(2) 電気探査結果

1. Introduction

The client, KOKUSAI KOGYO CO., LTD (KKC), is currently carrying out a Basic Design Study Project for Rural Water Supply and Rehabilitation in Tigray Region of Ethiopia. Towards this, KKC contracted Ezana Mining Development PLC (EMD) which in turn engaged the services of LUL Earth Sciences, an Ethiopian private consulting firm, to carry out hydro-geophysical surveys involving Vertical Electrical Sounding and Horizontal Electrical Profiling over sixty three sites in ten weredas of Tigray region. The ultimate aim of the survey is to maximize the success rate of subsequent water well drilling activity planned by KKC.

The survey sites were pre-selected by the KKC and Tigray Water Resource Mines and Energy Bureau (TWRME) based on the following criteria:

- Presence of water short communities
- proximity to the consumer, as well as
- prior limited hydrogeologic information

As per the agreement, field survey of 155 VES and 26 profiles has been carried out between the dates of January 9, 2007 and January 31, 2007 in close cooperation with staff of KKC, EMD, TWRME wereda bureaus and the Consultant. This document is the final technical report prepared by LUL Earth Sciences after having accomplished all the works laid down in the Terms of Reference provided by KKC, and consists of a brief description of all data acquisition procedures, presentation, processing and interpretation techniques used in the geophysical investigations, as well as the results obtained there from.

2. Scope and methodology

About Vertical Electrical Sounding (VES) and Horizontal Electrical Profiling (HEP) methods

Most rocks are insulators in their dry state. However, because rocks almost always hold interstitial water (sometimes with dissolved salts, clays etc) they acquire some amount of ionic conductivity the degree of which depends on:

- volume percent of open space (pores, microfissures, cracks etc.) in the rock;
- moisture content or degree of open space saturation of the rock;
- degree of connectivity of the open spaces in the rock;
- nature and amount of dissolved salts (and clays).

In employing electrical geophysical surveys, the key physical measurable property of rocks to be exploited is the ability to resist the flow of electric current. High volume percent of open space, high open space connectivity and/or high water saturation results in the lowering of the Resistivity of rocks. Resistivity, therefore, can in most cases be directly related to a rock's hydro-lithological qualities.

Resistivity survey can be conducted either by way of Vertical Electrical Sounding (VES) or by Horizontal Electrical Resistivity Profiling (HEP) methods. The object of VES survey (also known as electrical-drilling) is to determine depth-wise variations in resistivity at one location and up to very large depths, and is analogous to drilling at that point. The object of HEP profiling, on the other hand, is to determine lateral variations in resistivity at a given depth level (usually shallow) with higher degree of detail. Within the given depth level, HEP profiling also provides vertical resistivity variation of the ground.

Using a series of VES measurement points systematically arranged along a line, it is possible to build a semi-geologic section (geo-electric section) for the line. This is built by joining semi-stratigraphic zones with qualitative and/or quantitative similarity that can be recognized between the series of adjacent VES results.

VES and HEP profiling are, therefore, highly complementary methods which, together, enable us to investigate both vertical and lateral subsurface variations in rock quality (solid, fractured, loose, water saturated, dry, thermal etc.). Both methods are relatively quick.

Table 1. Adoption of geophysical method for various site conditions recommended by KKC.

Type of Survey	Geologic setting	Target Hydro-geologic condition	Recommended geophysical method
A	Alluvium	Aquifer	VES
	Limestone, conglomerate, sandstone and siltstone	Aquifer or fracture zone	VES
	conglomerate, sandstone and siltstone	Fracture zone	
B	Weathered basalt	Weathered zone	VES, HEP
C	Limestone, dolomite, shale and slate	Fracture zone	HEP
D	Volcanic, plutonic and metamorphic rocks	Weathered zone, fracture zone	VES, HEP

The interpretation of geo-electric results can be rather difficult in geologically complex areas due to extremely wide (often overlapping) resistivity ranges which characterize earth materials. This difficulty is greatly eased when at least one calibration drillhole data is available in proximity to the survey area.

3. Objective of the geophysical survey

The purpose of the electrical geophysical surveys is to cheaply and quickly provide subsurface hydro-geologic information which may directly or indirectly aid in locating potential ground water sites which shall ultimately maximize the success rate of subsequent water well drilling activity planned by KKC.

Results expected from the HEP survey are:

1. aid in indicating the presence and location of subsurface geological structures (e.g. fault zones, fracture zones, geologic contacts, fissures etc.) which are important factors for groundwater occurrence in some survey areas.

Relevant subsurface information expected to be obtained from the VES survey are:

1. an estimate of the thickness (and possible qualitative information on the water content) of the various geo-electrical layers within the depth of interest, which is nominally set at 100m (medium depth penetration) and 200m (deep depth penetration)
2. probable clues regarding the water quality (i.e., degree of salinity), if present.

4. Location, Physiography, climate and Accessibility of the Survey Areas

The sixty three sites surveyed in Tigray region are in Raya Azebo wereda (9 sites), Alamata wereda (8 sites), Hintalo wereda (7 sites), Saharti Samre wereda (6 sites), Enderta wereda (7 sites), Kilte Awlalo wereda (7 sites), Hawzen wereda (7 sites), Dega Tembien wereda (4 sites), Kola Tembien wereda (3 sites), Tanqua Abergele wereda (5 sites). Except Raya Azebo, Alamata and Enderta weredas some of the sites in the rest of the weredas are inaccessible or else difficult to find. Several sites have been cancelled for complete lack of access in these weredas.

The Raya Azebo and Alamata weredas are situated in a large valley characterized by generally flat and wide farmlands with surrounding high mountains. The rest of the weredas are characterized by rugged terrain composed of metamorphosed/sheared sedimentary and mostly exposed intrusive rocks. Altitudes in the areas range from 1350m to 2629m A.M.S.L. Most of the surveyed areas are generally characterized by sparse acacia & thornbush. It has scanty vegetation with the relatively vegetated areas being covered with thorny bush. Scattered trees usually occur along the main drainage system in the area. The area is generally characterized by medium to hot tropical climate. The major rainy season of the area is from June to September while the major dry season is from October to May. According to the National Meteorological Service Agency of Ethiopian (2001), the average rainfall is 800-1000 mm per annum with temperatures ranging from a mean daily maximum of 32.5o C in March to a mean daily minimum of 13 o C in January.

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5. Survey summary statistics

The field data acquisition of the geophysical survey was started on January 9, 2007 and completed on January 31, 2007. The volume of work during this field trip is summarized in tables 2 and 3.

Table 2. Summary of volume of geophysical work executed

			Schlumberger		Dipole-Dipole		
	Wereda name	Nº of Sites	medium depth penetration VES	high depth penetration VES	Hor. profiling (n=5)	Hor. profiling (n=7)	high depth penetration VES
1	Raya Azebo	9	4	35	0	0	0
2	Alamata	8	6	25	0	0	0
3	Hintalo	7	10	10	0	0	0
4	Saharti Samre	6	12	0	0	0	0
5	Enderta	7	14	0	0	0	0
6	Kilte Awlalo	7	10	0	2	2	2
7	Hawzen	7	4	0	5	5	5
8	Dega Tembien	4	8	0	0	0	0
9	Kola Tembien	3	4	0	1	1	1
10	Tanqua Abergele	5	0	0	5	5	5
	Total	63	72	70	13	13	13

Table 3. Detail of volume of geophysical work executed

Wereda	Site (VES) name	UTM-N	UTM-E	Elevetion	Date	Type of survey
Alamata	*Walka 1*	1364704	558436	1674	16-Jan-07	Schlumberger VES (Deep)
	Walka 2	1364660	558600	1616	16-Jan-07	Schlumberger VES (Deep)
	Walka 3	1364891	558781	1610	16-Jan-07	Schlumberger VES (Deep)
	Walka 4	1365094	558871	1609	16-Jan-07	Schlumberger VES (Deep)
	Walka 5	1365244	558911	1602	16-Jan-07	Schlumberger VES (Deep)
	Bedena leko 1	1361640	574030	1390	17-Jan-07	Schlumberger VES (Deep)
	Bedena leko 2	1361775	574235	1386	17-Jan-07	Schlumberger VES (Deep)
	Bedena leko 3	1361870	574350	1390	17-Jan-07	Schlumberger VES (Deep)
	Bedena leko 4	1361954	574453	1389	17-Jan-07	Schlumberger VES (Deep)
	Bedena leko 5	1362085	574591	1390	17-Jan-07	Schlumberger VES (Deep)
	Gerjele1	1379808	566674	1467	18-Jan-07	Schlumberger VES (Deep)
	Gerjele2	1379815	566848	1456	18-Jan-07	Schlumberger VES (Deep)
	Gerjele3	1379771	566988	1461	18-Jan-07	Schlumberger VES (Deep)
	Gerjele4	1379684	567209	1464	18-Jan-07	Schlumberger VES (Deep)
	Gerjele5	1379559	567360	1456	18-Jan-07	Schlumberger VES (Deep)
	Bubie 1	1382933	565891	1526	18-Jan-07	Schlumberger VES (Deep)
	Bubie 2	1382784	565809	1507	18-Jan-07	Schlumberger VES (Deep)
	Bubie 3	1382819	565627	1531	18-Jan-07	Schlumberger VES (Deep)
	Bubie 4	1382854	565351	1541	18-Jan-07	Schlumberger VES (Deep)
	Bubie 5	1382281	565972	1532	18-Jan-07	Schlumberger VES (Deep)
	Ula1	1382300	563760	1611	18-Jan-07	Schlumberger VES (Deep)
	Ula2	1382374	563821	1580	18-Jan-07	Schlumberger VES (Deep)

	Ula3	1382410	563980	1576	18-Jan-07	Schlumberger VES (Deep)
	Ula4	1382444	564152	1559	18-Jan-07	Schlumberger VES (Deep)
	Ula5	1382400	564302	1556	18-Jan-07	Schlumberger VES (Deep)
	Hadish kign 1	1373181	568827	1417	16-Jan-07	Schlumberger VES (Medium)
	Hadish kign 2	1372555	568831	1416	16-Jan-07	Schlumberger VES (Medium)
	Kunkura 1	1359619	567621	1437	16-Jan-07	Schlumberger VES (Medium)
	Kunkura 2	1359739	567735	1438	16-Jan-07	Schlumberger VES (Medium)
	Adi Mohoye 1	1371043	565855	1451	17-Jan-07	Schlumberger VES (Medium)
	Adi Mohoye 2	1370967	566135	1440	17-Jan-07	Schlumberger VES (Medium)
Dega Tembien	*Alasa 1*	1512574	528894	2421	28-Jan-07	Schlumberger VES (Medium)
	Alasa 2	1512921	528744	2387	28-Jan-07	Schlumberger VES (Medium)
	Denglet 1	1506499	518863	2586	28-Jan-07	Schlumberger VES (Medium)
	Denglet 2	1506374	518829	2579	28-Jan-07	Schlumberger VES (Medium)
	Raset 1	1511034	527979	2421	25-Jan-07	Schlumberger VES (Medium)
	Raset 2	1511440	527938	2454	25-Jan-07	Schlumberger VES (Medium)
	Enda Mariam 1	1501301	512831	2622	25-Jan-07	Schlumberger VES (Medium)
	Enda Mariam 2	1501164	512649	2629	25-Jan-07	Schlumberger VES (Medium)
Enderta	*Mai keyah 1*	1472642	557789	2332	21-Jan-07	Schlumberger VES (Medium)
	Mai keyh 2	1472719	557453	2336	21-Jan-07	Schlumberger VES (Medium)
	Filfil 1	1490221	543406	2154	24-Jan-07	Schlumberger VES (Medium)
	Filfil 2	1490467	543182	2158	24-Jan-07	Schlumberger VES (Medium)
	Chea 1	1491366	541508	2177	23-Jan-07	Schlumberger VES (Medium)
	Chea 2	1491405	541418	2226	23-Jan-07	Schlumberger VES (Medium)
	Mai Weini 1	1490771	541734	2177	23-Jan-07	Schlumberger VES (Medium)
	Mai Weini 2	1490767	541833	2165	23-Jan-07	Schlumberger VES (Medium)
	Adi Amik1	1489424	545046	2133	23-Jan-07	Schlumberger VES (Medium)
	Adi Amik2	1489653	544781	2138	23-Jan-07	Schlumberger VES (Medium)
	Kokahi 1	1487627	546457	2091	23-Jan-07	Schlumberger VES (Medium)
	Kokahi 2	1487775	546763	2110	23-Jan-07	Schlumberger VES (Medium)
	Sewhi 1	1480523	554938	2229	21-Jan-07	Schlumberger VES (Medium)
	Sewhi 2	1481038	554857	2245	21-Jan-07	Schlumberger VES (Medium)
Hawzen	*Berakit 1*	1539973	535062	1956	23-Jan-07	Schlumberger VES (Medium)
	Berakit 2	1540082	534979	1954	23-Jan-07	Schlumberger VES (Medium)
	Degamba 1	1558866	549883	2354	24-Jan-07	Schlumberger VES (Medium)
	Degamba 2	1558721	549906	2353	24-Jan-07	Schlumberger VES (Medium)
	teka	1555569	547074	2223		Dipole-Dipole VES (and 2 level profiling)
	Tsefah	1556555	543650	2131	27-Jan-07	Dipole-Dipole VES (and 2 level profiling)
	Merer hwa	1541523	532082	1914	23-Jan-07	Dipole-Dipole VES (and 2 level profiling)
	Mewkel	1539544	528952	1650	23-Jan-07	Dipole-Dipole VES (and 2 level profiling)
	Beraket	1542402	535422	1937	24-Jan-07	Dipole-Dipole VES (and 2 level profiling)
Hintalo Wajirat	*Netae 1*	1479878	536560	2162	20-Jan-07	Schlumberger VES (Deep)
	Netae 2	1479875	536326	2153	20-Jan-07	Schlumberger VES (Deep)
	Netae 3	1480112	136177	2144	20-Jan-07	Schlumberger VES (Deep)
	Netae 4	1480250	536044	2133	20-Jan-07	Schlumberger VES (Deep)
	Netae 5	1479818	53694	2163	20-Jan-07	Schlumberger VES (Deep)
	Dengolat 1	1470637	535751	2324	21-Jan-07	Schlumberger VES (Deep)
	Dengolat 2	1470446	536132	2329	21-Jan-07	Schlumberger VES (Deep)
	Dengolat 3	1469648	536992	2343	21-Jan-07	Schlumberger VES (Deep)
	Dengolat 4	1470044	536684	2338	21-Jan-07	Schlumberger VES (Deep)
	Dengolat 5	1470285	836546	2340	21-Jan-07	Schlumberger VES (Deep)

