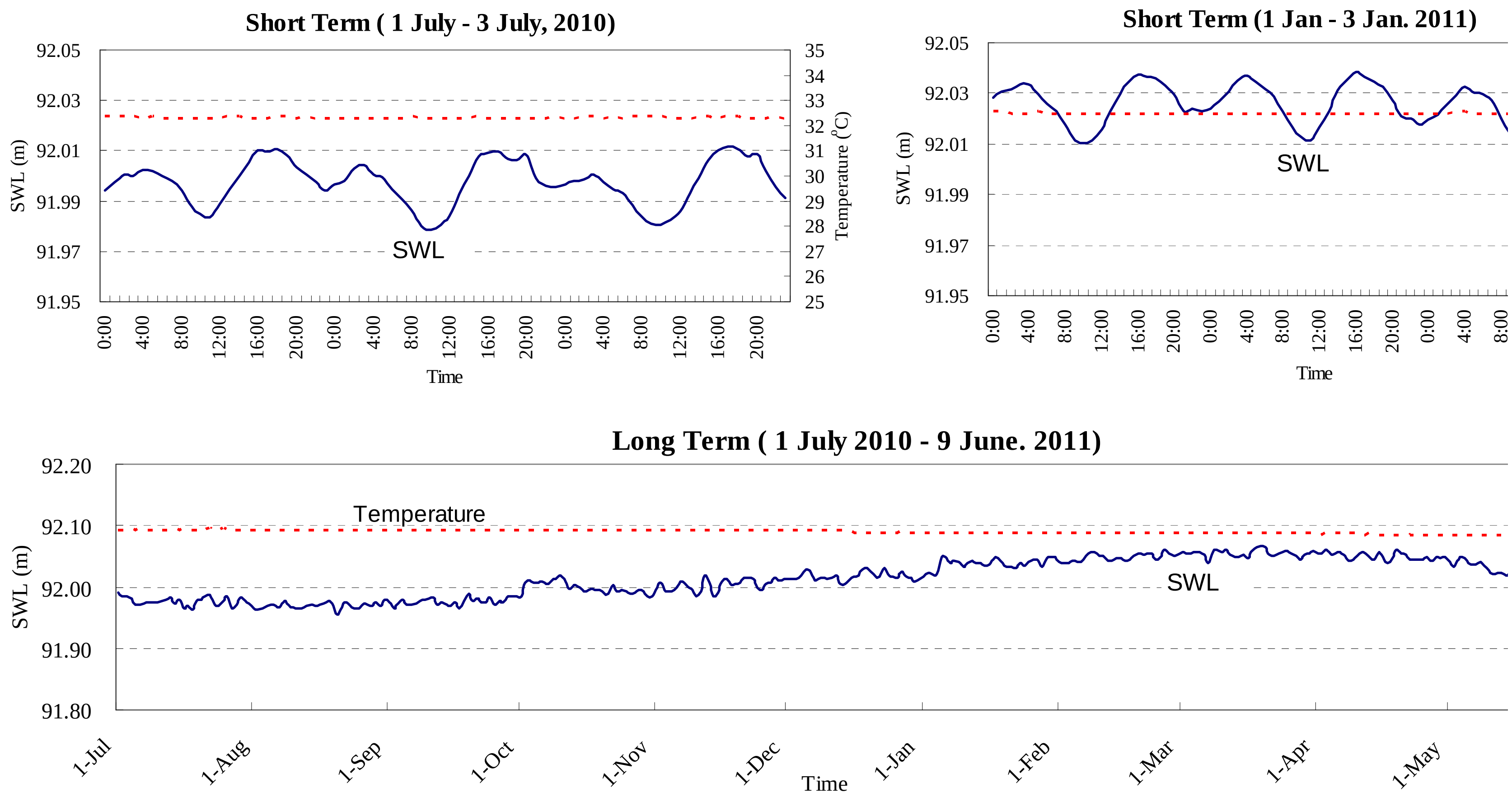


Figure 5.71	Groundwater Level Fluctuation in RVS BH -2
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