	Azeba 1	1457694	540614	2027	20-Jan-07	Schlumberger VES (Medium)
	Azeba 2	1457618	541025	2036	20-Jan-07	Schlumberger VES (Medium)
	Adidug 1	1466428	543622	2168	20-Jan-07	Schlumberger VES (Medium)
	Adidug 2	1466228	543871	2153	20-Jan-07	Schlumberger VES (Medium)
	Keyk hamed 1	1440779	561243	2331	19-Jan-07	Schlumberger VES (Medium)
	Keyk hamed 2	1440742	561273	2340	19-Jan-07	Schlumberger VES (Medium)
	Chekom 1	1464810	562321	2106	20-Jan-07	Schlumberger VES (Medium)
	Chekom 2	1465022	561795	2088	20-Jan-07	Schlumberger VES (Medium)
	Mai selas 1	1457456	552641	2236	20-Jan-07	Schlumberger VES (Medium)
	Mai selas 2	1456943	552338	2215	20-Jan-07	Schlumberger VES (Medium)
Kilte Awlalo	*Adi Wermai 1*	1520469	558621	2020	25-Jan-07	Schlumberger VES (Medium)
	Adi Wermai 2	1520736	558754	2018	25-Jan-07	Schlumberger VES (Medium)
	adi arbea 1	1524883	562860	1985	25-Jan-07	Schlumberger VES (Medium)
	adi arbea 2	1524684	562987	1984	25-Jan-07	Schlumberger VES (Medium)
	Sherafo 1	1512803	559943	1980	22-Jan-07	Schlumberger VES (Medium)
	Sherafo 2	1512783	559674	2020	22-Jan-07	Schlumberger VES (Medium)
	Adi btseat 1	1520651	548181	2005	22-Jan-07	Schlumberger VES (Medium)
	Adi btseat 2	1520804	548070	2020	22-Jan-07	Schlumberger VES (Medium)
	Ze Ana1	1522695	553992	2015	22-Jan-07	Schlumberger VES (Medium)
	Ze Ana2	1522394	553812	2018	22-Jan-07	Schlumberger VES (Medium)
	Adidino (maiougli)	1536890	561823	2355		Dipole-Dipole VES (and 2 level profiling)
	Adikulala	1532495	557038	2019		Dipole-Dipole VES (and 2 level profiling)
Kola Tembien	*Sheka 1*	1511600	501356	1883	29-Jan-07	Schlumberger VES (Medium)
	Sheka 2	1511956	501215	1881	29-Jan-07	Schlumberger VES (Medium)
	Deda 1	1504154	498980	1803	25-Jan-07	Schlumberger VES (Medium)
	Deda 2	1503989	498883	1805	25-Jan-07	Schlumberger VES (Medium)
	Wersege	1516135	502374	1881	29-Jan-07	Dipole-Dipole VES (and 2 level profiling)
Raya Azebo	*Had 1*	1377182	581146	1510	9-Jan-07	Schlumberger VES (Deep)
	had 2	1397210	580973	1509	9-Jan-07	Schlumberger VES (Deep)
	Had 3	1397272	580784	1507	9-Jan-07	Schlumberger VES (Deep)
	Had 4	1397350	580570	1506	10-Jan-07	Schlumberger VES (Deep)
	Had 5	1397412	580373	1481	10-Jan-07	Schlumberger VES (Deep)
	Hirika 1	1416576	575531	1695	11-Jan-07	Schlumberger VES (Deep)
	Hirika 2	1416364	575533	1695	11-Jan-07	Schlumberger VES (Deep)
	Hirika 3	1416153	575545	1685	11-Jan-07	Schlumberger VES (Deep)
	Hirika 4	1416576	575773	1686	11-Jan-07	Schlumberger VES (Deep)
	Hirika 5	1416577	575312	1697	11-Jan-07	Schlumberger VES (Deep)
	Fondel 1	1402447	568323	1707	11-Jan-07	Schlumberger VES (Deep)
	Fondel 2	1402362	568520	1681	11-Jan-07	Schlumberger VES (Deep)
	Fondel 3	1402316	568696	1687	12-Jan-07	Schlumberger VES (Deep)
	Fondel 4	1402229	568871	1679	12-Jan-07	Schlumberger VES (Deep)
	Fondel 5	1402139	569053	1673	12-Jan-07	Schlumberger VES (Deep)
	Gemed 1	1399436	567355	1671	12-Jan-07	Schlumberger VES (Deep)
	Gemed 2	1399222	567233	1671	12-Jan-07	Schlumberger VES (Deep)
	Gemed 3	1399011	567140	1686	12-Jan-07	Schlumberger VES (Deep)
	Gemed 4	1398818	567150	1680	12-Jan-07	Schlumberger VES (Deep)
	Gemed 5	1398802	966801	1693	12-Jan-07	Schlumberger VES (Deep)
	hasish 1	1389798	580105	1571	13-Jan-07	Schlumberger VES (Deep)
	hasish 2	1389874	579942	1557	13-Jan-07	Schlumberger VES (Deep)
	hasish 3	1389918	579771	1544	13-Jan-07	Schlumberger VES (Deep)

	hasish 4	1389918	579594	1537	13-Jan-07	Schlumberger VES (Deep)
	hasish 5	1389944	579441	1540	13-Jan-07	Schlumberger VES (Deep)
	Dodota 1	1382854	579974	1684	14-Jan-07	Schlumberger VES (Deep)
	Dodota 2	1382865	580102	1685	14-Jan-07	Schlumberger VES (Deep)
	Dodota 3	1382883	580214	1681	14-Jan-07	Schlumberger VES (Deep)
	Dodota 4	1382897	580326	1679	14-Jan-07	Schlumberger VES (Deep)
	Dodota 5	1382665	580175	1679	14-Jan-07	Schlumberger VES (Deep)
	GubaGalla1	1367578	574943	1399	15-Jan-07	Schlumberger VES (Deep)
	GubaGalla2	1367495	574752	1398	15-Jan-07	Schlumberger VES (Deep)
	GubaGalla3	1367595	574981	1392	15-Jan-07	Schlumberger VES (Deep)
	GubaGalla4	1367600	575133	1400	15-Jan-07	Schlumberger VES (Deep)
	GubaGalla5	1367429	574965	1399	15-Jan-07	Schlumberger VES (Deep)
	Asaye 1	1381664	583077	1728	14-Jan-07	Schlumberger VES (Medium)
	Asaye 2	1381572	583227	1735	14-Jan-07	Schlumberger VES (Medium)
	Kotkote 1	1371811	579368	1635	15-Jan-07	Schlumberger VES (Medium)
	Kotkote 2	1375487	579272	1624	15-Jan-07	Schlumberger VES (Medium)
Saharti Samre	*Gebana 1*	1447645	500543	1463	21-Jan-07	Schlumberger VES (Medium)
	Gebana 2	1447287	500764	1474	21-Jan-07	Schlumberger VES (Medium)
	Wete kezena 1	1448400	504146	1507	21-Jan-07	Schlumberger VES (Medium)
	Wete kezena 2	1448144	503928	1490	21-Jan-07	Schlumberger VES (Medium)
	Berezeba 1	1460061	532588	2010	21-Jan-07	Schlumberger VES (Medium)
	Berezeba 2	1460128	532668	1991	21-Jan-07	Schlumberger VES (Medium)
	adish shai 1	1483547	526062	1932	21-Jan-07	Schlumberger VES (Medium)
	adish shai 2	1483467	524636	1840	21-Jan-07	Schlumberger VES (Medium)
	Gunfal 1	1474963	517588	2049	22-Jan-07	Schlumberger VES (Medium)
	Gunfal 2	1474775	517407	2039	22-Jan-07	Schlumberger VES (Medium)
	Kebarit 1	1478966	517925	2239	22-Jan-07	Schlumberger VES (Medium)
	Kebarit 2	1479130	517769	2234	22-Jan-07	Schlumberger VES (Medium)
Tanqua Abergele	*Gomenge 2*	1478940	477598	1446	30-Jan-07	Dipole-Dipole VES (and 2 level profiling)
	Tekle mekarira	1477594	483621	1350	30-Jan-07	Dipole-Dipole VES (and 2 level profiling)
	Hidmo 1	1482985	480341	1443	31-Jan-07	Dipole-Dipole VES (and 2 level profiling)
	Gomenge 1	1478097	476329	1428	30-Jan-07	Dipole-Dipole VES (and 2 level profiling)
	Hidmo 2	1484208	482573	1494	30-Jan-07	Dipole-Dipole VES (and 2 level profiling)

6. Methodology, Instrumentation and Field Procedure

Vertical Electrical Sounding (VES) and Horizontal Electrical Profiling (HEP) surveys were carried out at the pre-selected locations. Schlumberger and Dipole-Dipole arrays were employed as specified by the client using two sets of instruments (two teams working at different sites):

- a heavy duty portable PASI ERM model 16GL Earth Resistivity Meter with maximum current electrode separation (AB/2) of up to 500 meters was employed as multiple and deep aquifers were envisaged.
- a heavy duty portable ABEM SAS 4000 Earth Resistivity Meter with maximum current electrode separation (AB/2) of up to 750 meters was employed as multiple and deep aquifers were envisaged.

1. Schlumberger array VES for medium depth of penetration was conducted to a maximum AB/2 of 220m (and some times 330m as field situations dictated)
2. Schlumberger array VES for high depth of penetration was conducted to a maximum AB/2 of 330m (and some times 500m as field situations dictated)
3. Dipole-Dipole array HEP was conducted at two levels for each line (a=10, n=5 & a=10, n=7). Line lengths vary from site to site, but maximum line length is 370m
4. Dipole-Dipole array VES using 6 segments to a maximum apparent depths of 120m

Location of the VES points was recorded using a high fidelity a GARMIN and MLR 24 GPS.

7. Data Processing and Presentation

The results of the VES survey was then be processed and interpreted using IPI2WIN & RESIX PLUS computer softwares especially adopted for this purpose. Note that these softwares are preferred by the Hydro-Geophysicist for its superior results. Other presentation software such as Autocad 2004, Global Mapper 7.0, Grapher 4.0, ImageFolio and Surfer 8.0 were also employed.

The interpretation of data from the VES method is hoped to indicate the geophysical stratigraphy of the study area to a sufficient depth and perhaps also thickness and quality variations of aquifer(s).

Lateral interpolation between VES results of two or more adjacent (closely spaced) stations is being increasingly employed for determining the geo-electrical section of the subsurface. A geo-electric section is essential in that it provides a simultaneous view of both the vertical as well as the horizontal electrical property distribution of the ground. On geo-electric sections, faults/fracture zones may also be inferred by abrupt interruptions and/or displacements of an otherwise horizontally continuous geo-electric layer.

In order to simplify the presentation of the data, inversion modeling results, apparent resistivity pseudo-sections and geo-electric sections of each site is presented together. Note that maximum attempt has been made to render each figure as self sufficient and self explanatory as possible. As a result, the interpretation and discussion section shall only be short and to the point.

8. Results and Interpretation

The final result for all survey sites has been presented in the form of stacks and overlays for direct and easy correlation of the various geophysical results and other information gathered. For reasons of simplicity, only zones of interest shall be discussed in brief. Resistivity values shall also be typified as follows:

- Resistivities less than 15 ohm-m are considered VERY LOW
- Resistivities between 15 - 45 ohm-m are considered LOW
- Resistivities between 45 - 100 ohm-m are considered INTERMEDIATE
- Resistivities between 100 – 300 ohm-m are considered HIGH, and
- Resistivities greater than 300 ohm-m are considered VERY HIGH

The diagnostic parameters resulting from VES / HEP surveys are, in general, resistivities and thickness of subsurface layers within the depth range of investigation. The electrical resistivity of a rock mass can, in general, be directly related to its:

- water content, which in turn is related to its bulk porosity and degree of pore connectivity of the rock
- conductive mineral content (e.g. pyrite, graphite, clay etc.), and
- the degree of salinity of the water in the rock.

Except clay zones, the presence of other highly conductive minerals (e.g. graphite, salts etc) has not been reported for all the surveyed areas. Therefore, varying water content of rock masses (vis-à-vis varying bulk porosity and degree of pore connectivity) is a major factor contributing to the observed low resistivities. Varying clay content may also be a probable major factor contributing to the commonly observed extremely low resistivity responses.

Electrical resistivity generally decreases with increase in clay content and water content (water content is directly proportional rock porosity and degree of pore-connectivity) of subsurface rocks.

Qualitatively stated, it follows from the above statements that geo-electric layers with relatively high resistivities should correspond to rock masses with relatively high degree of compactness, i.e. rocks with no water and clay content (e.g. fresh basalt). Conversely, geo-electric layers with relatively low resistivities should correspond to rock masses with high water and/or clay content (e.g. near surface quaternary sediments, subsurface aquifer zones etc.).

Note that a given geo-electric (resistivity) layer may not necessarily have a direct correspondence with a distinct geologic layer. This is because it is possible that a given geologically distinct layer may have different porosity and/or water contents vis-à-vis different resistivities at different depths or that any two geologically different layers may have similar water contents etc. and thus may have similar resistivities. It is, therefore, important not to confuse geo-electric layers (a rock mass with distinct electrical characteristics) with geologic layers (a rock mass with distinct geologic/mineralogical characteristic) and, thus, not to expect a one-to-one correspondence between the two.

A condensed and most revealing method of presenting the results of several closely situated sounding surveys is as a geo-electric section and apparent resistivity pseudo-section which, in simple terms, is a cross-section showing the resistivities and thickness of subsurface strata found within the effective depth of investigation.

The various geo-electrical layers on the figures can qualitatively be re-grouped and interpreted as follows:

- layers with resistivity in the ranges of <15 and 15-45 ohm-m: if found at depth, these zones are of interest and most probably represent the relatively least compact layers which may probably correlate with water bearing unconsolidated/fragmented rock masses and/or clay zones.
- layers with resistivity ranges of 45-100 and 100-300 ohm-m: these are zones of little interest and most probably represent the averagely compact layers with possibly little clay and some water content (e.g. fractured rock zones with little water)
- layers with resistivity ranges of 300-1000 and >1000 ohm-m: these most probably represent the highly compact layers which may probably correlate with dry and solid basalt, scoria etc.

8.1 RAYA AZEBO WEREDA

Hade alga

Results for Hade Alga site are presented on Figure 2a. The target lowermost very low to low resistivity strata in the vicinity of anywhere between VES-2 and VES–4 is recommended for borehole construction, and should be intersected sufficiently (at least 110m or more) during drilling. Total depth of drilling is recommended to be not less than 120m. Quick preliminary test (by blowing) is however recommended at around 100m (during drilling) in order to determine if sufficient water may be abstracted at this point. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers.

Though the depth to first water strike at the selected area is at about 100m, the depth to the bottom of this aquifer is unknown. In order to increase transmissivity (which is directly proportional to bore hole yield), the depth of the borehole is suggested to be not less than 120m. Refer to either Table 3 or figure 2a for UTM coordinate of the VES points.