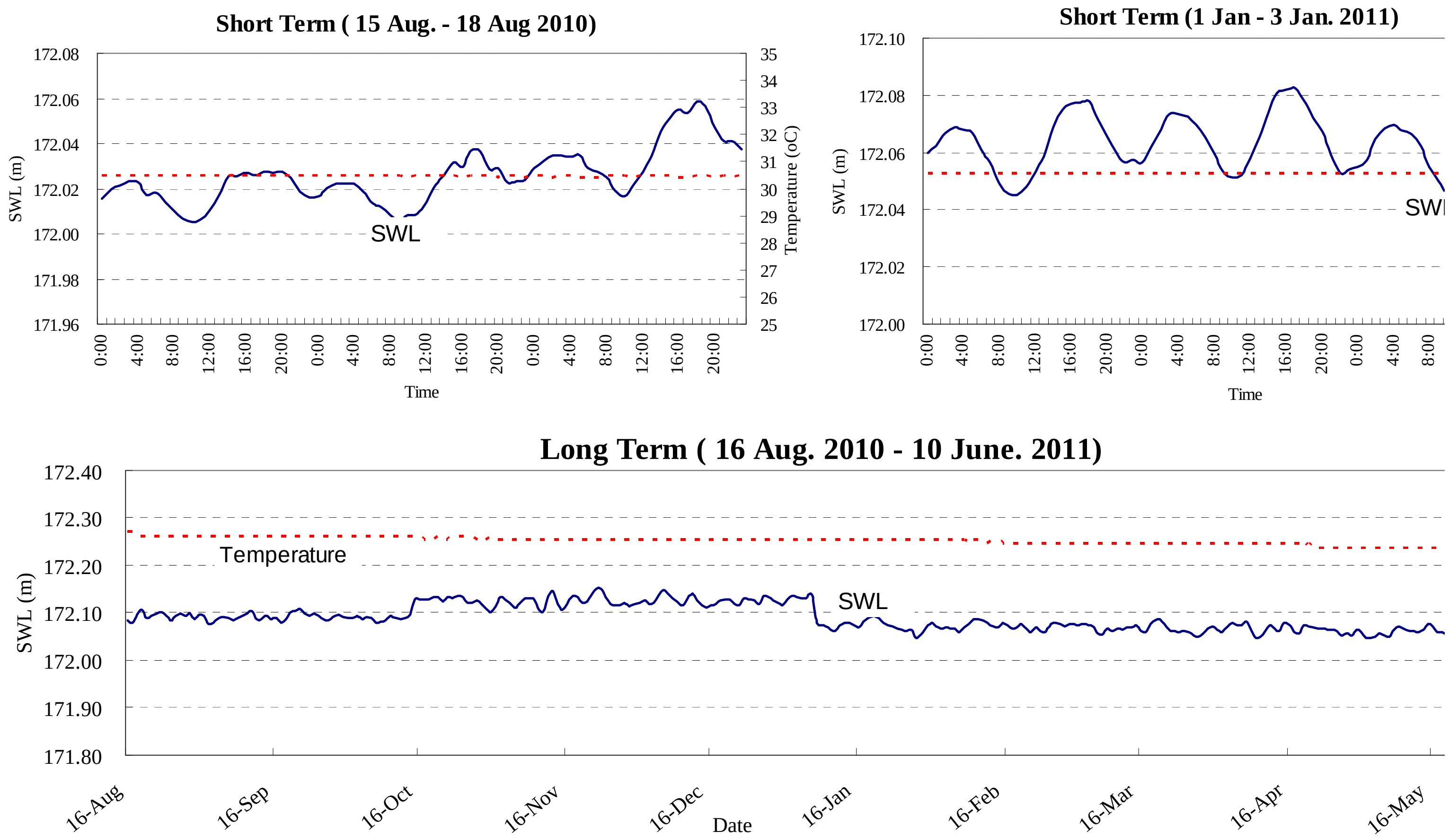


Figure 5.72	Groundwater Level Fluctuation in RVS BH -3
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

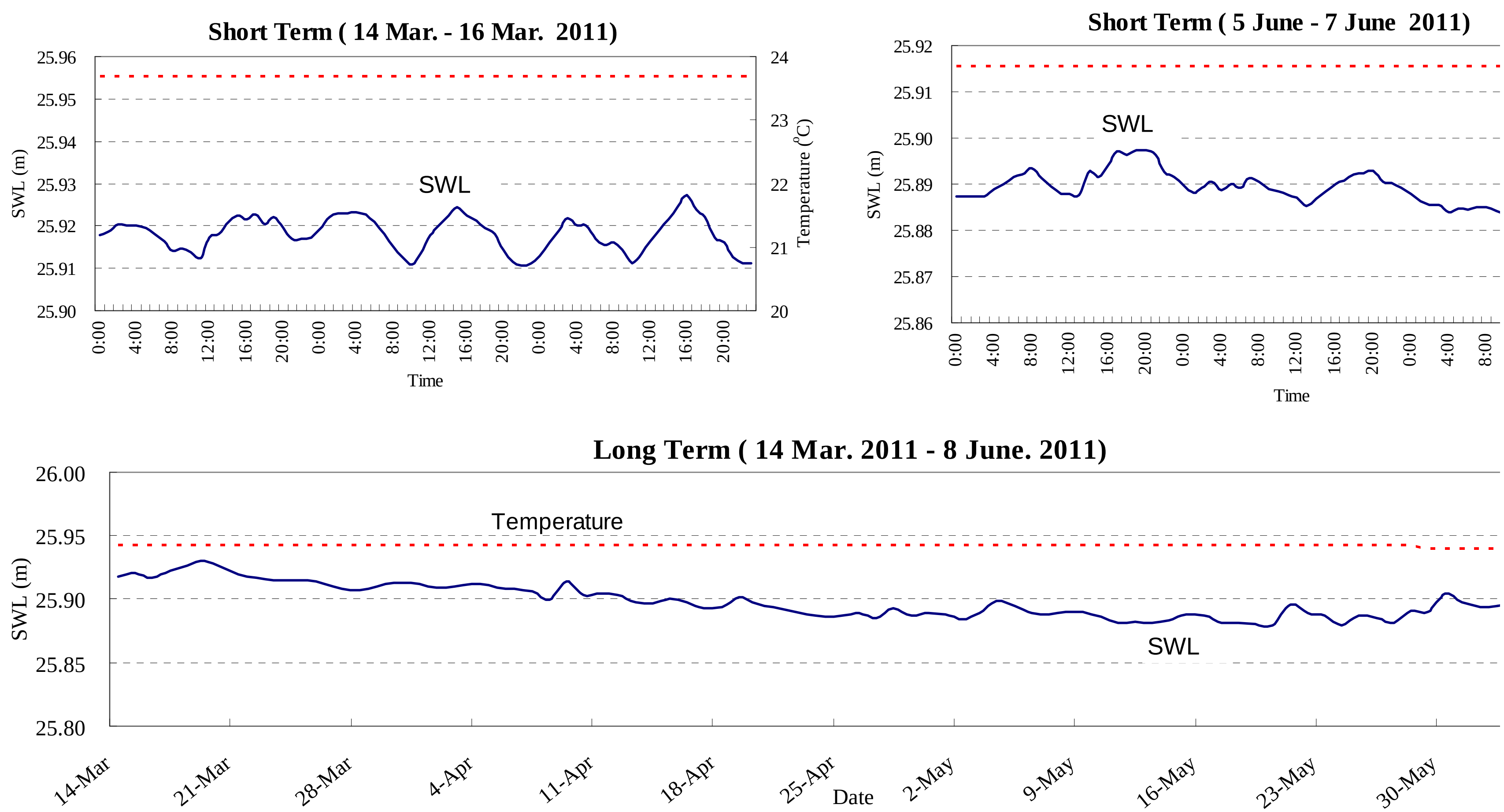


Figure 5.73	Groundwater Level Fluctuation in RVS BH -10N
THE STUDY ON GROUNDWATER RESOURCES ASSESSMENT IN THE RIFT VALLEY LAKES BASIN	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