Hirika

Results for Hirika site are presented on Figure 2b. The target lowermost very low to low resistivity strata in the vicinity of anywhere between VES-1 and VES–2 (the closer to VES-2 the better) is recommended for borehole construction, and should be intersected sufficiently during drilling. Total depth of drilling is recommended to be about 95m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 2b for UTM coordinate of the VES points.

Fondel

Results for Fondel site are presented on Figure 2c. The target lowermost very low to low resistivity strata in the vicinity of VES-3 (between depths of 50 – 78m) is recommended for borehole construction, and should be intersected sufficiently during drilling. Total depth of drilling is recommended to be about 80m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 2c for UTM coordinates of the relevant VES points.

Gemedadi

Results for Gemedadi site are presented on Figure 2d. The target lowermost very low to low resistivity strata in the vicinity of anywhere between VES-2 and VES-3 (between depths of 40 – 100m) is recommended for borehole construction, and should be intersected sufficiently during drilling. Total depth of drilling is recommended to be about 110m. The top few meters of the well should be grouted and sealed after drilling

in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 2d for UTM coordinates of the relevant VES points.

Hadish Kign

Results for Hadish Kign site are presented on Figure 2e. The target very low to low resistivity strata in the vicinity of anywhere between VES-3 and VES-4 (below depths of 100m) is recommended for borehole construction, and should be passed sufficiently during drilling. Total depth of drilling is recommended to be at least 130m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 2e for UTM coordinates of the relevant VES points.

Dodota

Results for Dodota site are presented on Figure 2f. The prospect for ground water in this site seems to be low. However, if drilling has to be conducted a relatively better chance of getting water seems to be in the vicinity of VES-5. The target low resistivity strata in the vicinity of VES-5 (below depths of 58m) is recommended for borehole construction, and should be passed sufficiently during drilling. Total depth of drilling is recommended to be at least 80m. Refer to either Table 3 or figure 2f for UTM coordinates of the relevant VES points.

Asaye

Results for Asaye site are presented on Figure 2g. The prospect for deep ground water in this site seems to be low. However, if drilling (or hand digging) has to be conducted a relatively better chance of getting water seems to be in the vicinity of VES-1. The target low resistivity strata in the vicinity of VES-1 (between depths of 5 and 9m) is recommended for borehole construction, and should be passed sufficiently during drilling (hand digging). Total depth of drilling is recommended to be about 10m. Refer to either Table 3 or figure 2g for UTM coordinates of the relevant VES points.

Kotkote

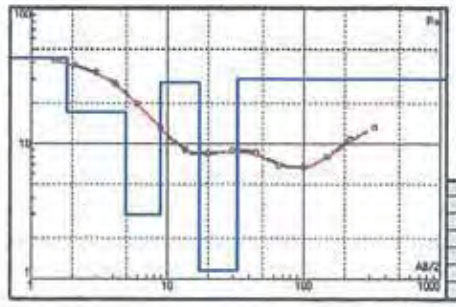
Results for Kotkote site are presented on Figure 2g. The prospect for deep ground water in this site also seems to be low. However, if drilling (or hand digging) has to be conducted a relatively better chance of getting water seems to be in the vicinity of VES-1. The target intermediate resistivity strata in the vicinity of VES-1 (between depths of 9 and 32m) is recommended for borehole construction, and should be intersected fully during drilling. Total depth of drilling is recommended to be about 35m. Refer to either Table 3 or figure 2g for UTM coordinates of the relevant VES points.

Tach GubaGalla

Results for Tach GubaGalla site are presented on Figure 2f. The target very low to low resistivity strata in the vicinity of VES-2 (between depths of 24 - 46m) is recommended for borehole construction, and should be passed sufficiently during

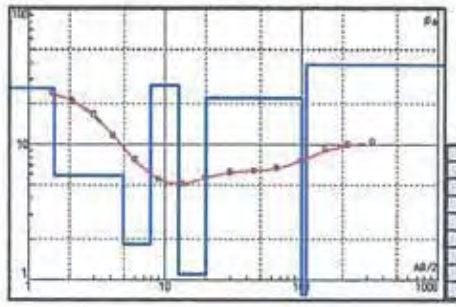
drilling. Total depth of drilling is recommended to be at least 50m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 2f for UTM coordinates of the relevant VES points.

	UTM-N	UTM-E	Elevetion
Had 1	1397182	581146	1510
had 2	1397210	580973	1509
Had 3	1397272	580784	1507
Had 4	1397350	580570	1506
Had 5	1397412	580373	1481



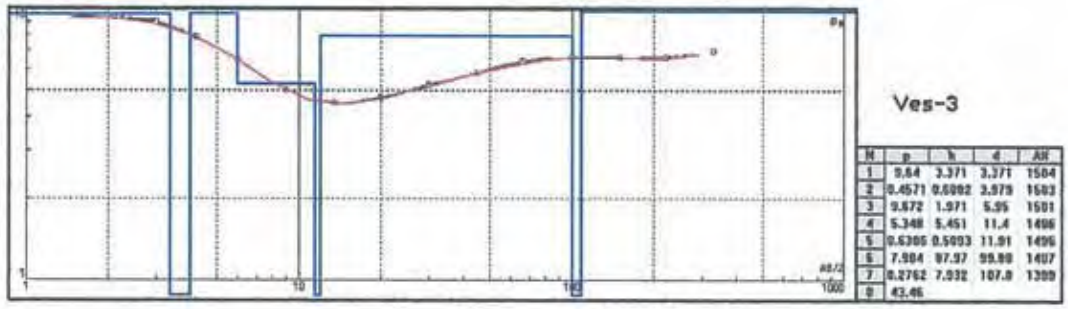
Ves-1

N	ρ	h	d	Alt
1	43.39	1.815	1.815	1508
2	17.47	3.131	4.946	1505
3	3.815	3.854	8.84	1501
4	28.87	8.369	17.21	1493
5	1.17	15.25	32.46	1478
6	38.73			



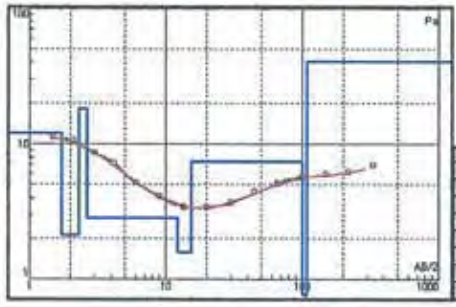
Ves-2

N	ρ	h	d	Alt
1	26.46	1.546	1.546	1507
2	5.838	3.354	4.84	1504
3	1.835	2.83	7.77	1501
4	27.67	4.851	12.62	1496
5	1.105	7.388	20.01	1488
6	22.14	79.87	99.88	1409
7	0.2695	7.932	107.8	1401
8	38.95			



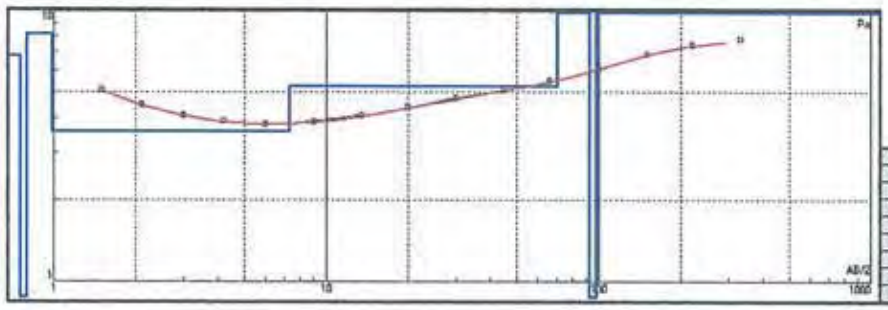
Ves-3

N	ρ	h	d	Alt
1	9.64	3.371	3.371	1504
2	0.4571	0.6092	3.979	1503
3	9.672	1.971	5.95	1501
4	5.348	5.451	11.4	1496
5	0.6305	0.5093	11.91	1496
6	7.984	87.97	99.88	1407
7	0.2762	7.932	107.8	1399
8	43.46			



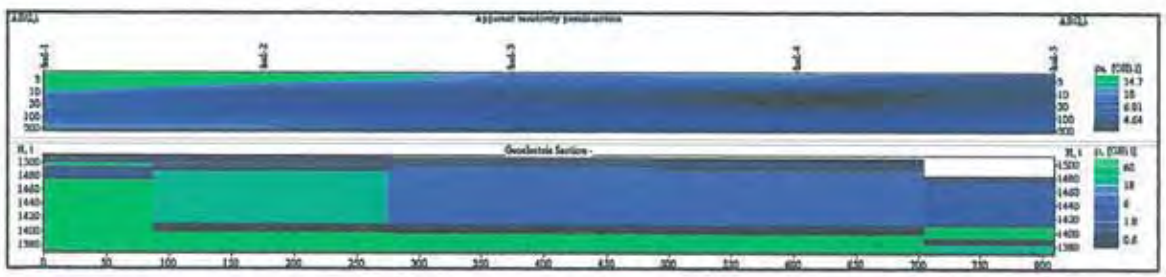
Ves-4

N	ρ	h	d	Alt
1	12.18	1.723	1.723	1504
2	2.144	0.5791	2.302	1504
3	18.52	0.3287	2.631	1503
4	2.884	9.672	12.3	1494
5	1.821	3.845	15.35	1491
6	7.521	84.53	99.88	1408
7	0.2653	7.932	107.8	1399
8	48.81			



Ves-5

N	ρ	h	d	Alt
1	6.846	6.75	6.75	148
2	0.3413	0.6425	0.7926	148
3	8.23	0.1958	0.9884	148
4	3.817	6.317	7.305	1474
5	5.283	63.68	70.39	1411
6	44.17	21.44	91.82	1389
7	0.1674	5.959	97.78	1383
8	27.67			



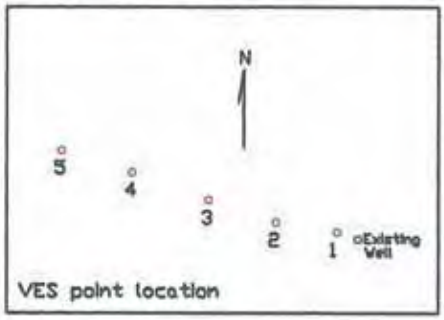
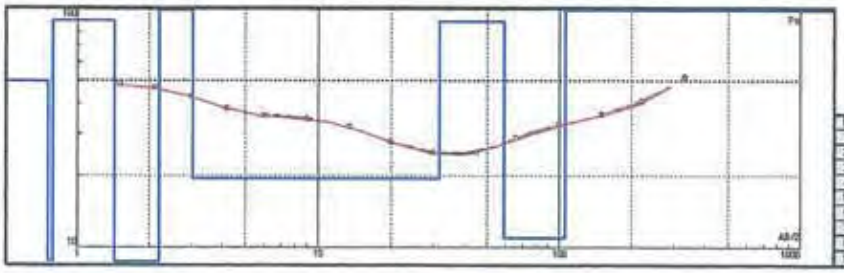
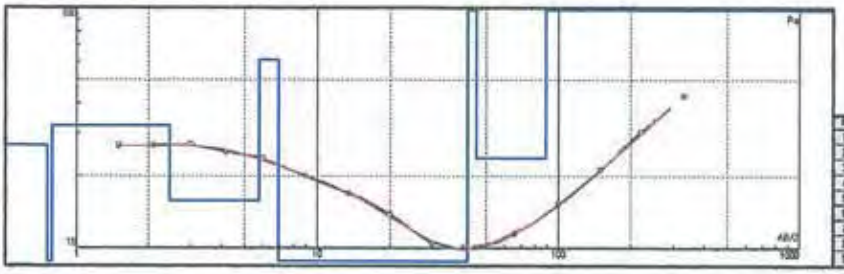


Figure 2a: Vertical Electrical Sounding results of Hade Alga site (Raya Azebo wereda).



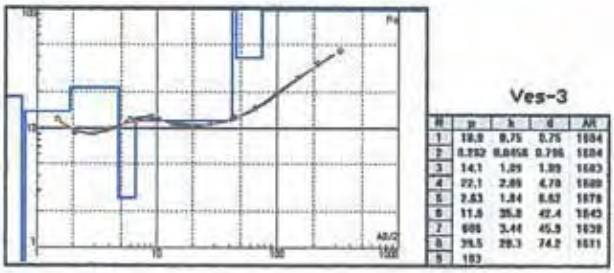
Ves-1

N	ρ	h	d	Alt
1	58.27	0.75	0.75	1694
2	8.297	0.040648	0.7887	1694
3	98.15	0.6292	1.42	1694
4	8.785	0.7658	2.187	1693
5	298.8	0.8214	3.013	1692
6	19.49	28.55	31.56	1665
7	88.79	27.11	58.67	1636
8	11.83	47.04	105.7	1589
9	869.4			



Ves-2

N	ρ	h	d	Alt
1	27.01	0.75	0.75	1694
2	6.196	3.036146	3.7881	1694
3	32.58	1.657	2.443	1693
4	15.84	3.232	5.775	1689
5	61.3	1.123	6.898	1688
6	7.25	34.55	41.05	1653
7	154.9	3.82	45.27	165
8	23.75	43.13	88.4	1607
9	513.8			

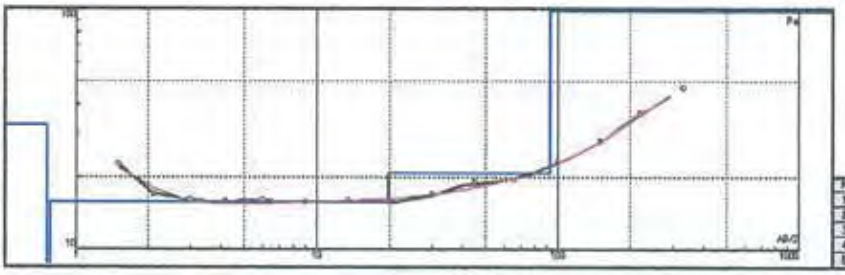


Ves-3

N	ρ	h	d	Alt
1	18.9	0.75	0.75	1694
2	0.252	0.0058	0.755	1694
3	14.1	1.05	1.80	1693
4	22.1	2.85	4.78	1689
5	2.63	1.84	6.62	1678
6	11.8	35.8	42.4	1643
7	606	3.44	45.9	1638
8	39.5	28.3	74.2	1611
9	183			

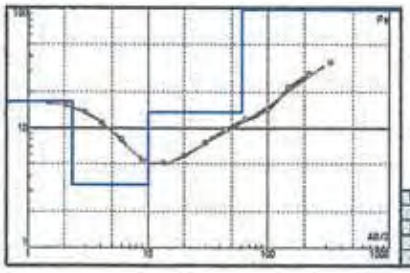
	UTN-N	UTN-E	Elevetion
Hirika 1	1416576	575531	1695
Hirika 2	1416364	575533	1695
Hirika 3	1416153	575545	1685
Hirika 4	1416576	575773	1686
Hirika 5	1416577	575312	1697