Table 5.19: Comparison of Borehole Lithology and Established Stratigrapy

Site	Depth	Major Lithology	Sign	Classification (Name of Strata)
No-1	5-49m	Pumice tuff, Pumice	W	Ketar River Acidic Volcanic Sedimentary Rocks
	49-89m	Welded tuff, Sand with gravel	G	Gonde Strongly Green Welded Tuff
	89-126m	Welded tuff, Rhyolite	rh	Gademotta Rhyolite
No-2	2-46m	Pumice, pumice tuff	Pm	Corbetti pumice flow and fall deposits
	46-71m	Sand and gravel with pumice	Y	Langano Poorly Welded Pumiceous Pyroclastics
	71-100m	Welded tuff	ob	Kulmusa highly welded Tuff
	100-172m	Sand with pumice	W	Ketar River Acidic Volcanic Sedimentary Rocks
No-3	5-46m	Pumiceous tuff	Y	Langano Poorly Welded Pumiceous Pyroclastics
	46-70m	Acidic tuff, slightly welded	ob	Kulumsa highly welded tuff
	70-98m	Tuff	W	Ketar River Acidic Volcanic Sedimentary Rocks
	98-143m	Tuff, welded tuff	G	Gonde strongly Green welded tuff
	143-250m	Tuff breccia	tb	Adami Tuleu Basaltic Pyroclastice
No-4	0-44m	silty and clay, weathered basalt	W	Ketar River Acidic Volcanic Sedimentary Rocks
	44-102m	Welded tuff	G	Gademotta Rhyolite
	102-129m	Basaltic breccia and lava	tb	Adami Tuleu Basaltic Pyroclastice
	129-154m	Crystaline basaltic lava	ba	Ogolche Plistocene basalt
	154-250m	Volcanic sand and gravel	rh	Gademotta Rhyolite
No-5	0-65m	Weathered tuff and pumice	W	Ketar River Acidic Volcanic Sedimentary Rocks
	65-82m	Basalt lava	ba	Ogolche Pleistocene Basalt
	82m-83m	Tuff breccia	ba	Ogolche Pleistocene Basalt
No-5N	3-17m	Acidic tuff	W	Ketar River Acidic Volcanic Sedimentary Rocks
	17-88m	Vesicular basalt lava	ba	(Pleistocene) Basalt
	88-164m	Welded tuff, weathered pyroclastic	rh	Gedemotta ryhyolite
	164-205m	Welded tuff, highly weathered	rht/N1_2n	N1_2n Rhyolitic Volcanics/Rhyolitic Tuff
	205-250m	Welded uff, highly altered	Ngs	Sharenga Rhyolite
No-6	5-50m	Pumice, tuff, rhyolitic pyroclastics	Y	Langano Poorly Welded Pumiceous Pyroclastics
	50-60m	Welded tuff	ob	Kulmusa Highly Welded Tuff
	60-223m	Acidic tuff	W	Ketar River Acidic Volcanic Sedimentary Rocks
	223-301m	Welded tuff	G	Gonde Strongly Green Welded Tuff
	301-400m	Volcanic sand and gravel, pumice	rh	Gedemotta ryhyolite
No-7	0-33m	Sand and gravel deposit	Q	Unclassified Fluvial Deposit
	33-44m	Basalat lava	ba	Ogolche Pleistocene Basalt
	44-85m	Tuff, pumice, rhyolite	Ngs	Sharenga Rhyolite
	85-200m	Volcanic sand and gravel	Pgl	Lower basalt
No-8	0-36m	Sand and silt deposite	Q	Unclassified Fluvial Deposit
	36-152	Basalt lava and related deposites	Pgl	Lower Basalt
No-9N	4-67m	Pumice and tuff, tuff breccia	W	Ketar River Acidic Volcanic Sedimentary Rocks
	67-89m	Welded tuff	G	Gonde Strongly Green Welded-Tuff
	89-200m	Tuff breccai, delayed acidic tuff	rht/N1 2n	N1_2n Rhyolite
No-10N	3-86m	Pumice tuff, Lapili tuff	W	Ketar River Acidic Volcanic Sedimentary Rocks
	86-141	Welded tuff	G	Gonde Strongly Green Welded-Tuff
	141-	sample lost	-	(tb ?)

Table 5.20: Summary of Well and Aquifer Characteristics of Observation Wells (1/2)

	RVS BH-1	RVS BH -2	RVS BH -3	RVS BH -4	RVS BH -5N
Well depth at completion	150 m	147 m	247 m	244 m	250 m
Aquifer section depth	67 m – 130 m	100 m – 172 m	200 m – 247 m	82 m – 154 m	28 m – 112 m
Aquifer lithology	- Sand with gravel - Fractured welded tuff	- Gravel with sand - Pumice - Sand with pumice - Sand	- Tuff breccia (unconsolidated)	• Welded tuff • Basalt lava	• Basalt lava
Static water level (GL-)	47.35 m	90.6 m	171.0 m	7.7 m	Flowing artesian
Aquifer type	Confined	Confined	Semi-confined	Confined	Confined
Specific capacity*	2.05 L/s/m (177.2 m^3/day/m)	6.91 L/s/m (597.1 m^3/day/m)	0.134 L/s/m (11.8 m^3/day/m)	0.16 L/s/m (13.8 m^3/day/m)	N/A (Flow rate 100L/s)
Well efficiency	56 % - 64 %	Very high	9 % - 51 %	75 % - 80 %	N/A
Transmissivity (T)	376.5 m^2/day	914.4 m^2/day	12.5 m^2/day	27 m^2/day	N/A
Hydraulic conductivity (K)	1.5 x 10^{-2} cm/sec	3.5 x 10^{-2} cm/sec	3.0 x 10^{-4} cm/sec	5.6 x 10^{-4} cm/sec	N/A
Storage coefficient (S)	4.84 x 10^{-8}	2.03 x 10^{-3}	1.1 x 10^{-2}	2.9 x 10^{-7}	N/A