VES point location



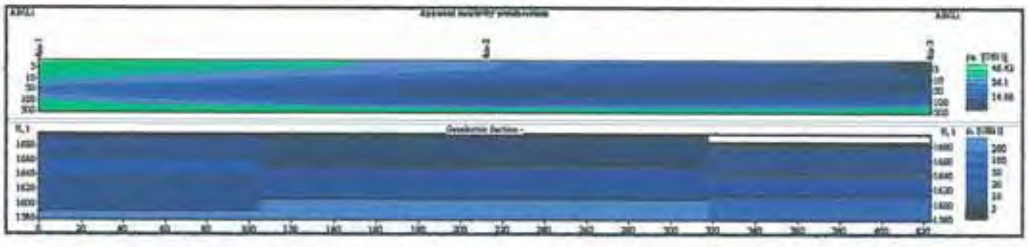
Ves-4

N	ρ	h	d	Alt
1	33.2	0.75	0.75	1694
2	0.651	0.0251	0.775	1694
3	15.9	18.9	19.7	1675
4	26.9	73	92.7	1602
5	120			



Ves-5

N	ρ	h	d	Alt
1	16.9	2.33	2.33	1693
2	3.33	7.6	9.93	1685
3	13.7	51.3	61.2	1634
4	88.6			



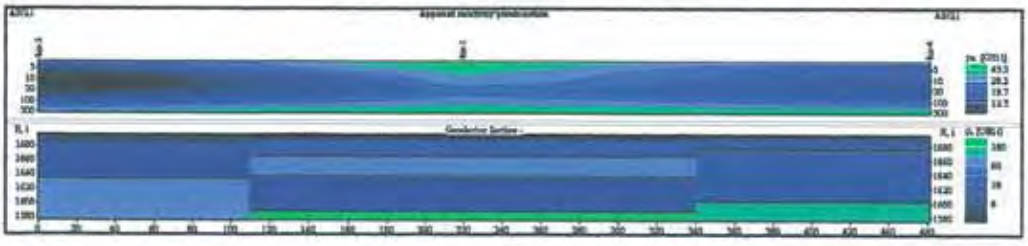
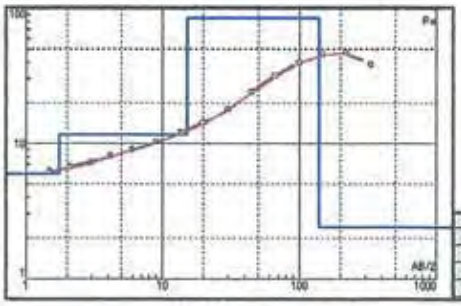


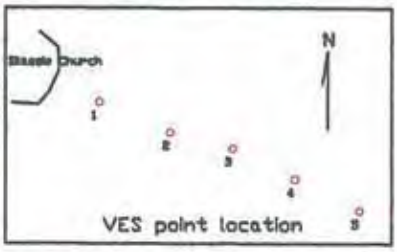
Figure 2b: Vertical Electrical Sounding results of Hirika site (Raya Azebo wereda).

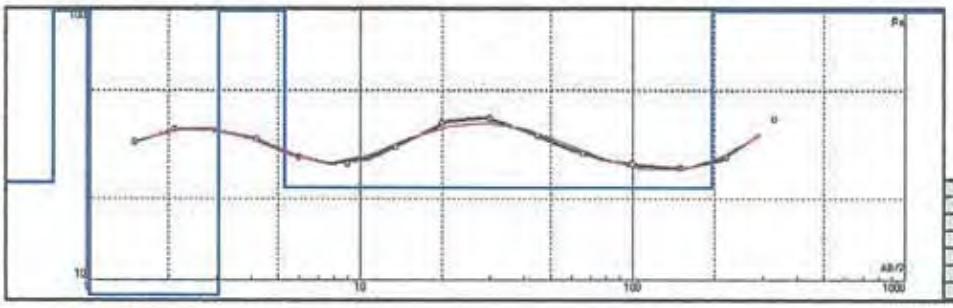
	UTM-N	UTM-E	Elevetion
Fondel 1	1402447	568323	1707
Fondel 2	1402362	568520	1681
Fondel 3	1402316	568696	1687
Fondel 4	1402229	568871	1679
Fondel 5	1402139	569053	1673



Ves-1

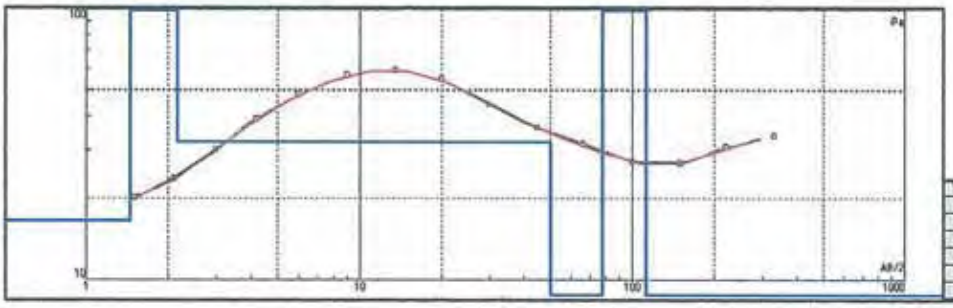
N	ρ	h	d	Alt
1	0.831	1.743	1.743	1705
2	11.88	13.48	15.22	1632
3	85.5	123	138.2	1568
4	2.428			





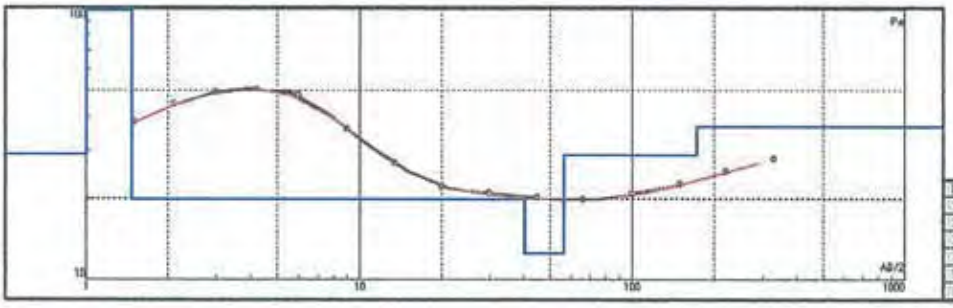
Ves-2

N	ρ	h	d	Alt
1	23	0.75	0.75	1680
2	257	0.274	1.02	1680
3	7.66	2.01	3.03	1678
4	293	2.25	5.28	1675
5	22.1	189	194	1487
6	3219			



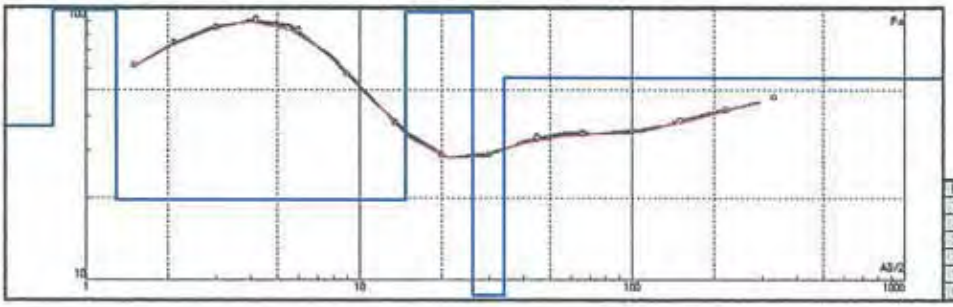
Ves-3

N	ρ	h	d	Alt
1	18.64	1.443	1.443	1686
2	695.9	0.7856	2.149	1685
3	32.36	47.85	50	1637
4	7.76	27.81	77.81	1609
5	357.2	34.62	112.4	1575
6	7.823			



Ves-4

N	ρ	h	d	Alt
1	28.37	0.0972	0.0972	1678
2	310.7	0.4748	1.472	1678
3	19.93	35.1	40.57	1638
4	12.63	15.49	56.06	1623
5	29.84	116.2	172.3	1507
6	37.15			



Ves-5

N	ρ	h	d	Alt
1	37.22	0.75	0.75	1672
2	618.5	0.5392	1.289	1672
3	19.73	13.36	14.65	1658
4	97.85	11.26	25.91	1647
5	6.086	7.099	33.0	1639
6	55.88			

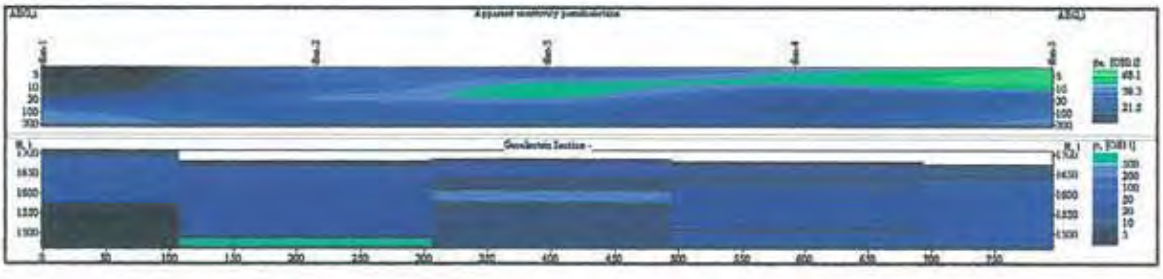
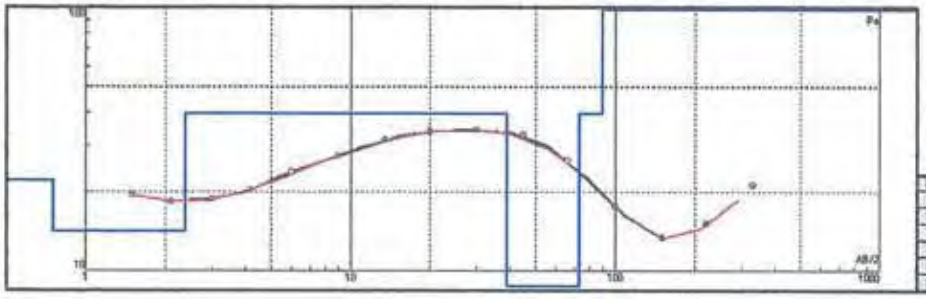


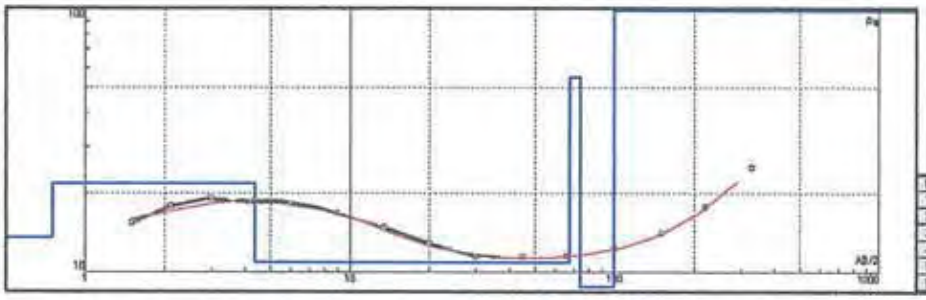
Figure 2c: Vertical Electrical Sounding results of Fondel site (Raya Azebo weredo).



Ves-1

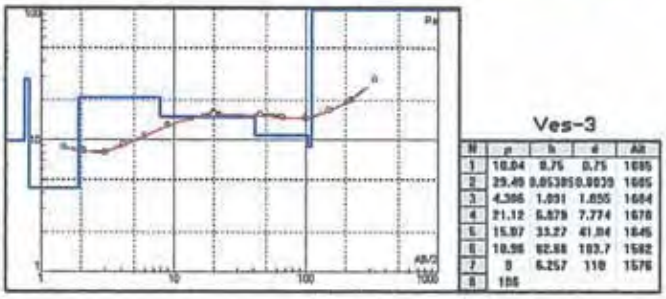
N	ρ	h	d	Alt
1	22.22	0.75	0.75	167
2	14.22	1.62	2.37	1669
3	39.8	36.39	38.76	1632
4	7.886	34.22	72.98	1598
5	39.72	16.17	88.15	1582
6	117.8			

VES point location



Ves-2

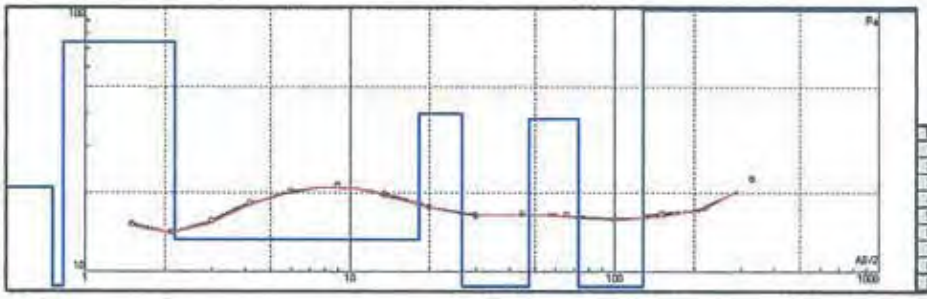
N	ρ	h	d	Alt
1	13.8	0.75	0.75	167
2	21.91	3.631	4.381	1667
3	10.84	63.35	67.73	1603
4	55.51	6.314	74.04	1597
5	3.729	25.5	99.54	1571
6	887.1			



Ves-3

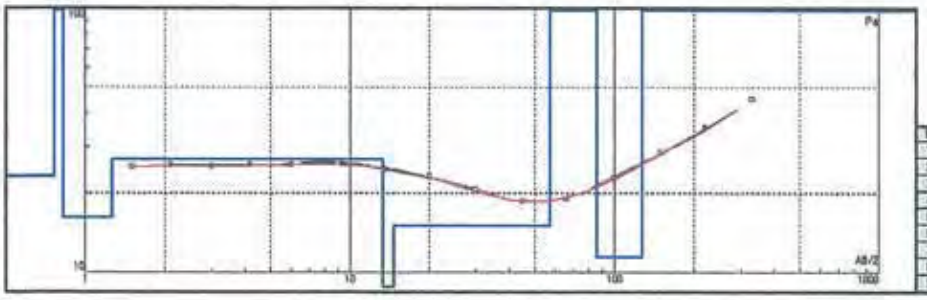
N	ρ	h	d	Alt
1	10.04	0.75	0.75	1685
2	29.49	0.053850	0.8039	1685
3	4.386	1.091	1.895	1684
4	21.12	5.879	7.774	1678
5	15.97	33.27	41.04	1645
6	10.56	62.68	103.7	1582
7	0	6.257	110	1576
8	186			

	UTM-N	UTM-E	Elevetion
Gemed 1	1399436	567355	1671
Gemed 2	1399222	567233	1671
Gemed 3	1399011	567140	1686
Gemed 4	1398818	567150	1680
Gemed 5	1398802	566801	1693



Ves-4

N	ρ	h	d	Alt
1	21.07	0.75	0.75	1679
2	0.6887	0.97665	0.8267	1679
3	74.83	1.349	2.176	1679
4	13.28	15.98	18.16	1662
5	48.28	8.288	26.44	1654
6	7.554	20.9	47.34	1633
7	38.4	25.43	72.77	1607
8	5.548	55.4	128.2	1552
9	479.3			



Ves-5

N	ρ	h	d	Alt
1	23.35	0.7862	0.7862	1692
2	147.7	0.56282	0.9282	1692
3	18.22	0.4326	1.261	1692
4	26.86	12.05	13.31	168
5	5.113	1.283	14.61	1679
6	15.1	42.87	57.18	1636
7	127.3	28.82	86.0	1607
8	11.5	40.71	126.5	1566
9	552.3			

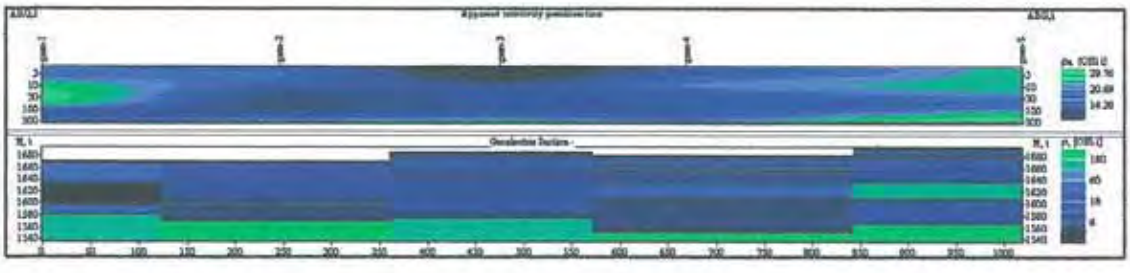
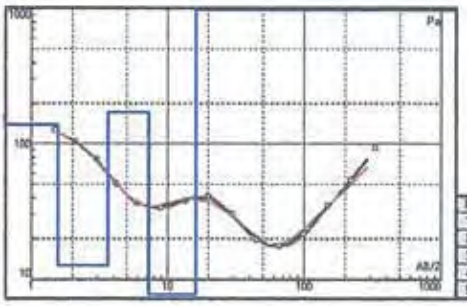


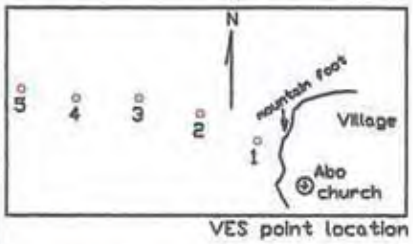
Figure 2d: Vertical Electrical Sounding results of Gemedadi site (Raya Azebo wereda).

	UTM-N	UTM-E	Elevetion
hadish Kign 1	1389798	580105	1571
hadish Kign 2	1389874	579942	1557
hadish Kign 3	1389918	579771	1544
hadish Kign 4	1389918	579594	1537
hadish Kign 5	1389944	579441	1540

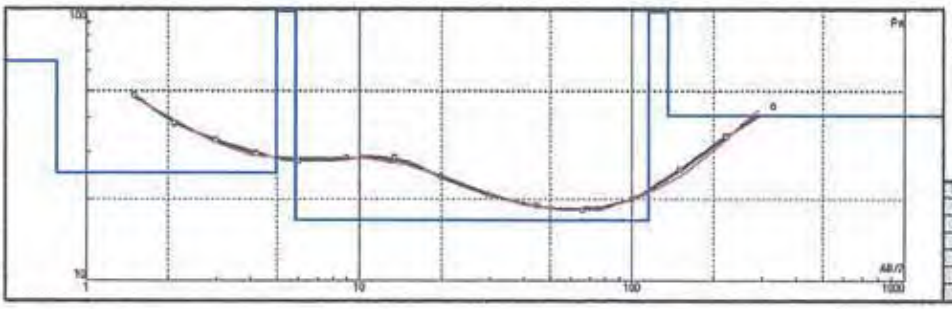


Ves-1

N	ρ	h	d	Alt
1	141	1.55	1.55	1569
2	12.7	2.3	3.85	1567
3	175	3.37	7.22	1564
4	2.18	8.82	16	1555
5	8172			

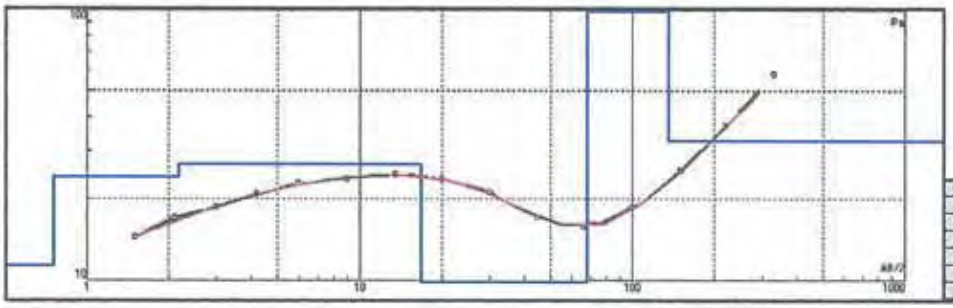


VES point location



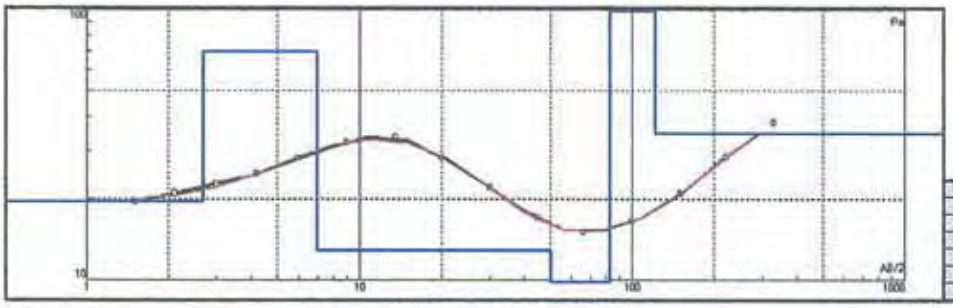
Ves-2

N	ρ	h	d	Alt
1	95	0.779	0.779	1556
2	25.1	4.19	4.96	1552
3	129	0.892	5.85	1551
4	16.3	109	115	1442
5	57756	20	135	1422
6	41			



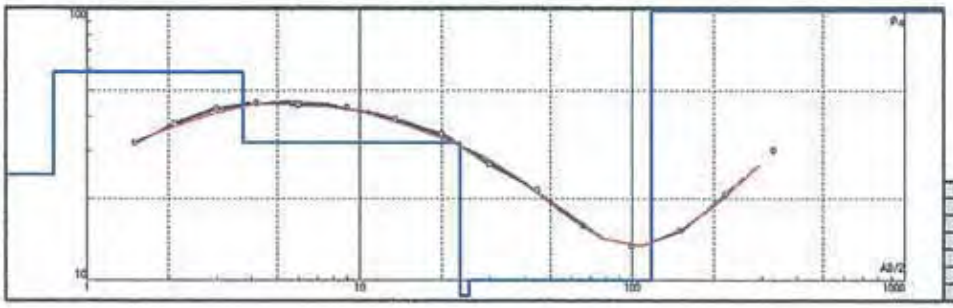
Ves-3

N	ρ	h	d	Alt
1	11.36	0.75	0.75	1543
2	24.16	1.425	2.175	1542
3	28.89	14.59	16.76	1527
4	9.963	51.56	68.32	1476
5	46181	66.13	134.5	141
6	32.83			



Ves-4

N	ρ	h	d	Alt
1	19.58	2.665	2.665	1534
2	70.27	4.314	6.979	153
3	12.98	43.88	50.86	1487
4	9.866	32.77	83.63	1454
5	948.7	38.25	121.1	1416
6	35.26			



Ves-5

N	ρ	h	d	Alt
1	24.8	0.75	0.75	1539
2	58.95	2.98	3.73	1538
3	32.47	19.55	23.28	1517
4	2.511	1.88	25.16	1515
5	10.05	92.75	117.9	1422
6	1233			

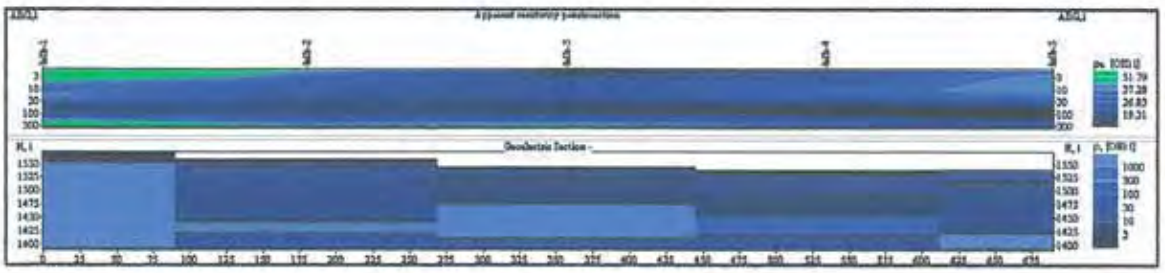
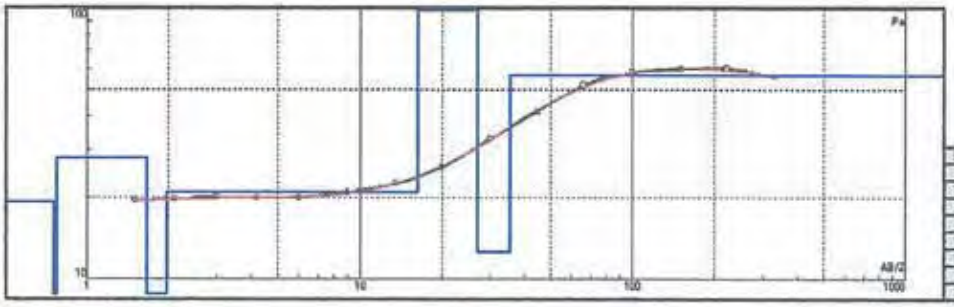
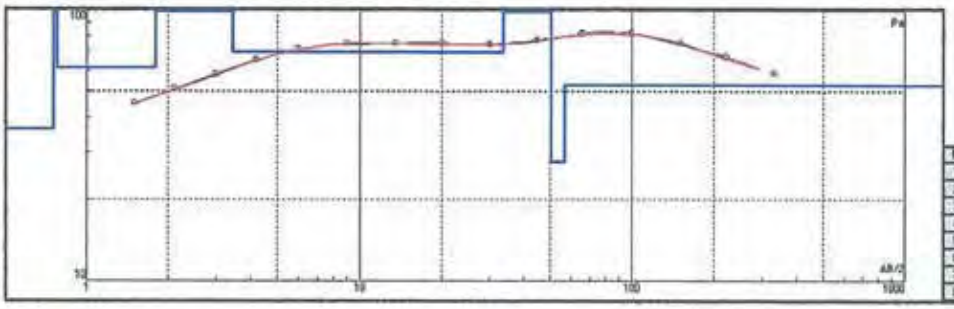


Figure 2e: Vertical Electrical Sounding results of Hadish kign site (Raya Azebo weredo).



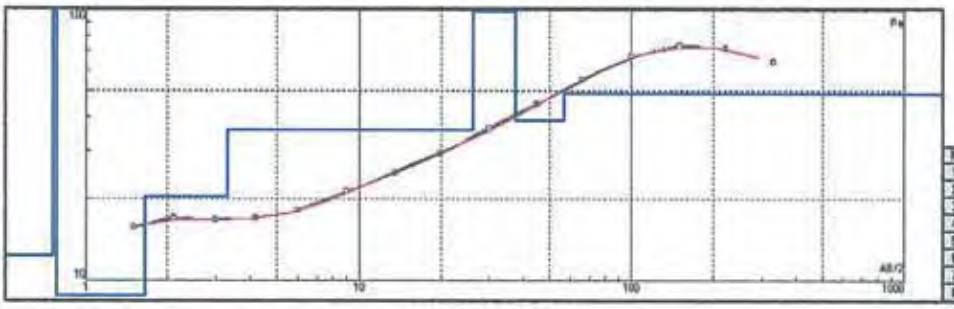
Ves-1

N	ρ	h	d	Alt
1	19.38	0.75	0.75	1683
2	2.177	0.02188	0.772	1683
3	28.09	0.8911	1.663	1682
4	7.526	0.3034	1.966	1682
5	21.83	14.2	16.17	1668
6	378.1	10.85	26.92	1657
7	12.68	8.737	35.55	1649
8	57			



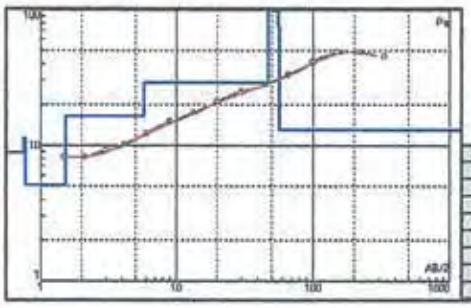
Ves-2

N	ρ	h	d	Alt
1	36.45	0.75	0.75	1684
2	121.4	0.02356	0.7735	1684
3	61.51	1.016	1.79	1683
4	114.9	1.663	3.453	1682
5	79.37	30.23	33.68	1651
6	205.1	16.98	50.66	1634
7	27.77	6.874	58.74	1628
8	53.29			



Ves-3

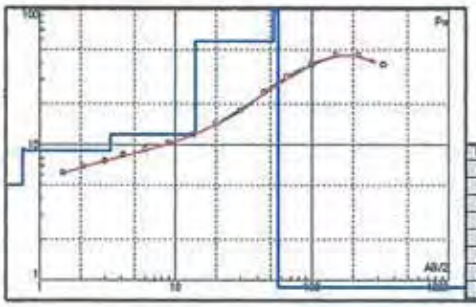
N	ρ	h	d	Alt
1	12.4	0.75	0.75	158
2	761.1	0.02355	0.7735	158
3	6.875	0.0602	1.642	1679
4	20.36	1.557	3.299	1678
5	36.88	22.9	25.1	1655
6	572.1	11.41	37.51	1643
7	39.32	19.23	56.74	1624
8	49.24			