Note: Static water level at the time of pumping test, Specific capacity at the time of continuous pumping test

Table 5.21: Summary of Well and Aquifer Characteristics of Observation Wells (2/2)

	RVS BH -6	RVS BH -7	RVS BH -8	RVS BH -9N	RVS BH -10N
Well depth at completion	356 m	200 m	152 m	201 m	202 m
Aquifer section depth	266 m – 350 m	86 m – 146 m	50 m – 122 m	87 m – 105 m	64 m – 142 m
Aquifer lithology	- Welded tuff - Sand and gravel	- Fluvial sand and gravel	- Volcanic sand and gravel (alluvial)	- Tuff with volcanic sand - Tuff breccia	- Sand with gravel - Fractured welded tuff
Static water level (GL-)	247.6 m	4.89 m	15.3 m	43.41 m	25.32 m
Aquifer type	Confined	Confined	Confined	Confined	Confined
Specific capacity*	0.86 L/s/m (74.3 m^3/day/m)	0.34 L/s/m (29.4 m^3/day/m)	10.4 L/s/m (898.6 m^3/day/m)	1.9 L/s/m (164.2 m^3/day/m)	2.48 L/s/m (214.3 m^3/day/m)
Well efficiency	21 % - 22 %	85 % - 92 %	N/A	90 % - 95 %	74 % - 82 %
Transmissivity (T)	88 m^2/day	41 m^2/day	1015 m^2/day	261 m^2/day	521 m^2/day
Hydraulic conductivity (K)	1.6×10^{-3} cm/sec	7.9×10^{-4} cm/sec	2.0×10^{-2} cm/sec	1.68×10^{-2} cm/sec	9.13×10^{-3} cm/sec
Storage coefficient (S)	2.0×10^{-3}	1.7×10^{-4}	4.8×10^{-2}	3.0×10^{-5}	5.8×10^{-11}

Note: Static water level at the time of pumping test, Specific capacity was calculated of the step pumping test (maximum value)

Table 5.22: Setting of Automatic Water Level Recorder

Device Setting	Site No-1, Abaya north		Site No-2, Meki		Site No-3, Sheshemene		Site No-4, Yiga Alem		Site No-5N, Abaya North	
Instrument type	Piezometer (10m range)	Barometer	Piezometer (10m range)	Barometer	Piezometer (10m range)	Barometer	Piezometer (10m range)	Barometer	Piezometer (10m range)	Barometer
Serial number	4806397	4806441	4806398	4806444	4806399	4806445	4806392	4806446	N/A	N/A
Project ID	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS	N/A	N/A
Location	RVS BH No-1	RVS BH No-1	RVS BH No-2	RVS BH No-2	RVS BH No-3	RVS BH No-3	RVS BH - 4	RVS BH - 4	N/A	N/A
Sample mode	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	N/A	N/A
Sample rate	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	N/A	N/A
Altitude (m)	1237	1237	1688	1688	1801	1801	1632	1632	N/A	N/A
S&DL mini Time*	EWT	EWT	EWT	EWT	EWT	EWT	EWT	EWT	N/A	N/A
First sampling time	15:00	15:00	17:00	17:00	8:00	8:00	14:00	14:00	N/A	N/A
First sampleing date	1-Jul-10	1-Jul-10	30-Jun-10	30-Jun-10	15-Aug-10	29-Jul-10	19-Nov-11	19-Nov-11	N/A	N/A
Offset	None	None	None	None	Noe	None	None	None	N/A	N/A
Device set at	aox. 10m below SW	apx.at ground level	apx. 10m below SW	apx.at ground level	apx. 10m below SW	apx. at ground level	aox. 10m below SW	apx. at ground leve	N/A	N/A
Casing pipe stick up**	0.38 m		0.45 m		0.64 m		0.61m		N/A	
Obs. tube stick up**	0.33 m		0.44 m		NA		0.42 m		N/A	

Device Setting	Site No-6, Alaba		Site No-7, Arbaminch		Site No-8, Chamo south		Site No-9N, Langano SW		Site No-10N, Ziway East	
Instrument type	Piezometer (10m range)	Barometer	Piezometer (10m range)	Barometer	Piezometer (10m range)	Barometer	Piezometer (10m range)	Barometer	Piezometer (10m range)	Barometer
Serial number	4806395	4806437	4806394	4806438	4806393	4806440	4806401	4806439	4806958/480639	4806442
Project ID	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS	RVGWS
Location	RVS BH - 6	RVS BH - 6	RVS BH - 7	RVS BH - 7	RVS BH - 8	RVS BH - 8	RVS BH-9N	RVS BH-9N	RVS BH -10N	RVS BH -10N
Sample mode	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear
Sample rate	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour	1 hour
Altitude (m)	1869	1869	1198	1198	1157	1157	1630	1630	1685	1685
S&DL mini Time*	EWT	EWT	EWT	EWT	EWT	EWT	EWT	EWT	EWT	EWT
First sampling time	13:00	13:00	17:00	17:00	16:00	16:00	16:00	16:00	14:00/12:00:00	14:00
First sampleing date	21-Nov-11	21-Nov-11	23-Nov-11	23-Nov-11	23-Nov-11	23-Nov-11	22-Nov-11	22-Nov-11	03/13/2011,11/2	13-Mar-11
Offset	None	None	None	None	None	None	None	None	None	None
Device set at	aox. 10m below SWL	apx. at ground level	aox. 10m below SWL	apx. at ground level	aox. 10m below SWL	apx. at ground level	aox. 10m below SWL	apx. at ground level	aox. 10m below SWL	apx.at ground level
Casing pipe stick up**	0.63 m		0.59 m		0.63 m		0.48 m		0.59 m	
Obs. tube stick up**	0.36 m		NA		0.3 m		0.22 m		0.4 m	

Note *EWT: Time of Ethiopia shown in western (international) notation
* Measured from the concrete base

Table 5.23: Example of Mud Loss at Site No-2 and No-10N

1. Site No-2 Meki

Mud pit surface area = 5 m^2

Date	Time	Drill Depth (GL- m)	Drop in mud level (m)	Loss volume (m^3)	Period (min)	Loss rate (m^3/min)	Remarks
25-Apr-10		76	0.5	2.5	10	0.25	
26-Apr-10		76.5	0.8	4	10	0.4	
2-May-10		78	0.7	3.5	5	0.7	
6-May-10			0.15	0.75	10	0.075	happened while reaming
8-May-10	13:50	79.2	0.4	2	5	0.4	
	16:00	79.2	0.9	4.5	10	0.45	while injecting mud after previous loss
9-May-10	18:00	82.6	0.4	2	-	-	
	23:00	82.6	0.7	3.5	-	-	
10-May-10	8:20	83.4	0.8	4	5	0.8	

Total mud loss volume : 26.8 m^3
Average mud loss rate : 0.44 m^3/min

2. Site No-10N Ziway East (Ogolcho)

Mud pit surface area = 10.5m^2

Date	Time	Drill Depth (GL- m)	Drop in mud level (m)	Loss Volume (m^3)	Period (min)	Loss Rate (m^3/min)	Remarks
9-Feb-11	10:00	142	0.30	3.2	10	0.32	
10-Feb-11	9:30	146	0.40	4.2	10	0.42	
10-Feb-11	10:30	152	0.50	5.3	5	1.05	
10-Feb-11	14:00	152	0.60	6.3	7	0.90	
11-Feb-11	9:30	153	0.40	4.2	8	0.53	
11-Feb-11	11:30	159	0.70	7.4	10	0.74	
11-Feb-11	12:30	161	0.60	6.3	10	0.63	
13-Feb-11	8:40	24	0.21	2.2	12	0.18	Reaming process
13-Feb-11	8:50	45	0.37	3.9	9	0.43	Reaming process
13-Feb-11	9:50	86	0.51	5.4	10	0.54	Reaming process
14-Feb-11	10:30	130	0.45	4.7	8	0.59	Reaming process
14-Feb-11	12:00	177	0.68	7.1	12	0.60	
15-Feb-11	8:30	171	0.20	2.1	3	0.70	Reaming process
15-Feb-11	8:40	176	0.40	4.2	2	2.10	Reaming process
15-Feb-11	9:10	188	0.30	3.2	5	0.63	
15-Feb-11	9:20	194	0.60	6.3	4	1.58	
15-Feb-11	11:00	201	0.47	4.9	7	0.71	

Total mud loss volume : 80.7 m^3
Average mud loss rate : 0.74 m^3/min

Chapter 6

GIS/Database Utilization on Groundwater Development Study

6 GIS/Database Utilization on groundwater development study

6.1 Introduction

In this chapter, collecting and compiling GIS data which is required for hydrogeological mapping and water supply planning is reported.

Ministry of Water and Energy (hereafter MoWE) has been trying to establish a database for collecting/utilizing the essential information to develop water resources from the 2000s. MoWE is attempting to continue the database project, the Ethiopia National Groundwater Information System project (hereafter ENGWIS) had implemented from 2009 to 2010. Based on the above, the GIS/database which is made by the Study is required to have a compatibility with ENGWIS for contributing the groundwater development in Ethiopia. The investigation of the ENGIWS project is implemented for the contribution. The investigation result is also reported in this chapter.

6.2 Status of GIS/DB of Ministry of Water and Energy

6.2.1 ENGWIS project (until March 2010)

There was a strong need to have a national groundwater database. Ethiopia National Groundwater Database Project (hereafter referred to as "ENGDA") was established in 2000 but the database that was developed had the following problems:

- The database doesn't have a user friendly interface

- Users can not use the database on demand because it is a standalone type

- The database has a limited capacity of data storage because of its technical specifications

Based on the achievements and problems, the groundwater study development & management team of MoWR established the ENGWIS (Ethiopia National Groundwater Information System) project. Table 6.1 shows the summary of the ENGWIS project.

Table 6.1: Summary of the ENGWIS Project

Period	Jun. 2009 - Mar. 2010
Milestones	Aug. 2009: Kickoff meeting Sep. 2009: Training (HydroGeoAnalyst) Sep. - Dec. 2009: Data compilation Jan. 2010: System test Feb 2010 : Training (HydroManager, AquaChem) Mar. 2010: Workshop, Final report
Study area	Whole of Ethiopia
Target, C/P	・ Ministry of Water Resource: MoWR ・ Geological Survey of Ethiopia: GSE ・ Regional Water Bureau: RWB
Objectives	・ Establish a centralized, web-enabled information management system ・ Training for data collection/compilation of groundwater recourses ・ Training for system utilization by MoWR/RWB
Activities	(1) Develop and deploy a centralized GIS based and Web enabled central water resource information management system (2) Develop and deploy handheld (Pocket PC) data collection software with licenses for up to 50 stand-alone installations (3) Provide software license HydroGeo Analyst, AquaChem and AquiferTest Pro to all 9 Regional Bureaus and 3 other offices including the Ministry of Mines and the Geological Survey of Ethiopia (4) Train and Support the Ministry in inventorying, reviewing, and quality controlling of all existing groundwater resources related data (5) Oversee the migration of existing water resource data to the central database (6) Provide extensive training to be composed of; a) Continuous on-the- job training, b) Up to 3 on-site classroom style training courses to up to 20 designated Ministry staff (7) Organize 1 workshop (lasting 1 to 2 days) at the end of the project (8) Provide 1 full year expert technical support post project completion (9) Setup the system for efficient data transfer between the Regional Bureaus (10) Analyze existing data loggers and make recommendations for automated data import from any such loggers into the central database; data loggers that area already supported by the system will be linked as part of this project (11) Training; 1) Data compilation, quality control and migration into the central database, 2) HydroGeoAnalyst, 3) Hands-on-training on data compilation, quality control and migration, 4) WQ data management with AquaChem, 5) Web based data management through HydroManager
Merit of the ENGWIS system	・ Save labor/improvement of efficiency for collecting data using handheld terminal with ・ Unlimited data storage of the system ・ The archive is established for analysis ・ Supporting the water quality check, suitable area selection and so on by analysis tools of the system. ・ Supporting the suitable area selection for drilling and drawing geological cross section by spatial analysis tool ・ Supporting simulation/check of sustainability of water resource use ・ Assistance of the report making work; the system can make graphs and tables easily. ・ Enable remote access (LAN, WAN, Internet, etc.) ・ Multilingualization including Amharic