Ves-4

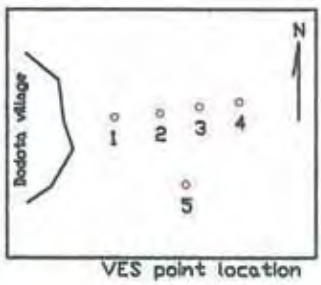
N	ρ	h	d	Alt
1	0.929	0.75	0.75	1678
2	11.42	0.02333	0.7733	1678
3	5.149	0.7647	1.538	1677
4	15.72	4.154	5.712	1673
5	29.45	41.49	47.2	1632
6	954.9	8.688	55.87	1623
7	75.55	0.8868	56.74	1622
8	13.26			

	UTM-N	UTM-E	Elevetion
Dodota 1	1382854	579974	1684
Dodota 2	1382865	580102	1685
Dodota 3	1382883	580214	1681
Dodota 4	1382897	580326	1679
Dodota 5	1382665	580175	1679



Ves-5

N	ρ	h	d	Alt
1	5.102	0.75	0.75	1678
2	9.389	0.023330	0.7733	1678
3	9.188	2.513	3.286	1676
4	12.87	10.75	14.04	1655
5	58.45	38.48	52.52	1626
6	2954	3.836	56.35	1623
7	62.87	0.3780	56.73	1622
8	0.9041			



VES point location

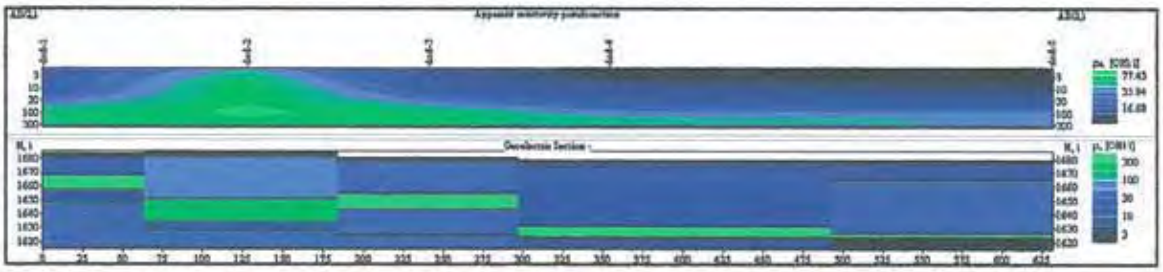
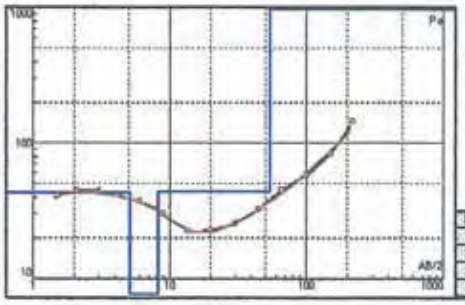


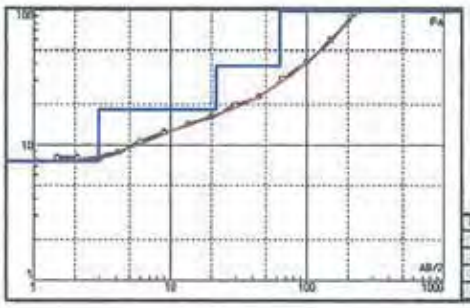
Figure 2f: Vertical Electrical Sounding results of Dodota site (Raya Azebo wereda).

	UTM-N	UTM-E	Elevetion
Asaye 1	1381664	583077	1728
Asaye 2	1381572	583227	1735



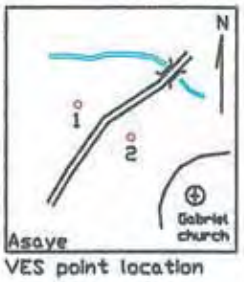
Ves-1

N	ρ	h	d	Alt
1	43.9	5.06	5.06	1723
2	5.62	3.12	8.18	1720
3	44.5	45.8	53.8	1674
4	16264			

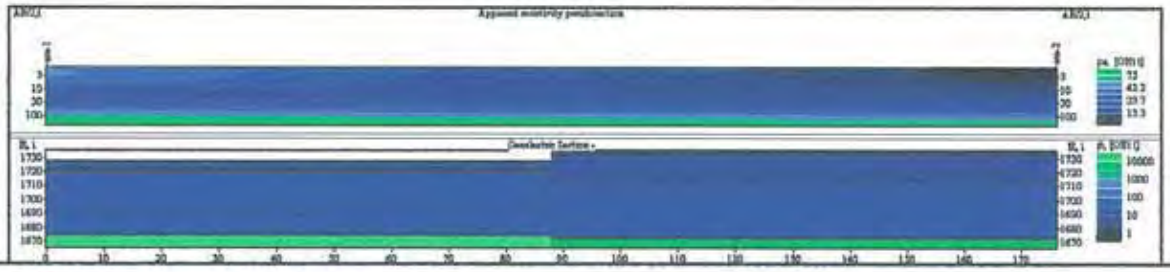


Ves-2

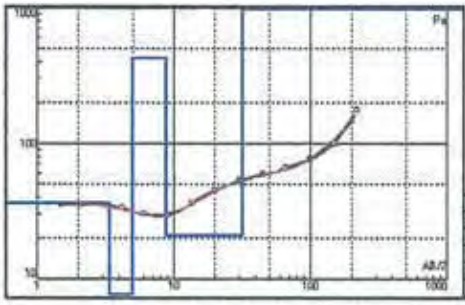
N	ρ	h	d	Alt
1	7.74	2.96	2.96	1732
2	18.4	18.7	21.7	1713
3	38.6	41	62.7	1672
4	9851			



VES point location

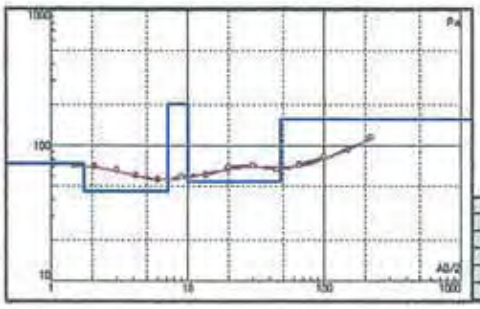


	UTM-N	UTM-E	Elevetion
Kotkote 1	1375811	579368	1635
Kotkote 2	1375487	579272	1624



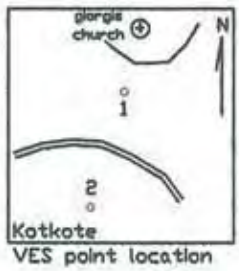
Ves-1

N	ρ	h	d	Alt
1	36.9	3.34	3.34	1632
2	6.92	1.56	4.9	1630
3	430	3.75	8.66	1626
4	21.3	22.8	31.5	1604
5	25477			



Ves-2

N	ρ	h	d	Alt
1	74.31	1.739	1.739	1622
2	46.52	5.445	7.184	1617
3	287.2	2.855	10.04	1614
4	54.76	37.95	47.98	1576
5	157.9			



VES point location

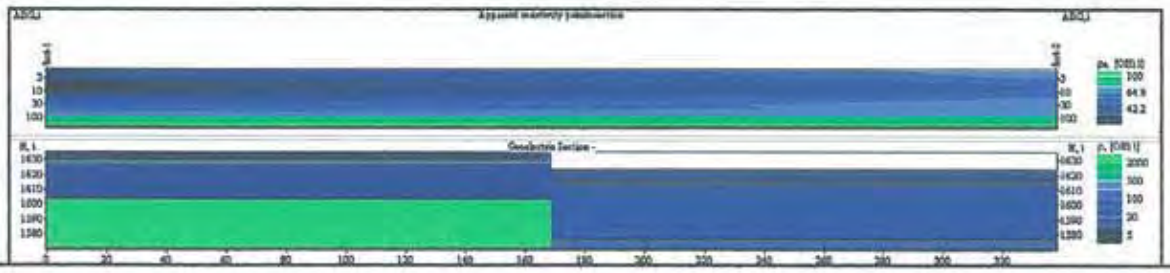
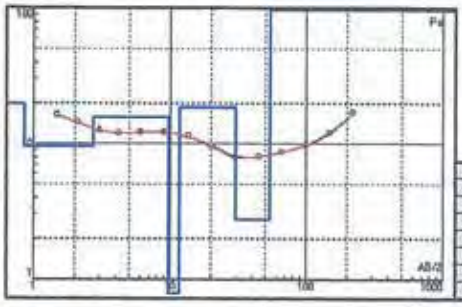


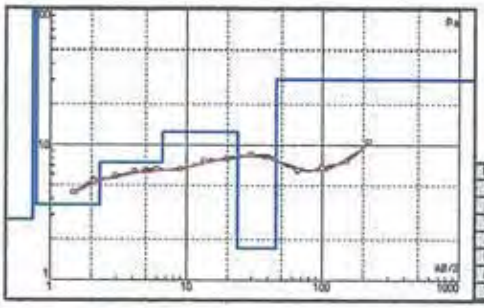
Figure 2g: Vertical Electrical Sounding results of Asaye & Kotkote sites (Raya Azebo wereda).

	UTM-N	UTM-E	Elevetion
Tach GubaGalla1	1367578	574943	1399
Tach GubaGalla2	1367495	574752	1398
Tach GubaGalla3	1367595	574981	1392
Tach GubaGalla4	1367600	575133	1400
Tach GubaGalla5	1367429	574965	1399



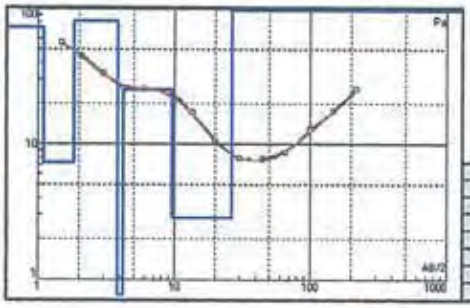
Ves-1

N	ρ	h	d	Alt
1	15.82	0.8681	0.8681	1398
2	9.641	1.887	2.727	1396
3	15.78	6.975	9.706	1388
4	0.7865	2.01	11.72	1387
5	18.77	18.42	30.14	1368
6	2.809	24.07	54.21	1345
7	545.1			



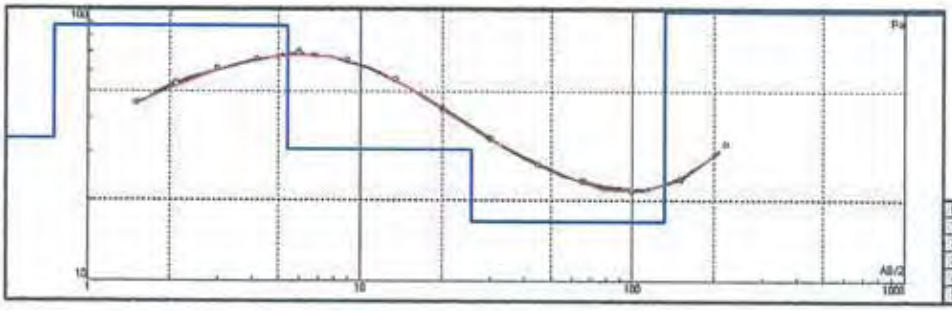
Ves-2

N	ρ	h	d	Alt
1	2.84	0.75	0.75	1397
2	266	0.8435	0.794	1397
3	3.81	1.49	2.28	1396
4	7.45	4.37	6.65	1391
5	12.5	16.9	23.6	1374
6	1.75	22	45.6	1352
7	38.8			



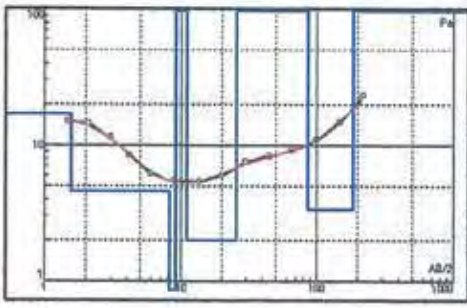
Ves-3

N	ρ	h	d	Alt
1	73.14	1.095	1.095	1391
2	7.339	0.7152	1.811	139
3	81.74	1.989	3.8	1388
4	0.1698	0.3679	4.168	1388
5	25.51	5.334	9.502	1382
6	2.906	16.62	26.12	1366
7	876.9			



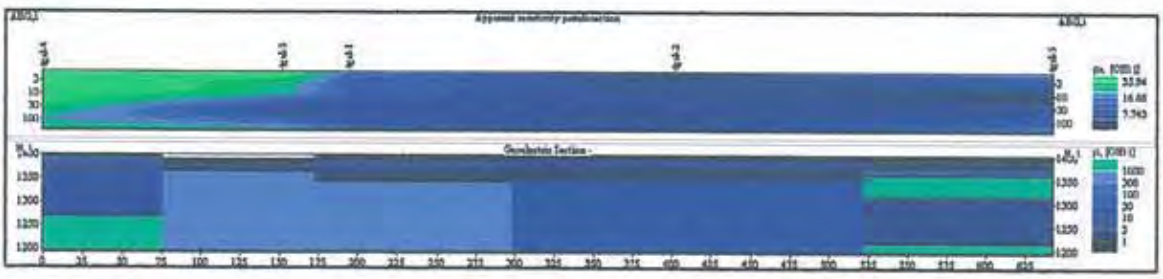
Ves-4

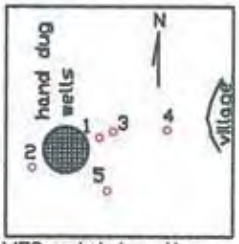
N	ρ	h	d	Alt
1	33.83	0.75	0.75	1399
2	87.87	4.677	5.427	1395
3	38.89	20.12	25.55	1374
4	18.66	105.5	131	1269
5	3813			



Ves-5

N	ρ	h	d	Alt
1	17.1	1.55	1.55	1397
2	4.84	6.7	8.25	1391
3	0.868	0.889	9.14	1390
4	134	1.82	11	1388
5	2.83	14.8	25.8	1373
6	277	13.2	38.8	1360
7	6681	47.5	86.3	1313
8	3.4	98.6	185	1214
9	5533			





VES point location

Figure 2h: Vertical Electrical Sounding results of Tach GubaGalla site (Raya Azebo wereda).

8.2 ALAMATA WEREDA

Walka

Results for Walka site are presented on Figure 3a. Though prospects are low, the relatively better chances of striking water at Walka is in the vicinity of VES-5 (between depths of 22 - 47m) and is recommended for borehole construction, and should be intersected sufficiently during drilling. Total depth of drilling is recommended to be at least 55m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 3a for UTM coordinates of the relevant VES points.

Bedeno Leko

Results for Bedeno Leko site are presented on Figure 3b. Though prospects for groundwater anywhere in Bedeno is very good, the relatively best location for drilling is in the vicinity of VES-2 (target depths between 10 - 110m) and is recommended for borehole construction. The target depth should be intersected sufficiently during drilling. Total depth of drilling is recommended to be at least 100m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 3b for UTM coordinates of the relevant VES points.