Figure 6.1 shows the structure and relevant authorities of the ENGWIS project. MoWR, Regional Water Bureaus (hereafter referred to as "RWB"), Geological Survey of Ethiopia

(hereafter referred to as "RWB"), Universities and UNICEF cooperated in provision of data. The ENGWIS project tried to compile the information held by these authorities, achievements of the research by Universities and outcomes of projects by UNICEF.

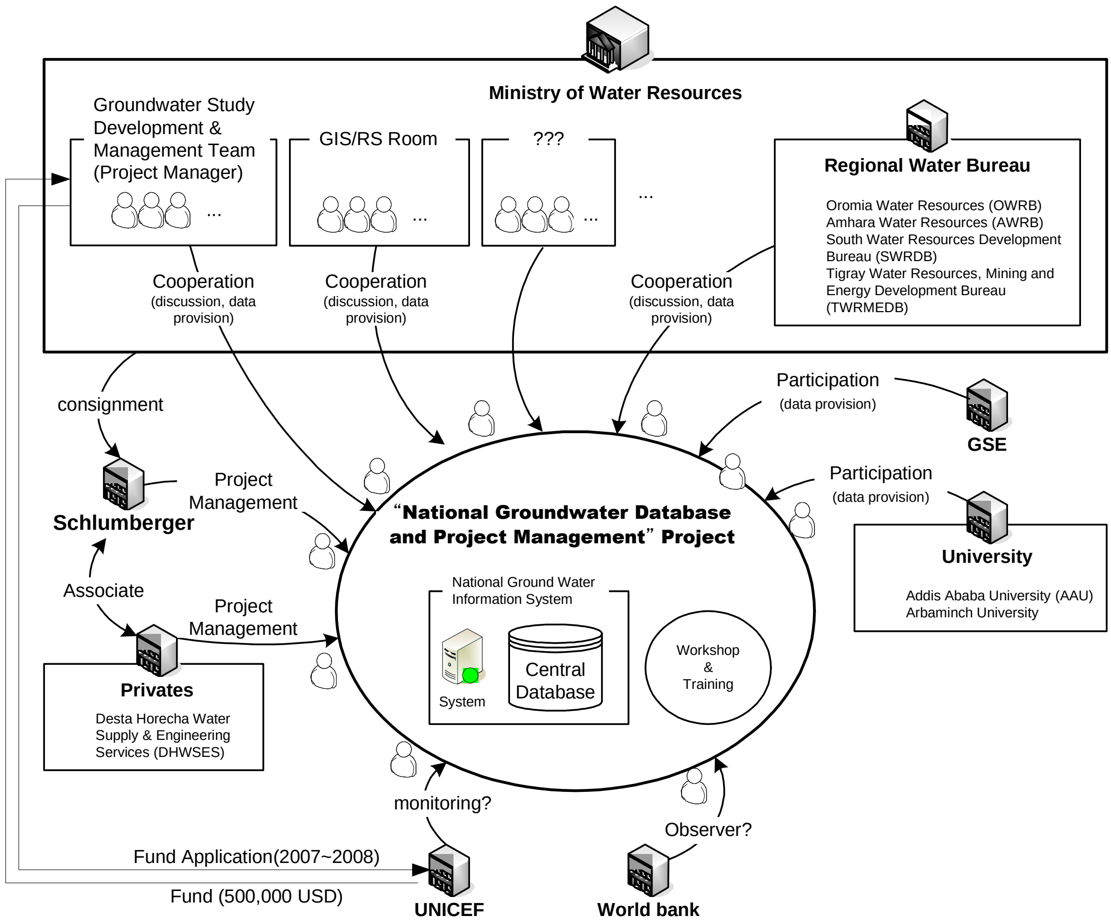


Figure 6.1: Structure of the ENGWIS Project

The system was composed of several applications (HydroGeo Analyst, AquaChem, HydroManager, Hand Held Data collection). It can support acquisition, management, analysis, mapping, spatial analysis, interpretation, visualization, prediction/simulation, and reports. This system was developed to be web-based; therefore, users can use the system through an internet browser.

6.2.2 Post ENGWIS project (after April 2010)

The status of the database project by MoWE after finish ENGWIS is investigated. Table 6.2 shows the summary of the investigation results.

Table 6.2: Status of the Database Projects by MoWE after the Termination of ENGWIS

Item	Content
Responders	Mr. Tesfaye: Ministry of Water & Energy Mr. Zenaw: Ministry of Water & Energy (Former job) Dr. Aschalew Debebe: Schlumberger Company Mr. Desta Horeha (Desta Horecha Water Supply Engineering Service) Mr. Michael: Ministry of Water & Energy (Former job)
Status	・ ENGIWS system operation is not confirmed. ・ ENGWIS system, software and database is installed a server in the server room on 5th floor of MoWE ・ Staff in charge of ENGWIS also can not access ENGWIS system through intranet of MoWE/internet. ・ It is not possible to access the ENGWIS system through internet. Therefore, Regional Water Bureaus and relevant organizations can not browse/update the data. ・ Technical issue: the spec/performance of server on which ENGWIS system is installed is low, therefore the server can not process simultaneous/multiple access. ・ Operation side issues (regulations/rules): Registration of user accounts to the server is necessary to use the system. But, there are no rules/regulations regarding issuing accounts. This must be some cause for concern as to believability of the data.
Organization structure	・ About 20 persons have cooperated data providing to ENGWIS project form Regional Water Bureau, Geological Survey of Ethiopia, Addis Ababa University, Arbaminch University, World Bank, UNICEF until March 2010. ・ The staff in charge of ENGWIS project of MoWE was Groundwater Study Development & Management Team. The team members and roles are as below; 1) Manager: fund procurement, management 2) Coordinator: making proposal of fund procurement, management, coordinate, (left the position in May 2010) 3) Computer/System engineer: installation/operation/maintenance the system (left the position in 2011) ・ New coordinator was assigned from March 2011 ・ ENGWIS project was not top-down type as MoWE
Budget	・ Groundwater Study Development & Management Directorate applied a fund to UNICEF for ENGWIS project (80,000USD) in 2010. The result is not notified yet. ・ The purpose of the application is addition/update/collection of the water resource point data which is estimated to be 100,000 points. ・ Budgetary support is only received from UNICEF. There is no budget from the government or MoWE.
Data collecting	・ Data of the ENGWIS system must be collected/uploaded/updated by MoWE/Regional Water Bureau staff ・ Training of the data collection, operation of the system was delivered in the ENGIWS project. Therefore, some of staff of MoWE/Regional Water Bureaus has a knowledge and skill of the ENGWIS system. ・ About 30,000 water resource point data was compiled to central database server of the system based on the collected data until 2009.
Remaining issue	・ The system has already been developed and is ready to be used, but there are some issues. ・ Securing budget: Budget for system maintenance, installation of high spec server, network infrastructure, data collection/update and so on are required. ・ Organization structure: Positioning as MoWE, cooperative framework with

	regional water bureaus, additional staff and so on are required. ・ Regulations/rules: The improvement of legal systems regarding water resource data collection should be discussed. And, the regulations/rules of access account of the system are also required to keep the believability.

6.3 Data collected and collation

Table 6.3 shows the collected data by this study

Table 6.3: Data Collected in the Study

No.	Name	Type	Content/Attribute	Scale/ Resolution	Data Source
1	Report and GIS data of Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project	GIS data	Road, Administrative boundary, Hydrology, Geology, Population, Socio-economics, Water-supply, Agriculture, Land cover		GIS/RS team of MoWE
2	Topographic map	Hard copy	-	1/250,000	EMA
3	Geological map	Hard copy	-	1/250,000	GSE
4	SPOT	Satellite image	HRV-P(Panchromatic)、Band: P	5m	EMA
5	Geological map	SHP(Point/Line /Polygon)	Class, ID	1/250,000	The study team
6	Geological cross section	Hard copy		-	The study team
7	Candidate towns for water supply	SHP(Point)	Existing water supply facility, Administration facility	-	The study team
8	Drilling points	SHP(Point)		-	The study team
9	Cross section line of geology	SHP (Line) CAD(DXF)		-	The study team
10	Populated place	SHP(Point)	Name	1/1,000,000	DCW
11	Major road	SHP (Line)	-	1/1,000,000	DCW
12	Major river	SHP (Line)	-	1/1,000,000	DCW
13	National boundary	SHP (Polygon)	-	1/1,000,000	DCW
14	Administrative boundary	SHP (Polygon)	Region/Zone/ Woreda name	-	GSE
15	Basin	SHP (Polygon)	Basin name	-	GSE
16	River	SHP (Polygon)		-	GSE
17	Towns	SHP (Point)	Town name, Population, Rain, Elevation	-	GSE
18	Road	SHP (Line)	Name, Class, Type	-	GSE
19	River	SHP (Line)	Name, Class, Type	-	GSE
20	ASTER-GDEM(Digital Elevation Model)	Satellite (Raster)	Elevation	30m	ASTER-GDEM project website
21	SRTM(Digital Elevation Model)	Satellite (Raster)	Elevation	90m	USGS
22	LANDSAT	Satellite (Raster)		30m	USGS

EMA: Ethiopia Mapping Agency, DCW: Digital Chart of the World, GSE: Geological Survey of Ethiopia

6.3.1 Collection of water source point data and quality control

Water source data shown in Table 6.4 were collected and compiled. Table 6.5 shows the attribute of compiled water source point data. The compiled data had problems as below;

- There are multiple data which have same coordinate/location.

- There are not attribute information (only coordinate/location).

- Irregularity in value of coordinate/location

Thus, a data quality check and revision (delete duplicated location data, delete irregular values) were undertaken. The number of the data points was reduced to about 16,000.

Table 6.4: Sources of Water Source Data Points

No.	Name of data source	Number of water source point
1	Water source point data by Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project	2854
2	Water source data by South Water Works Construction Enterprise	410
3	Water source point data surrounding Awasa Lake	5913
4	Water source point data surrounding Awasa Lake by MoWE	117
5	Water source point data of Oromia Region by ENGWIS project	787
6	Water source point data of SNNPR Region by ENGWIS project	110
7	Well data of Grant aid project in SNNPR, 2009	5913