Gejele

Results for Gerjele site are presented on Figure 3b. Though prospects for groundwater anywhere in Gerjele is very good, the relatively best location for drilling is in the vicinity of VES-1 (target depths between 12 - 75m) and is recommended for borehole construction. The target depth should be intersected sufficiently during drilling. Total depth of drilling is recommended to be at least 80m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 3c for UTM coordinates of the relevant VES points.

Bubie

Results for Bubie site are presented on Figure 3d. Though prospects for groundwater in Bubie is very low (there are 2 fully constructed but completely dry wells in the area), the relatively best location for drilling where there is a potentially water bearing strata is in the vicinity of VES-4 (target depths between 10 - 80m) and is recommended for borehole construction. The target depth should be intersected sufficiently during drilling. Total depth of drilling is recommended to be at least 85m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 3d for UTM coordinates of the relevant VES points.

Ula

Results for Ula site are presented on Figure 3e. Though prospects for groundwater in Ula is not so high, the relatively best location for drilling where there is a potentially water bearing strata is in the vicinity of VES-3 (target depths between 10 - 47m) and is recommended for borehole construction. The target depth should be intersected sufficiently during drilling. Total depth of drilling is recommended to be at least 55m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 3e for UTM coordinates of the relevant VES points.

Hadish kign

Results for Hadish Kign site are presented on Figure 3f. Though prospects for groundwater in Hadish Kign is generally high, the relatively best location for drilling where there are multiple and distinct potentially water bearing strata is in the vicinity of VES-2 (target depths between 6 - 60m), and is recommended for borehole construction. The target depth should be intersected sufficiently during drilling. Total depth of drilling is recommended to be at least 65m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 3f for UTM coordinates of the relevant VES points.

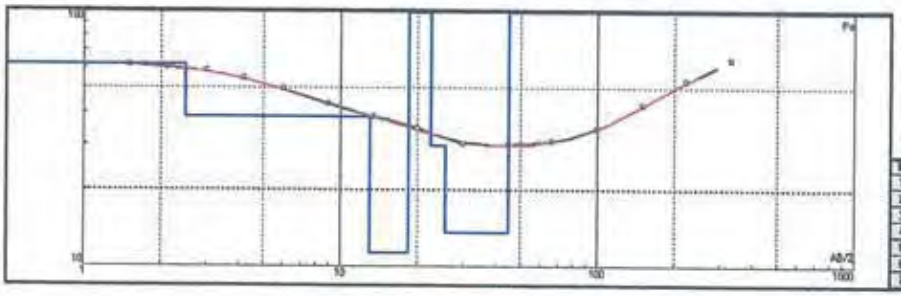
Kunkura

Results for Kunkura site are also presented on Figure 3f. Prospects for groundwater in Kunkura is generally good. However, the relatively best location for drilling where there there is distinct potentially water bearing strata is in the vicinity of VES-2 (target depths between 13 - 110m), and is recommended for borehole construction. The target depth should be intersected sufficiently during drilling. Total depth of drilling is recommended to be at least 120m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 3f for UTM coordinates of the relevant VES points.

Adi Mohoye

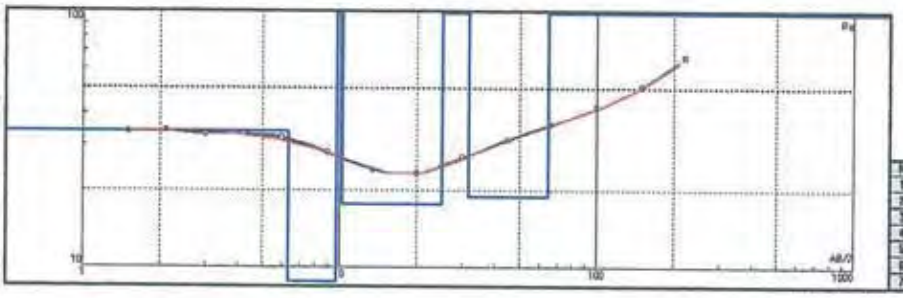
Results for Adi Mohoye site are also presented on Figure 3f. Prospects for groundwater in Adi Mohoye is generally very good. The relatively better location for drilling, where there there is distinct potentially water bearing strata, is in the vicinity of VES-1 (target depths between 32 - 57m), and is recommended for borehole construction. The target depth should be intersected sufficiently during drilling. Total depth of drilling is recommended to be at least 65m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 3f for UTM coordinates of the relevant VES points.

	UTM-N	UTM-E	Elevation
Walka 1	1364704	558436	1674
Walka 2	1364660	558600	1616
Walka 3	1364891	558781	1610
Walka 4	1365094	558871	1609
Walka 5	1365244	558911	1602



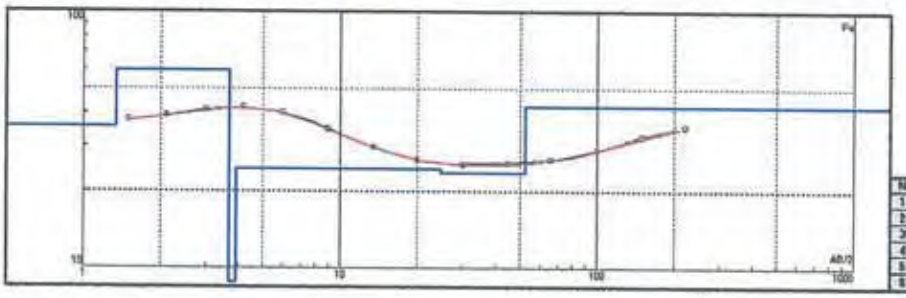
Ves-1

N	ρ	h	d	Alt
1	82.14	2.469	2.469	1672
2	38.8	10.49	12.96	1661
3	11.42	5.311	18.27	1656
4	172.6	4.84	22.31	1652
5	20.57	3.155	25.47	1649
6	13.55	19.63	45.1	1629
7	88.7			



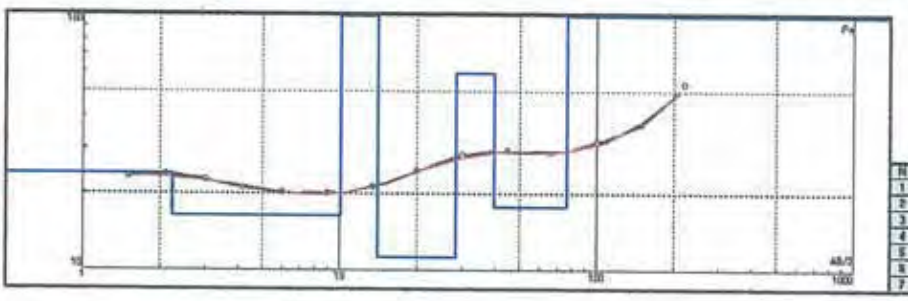
Ves-2

N	ρ	h	d	Alt
1	34.19	0.308	0.308	161
2	6.594	3.354	3.663	1606
3	1451	0.5886	18.25	1606
4	17.94	14.5	24.85	1581
5	282.4	6.731	31.59	1584
6	18.01	32.9	64.49	1552
7	1848			



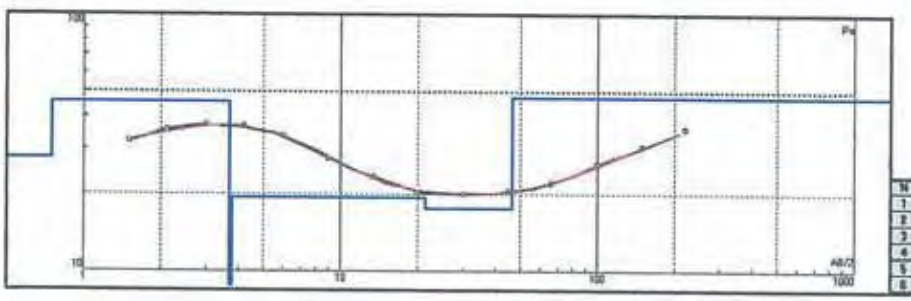
Ves-3

N	ρ	h	d	Alt
1	36.86	1.338	1.338	1609
2	59.45	2.341	3.68	1606
3	4.886	0.2330	3.914	1606
4	24.84	20.59	24.5	1585
5	73.55	27.88	52.38	1558
6	42.94			



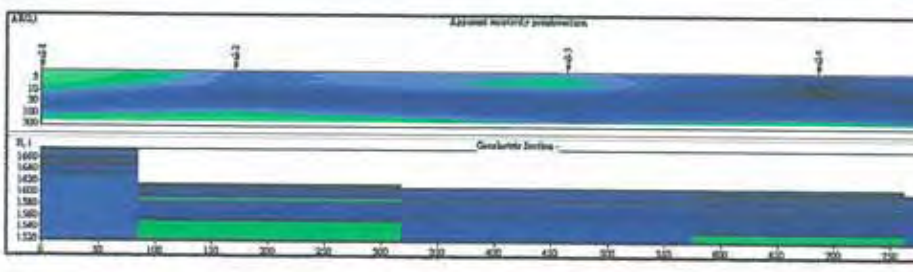
Ves-4

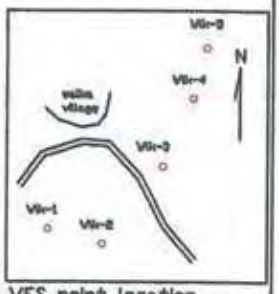
N	ρ	h	d	Alt
1	23.94	2.222	2.222	1607
2	18.41	7.863	10.09	1599
3	157.5	3.921	14.01	1595
4	11.33	14.27	28.28	1581
5	53.46	11.46	39.74	1569
6	17.82	36.76	76.5	1533
7	1438			



Ves-5

N	ρ	h	d	Alt
1	27.65	0.76	0.76	1601
2	46.09	2.928	3.678	1598
3	1.229	0.197	3.785	1598
4	18.51	17.57	21.35	1581
5	17.66	25.16	46.51	1555
6	47.83			

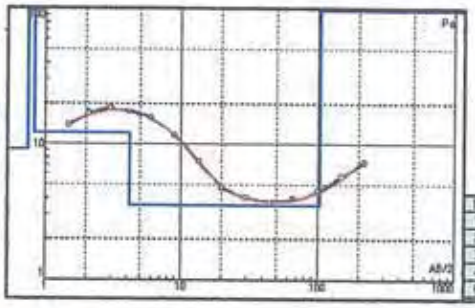




VES point location

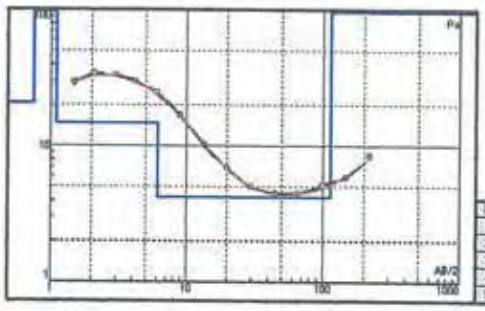
Figure 3a: Vertical Electrical Sounding results of Walka site (Alamata wereda).

	UTM-N	UTM-E	Elevetion
Bedena leko 1	1361640	574030	1390
Bedena leko 2	1361775	574235	1386
Bedena leko 3	1361870	574350	1390
Bedena leko 4	1361954	574453	1389
Bedena leko 5	1362085	574591	1390



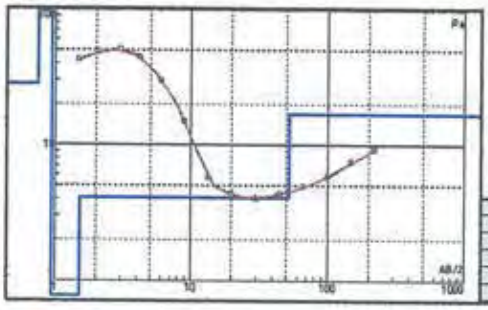
Ves-1

N	ρ	h	d	Alt
1	9.2	0.75	0.75	1389
2	475	0.0752	0.826	1389
3	12.2	3.37	4.2	1386
4	3.59	98.8	103	1287
5	322			



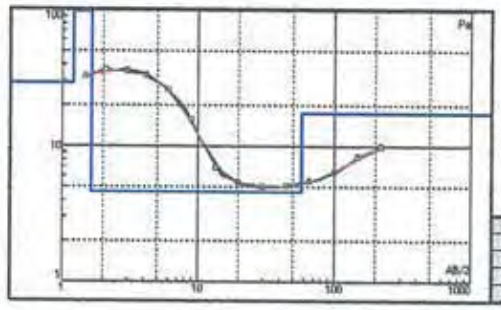
Ves-2

N	ρ	h	d	Alt
1	21	0.75	0.75	1385
2	188	0.349	1.1	1385
3	14.8	5.05	6.15	1380
4	4.22	107	113	1273
5	157			



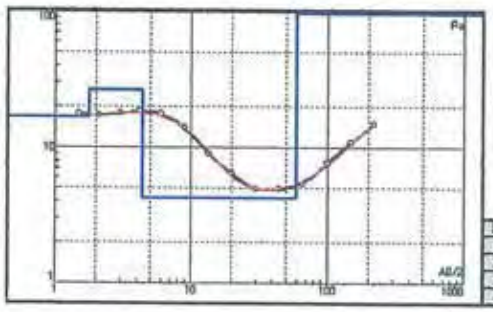
Ves-3

N	ρ	h	d	Alt
1	28.32	0.75	0.75	1389
2	758.9	0.1895	0.9395	1389
3	8.5158	0.5839	1.523	1388
4	4.12	51.33	52.86	1337
5	17.17			



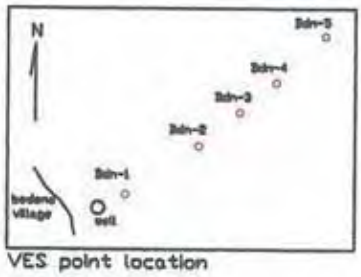
Ves-4

N	ρ	h	d	Alt
1	29.3	1.21	1.21	1389
2	222	0.42	1.63	1387
3	4.67	55.7	57.3	1332
4	17.5			



Ves-5

N	ρ	h	d	Alt
1	16.8	1.77	1.77	1388
2	28.7	2.57	4.34	1385
3	4.28	55.2	59.5	1330
4	163			



VES point location

- well depth ~90m
- pump being pulled up every 3 months (clay)
- pump now @ 30m
- SWL ~15m

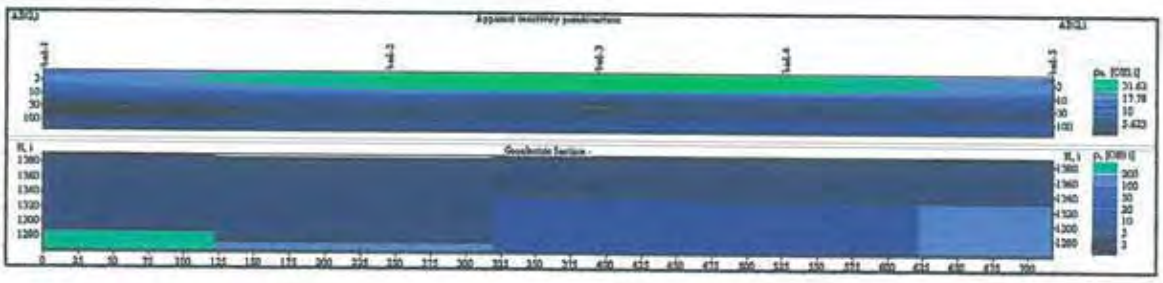
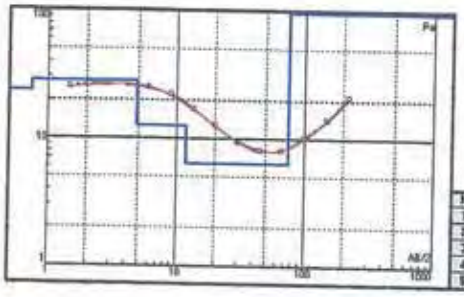


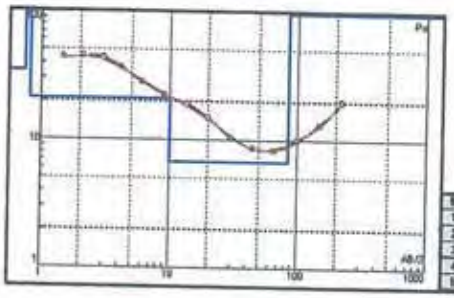
Figure 3b: Vertical Electrical Sounding results of Bedeno Leko site (Alamata wereda).