Table 6.5: Attributes of Compiled Water Source Data Points

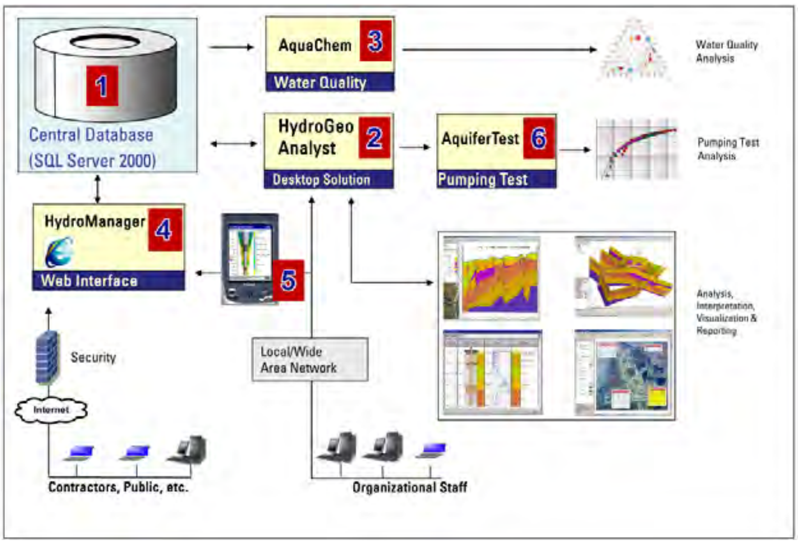
No.	Content	No.	Content	No.	Content
1	ID	46	Depth to GWL(m)	91	F
2	SourceID	47	PumpCategory	92	Fe
3	Source	48	WellDiameter(Inch)	93	Mg
4	orgID	49	CasingType	94	Mn
5	station name	50	CasingDiameter(Inch)	95	NO_3
6	SerialNo	51	ScreenPosition(m)	96	pH
7	FID_	52	WaterStrike	97	pH_Field
8	Temp	53	PT_Date	98	pHLab
9	Code	54	Q(l/sec)	99	PO_4
10	Zno	55	PT_SWL(GL-m)	100	SO_4
11	Wno	56	GWL(m)	101	TDS
12	Locality Name	57	D_SWL(GL-m)	102	Temp(℃)
13	PlaceName_Community	58	SWL(m)	103	Total_Alka
14	Zone_Speci	59	PT_DWL(GL-m)	104	Total Hardness
15	Ana-code	60	DWL(m)	105	Turbidity
16	Ana	61	TDD(m)	106	$CaCO_3$
17	PA	62	T(m^2/day)	107	Bicarbonate
18	Site Name	63	Yield(l/s)	108	Carbonate_
19	Woreda	64	RecWL(m)	109	Sodium
20	Kebele	65	Recv(%min)	110	Potassium
21	VillageName	66	PumpPos(mt)	111	Nitrate

22	SpecificLocation	67	HP Type(forSW)	112	Nitrite
23	Rural_Ur	68	Draw_Down	113	Arsenic
24	Location(km)	69	Transmissi	114	Cadmium
25	utmEcomp	70	Aquifer	115	Lead
26	utmNcomp	71	Scheme code	116	Chromium
27	utmE	72	SiteTransferdate	117	Zinc
28	utmN	73	WDC_D_RigNo	118	Ammonia
29	Altitude	74	WDC_D_DateofStart	119	Sulfate
30	LonToUtmE	75	WDC_D_DateofFinish	120	phosphate
31	LatToUtmN	76	WDC_WQ_Date	121	DO
32	Lon	77	ApronConst_Started	122	Status
33	Lat	78	ApronConst_Completion	123	Source_Halcrow
34	Status	79	HPI_InstDate	124	TDS1
35	PopServed	80	HPI_Type	125	Fluoride1
36	ConstYear	81	HPI_Depth(m)	126	Missing
37	Donor	82	HandOver_ExecutedDate	127	DataSheet
38	Constructed By	83	WDC_WQ_OK	128	Remark
39	ConstructionCost(Birr)	84	Al		
40	SourceType	85	Ca		
41	Scheme Type	86	Cl		
42	Depth	87	Color		
43	BH_Depth(m)	88	Cu		
44	CasingDepth(GL-m)	89	EC(mS/cm)		
45	ScreenPosition(GL-m)	90	EC		

6.4 Outline of GIS/Database and relation with ENGWIS

The database to be developed in this study will compile the relevant sets of data into a GIS database with the purpose of analyzing and formulating water supply plans in the target area. The accumulated data and the results of survey and analysis will be digitized and integrated into a GIS database. This database will be established, and an operation plan made, based on the results of the confirmation of ENGWIS operational status described in

Figure 6.2.



(Reference: Interim report of National Groundwater Information System)

Figure 6.2: Architecture of ENGWIS

Figure 6.2 shows the architecture of ENGWIS system. The software which the system is composed of are able to input/output the collected data and analysis result between the central database and software. The central database attempts to manage the data of the following two categories using database framework of SQL server.

1) GIS format (Arc GIS format)

2) Others (Access, Excel, CSV, txt, figures, drawings, photos…)

The database to be developed in this study will be designed to be linkable with the above two types of data. Figure 6.3 shows the conceptual diagram of the database by the study.

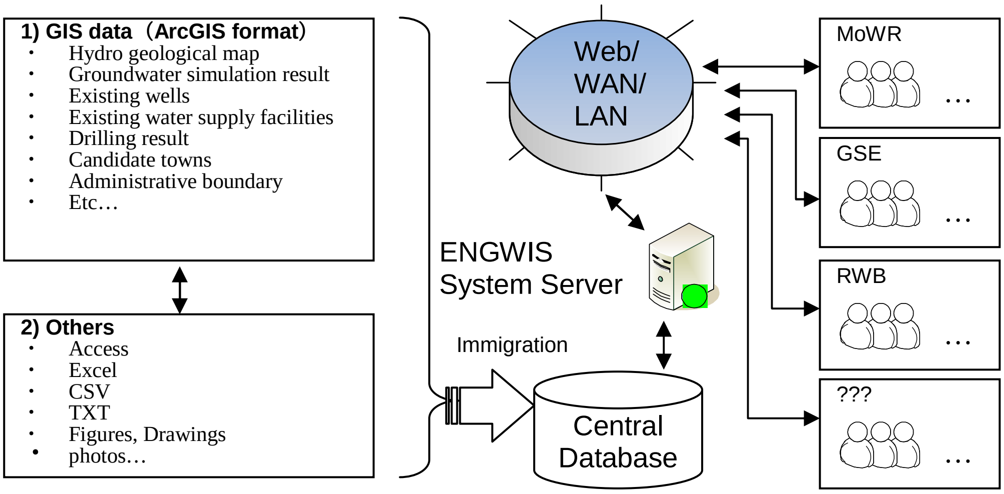


Figure 6.3: Conceptual Diagram of the Database by the Study