	UTM-N	UTM-E	Elevation
Gerjele1	1379808	566674	1467
Gerjele2	1379815	566848	1456
Gerjele3	1379771	566988	1461
Gerjele4	1379684	567209	1464
Gerjele5	1379559	567360	1456



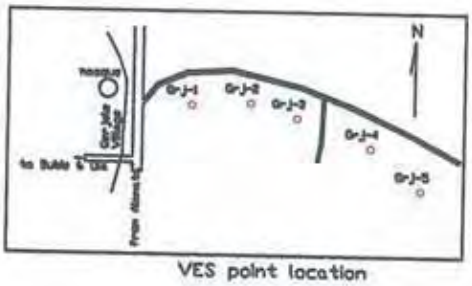
Ves-1

N	ρ	h	d	Alt
1	23.7	0.75	0.75	1466
2	20.58	4.081	4.831	1462
3	12.85	7.005	11.84	1455
4	6.391	82.68	74.52	1382
5	3333			

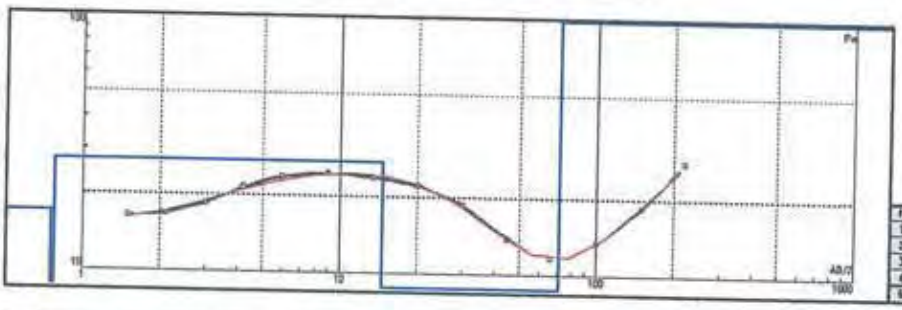


Ves-2

N	ρ	h	d	Alt
1	34.78	0.75	0.75	1466
2	771.5	0.06931	0.82	1455
3	21.25	9.204	10.02	1446
4	6.842	73.89	83.91	1372
5	3838			

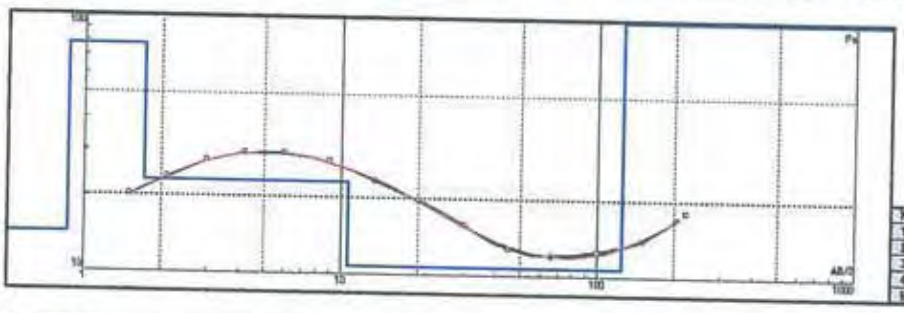


VES point location



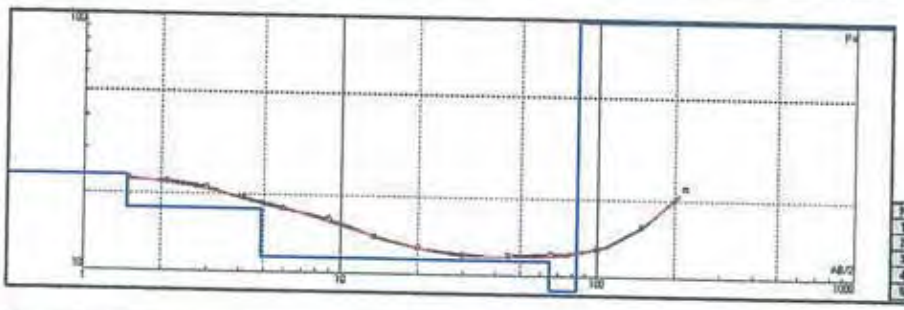
Ves-3

N	ρ	h	d	Alt
1	17.87	0.75	0.75	146
2	0.73439	0.02282	0.7739	146
3	27.41	13.79	14.56	1446
4	7.589	56.63	71.18	139
5	3097			



Ves-4

N	ρ	h	d	Alt
1	14.38	0.8627	0.8627	1463
2	76.21	0.9527	1.715	1462
3	23.86	8.816	10.53	1453
4	10.0	114.4	125	1339
5	181.5			



Ves-5

N	ρ	h	d	Alt
1	23.58	1.465	1.465	1455
2	17.61	3.451	4.916	1451
3	11.5	80.17	85.09	1391
4	3.586	18.08	83.17	1373
5	2487			

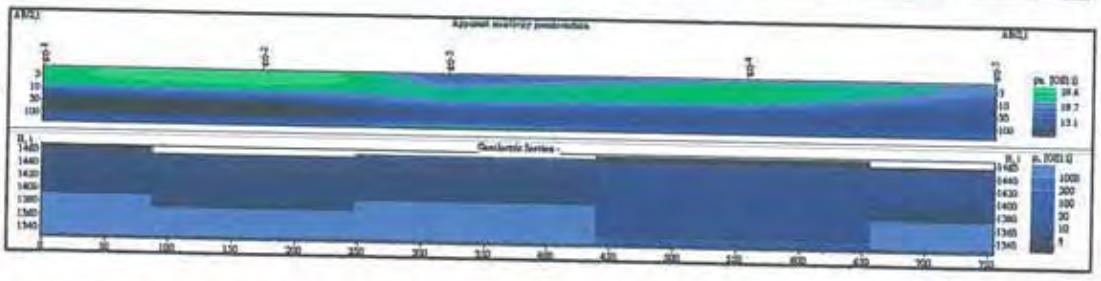
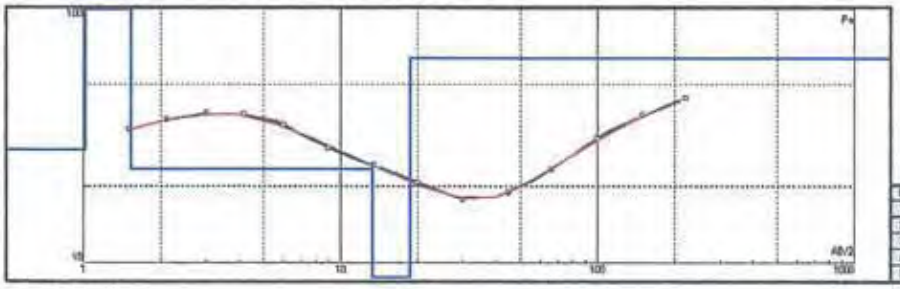


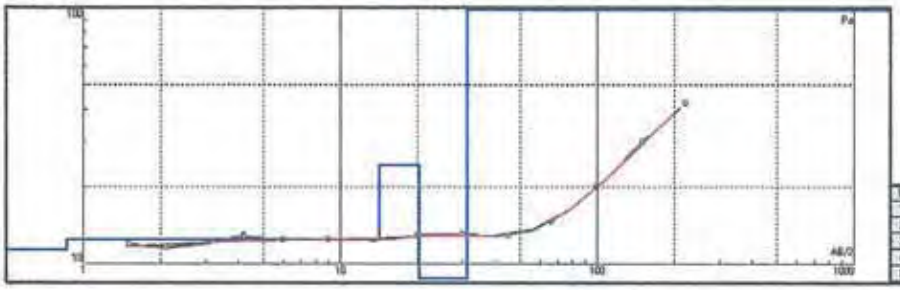
Figure 3c: Vertical Electrical Sounding results of Gerjele site (Alamata wereda).

	UTM-N	UTM-E	Elevation
Bubie 1	1382933	565891	1526
Bubie 2	1382784	565809	1507
Bubie 3	1382819	565627	1531
Bubie 4	1382854	565351	1541
Bubie 5	1382281	565972	1532



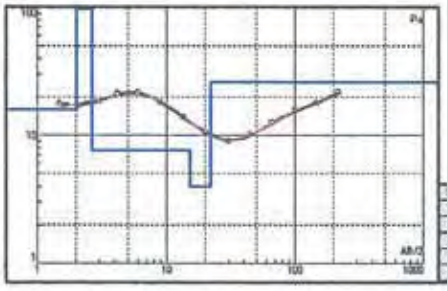
Ves-1

N	ρ	h	d	Alt
1	27.91	1.812	1.812	1525
2	127.5	0.5196	1.531	1524
3	23.42	11.8	13.33	1513
4	3.667	5.278	18.61	1507
5	84.84			



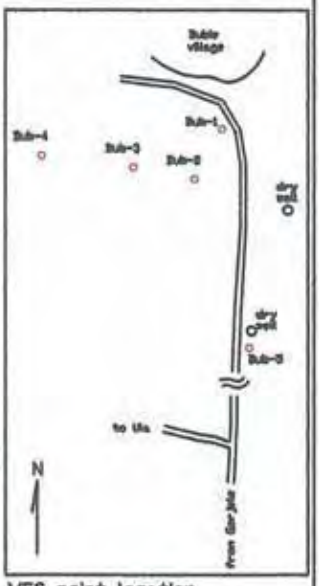
Ves-2

N	ρ	h	d	Alt
1	11.43	0.8572	0.8572	1536
2	12.54	13.3	14.17	1493
3	24.5	5.871	20.04	1487
4	3.814	10.94	31.18	1476
5	3288			

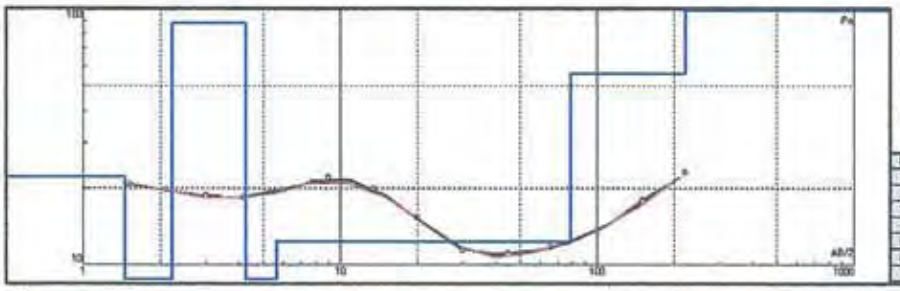


Ves-3

N	ρ	h	d	Alt
1	18.2	2.81	2.81	1529
2	122	8.836	2.65	1520
3	7.75	12.6	15.1	1516
4	4.03	6.71	21.8	1509
5	26.6			

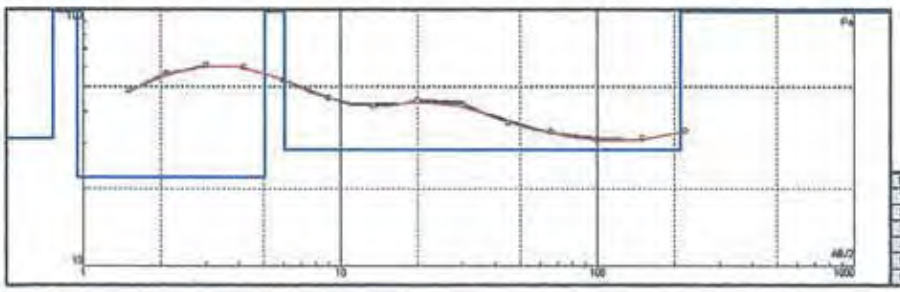


VES point location



Ves-4

N	ρ	h	d	Alt
1	22.27	1.447	1.447	154
2	5.883	0.7587	2.158	1539
3	88.19	2.868	4.208	1537
4	0.9773	1.281	5.627	1535
5	12.43	73.89	79.72	1462
6	58.3	141.3	229	1321
7	758.2			



Ves-5

N	ρ	h	d	Alt
1	31.75	0.7884	0.7884	1531
2	817.8	0.1826	0.948	1531
3	22.35	4.112	5.061	1527
4	451.8	0.5656	6.027	1526
5	29.7	204.1	210.1	1322
6	200.7			

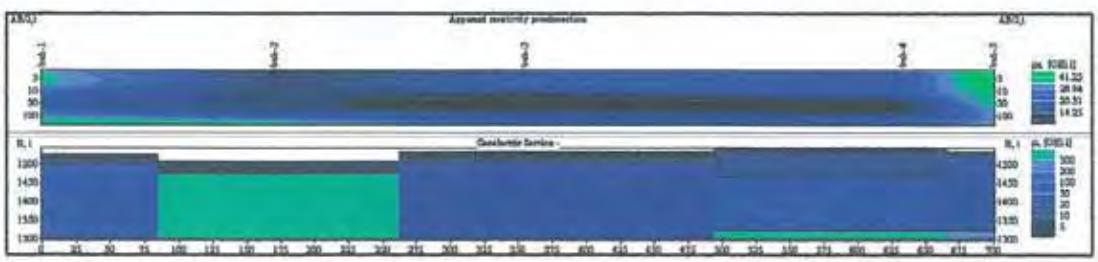
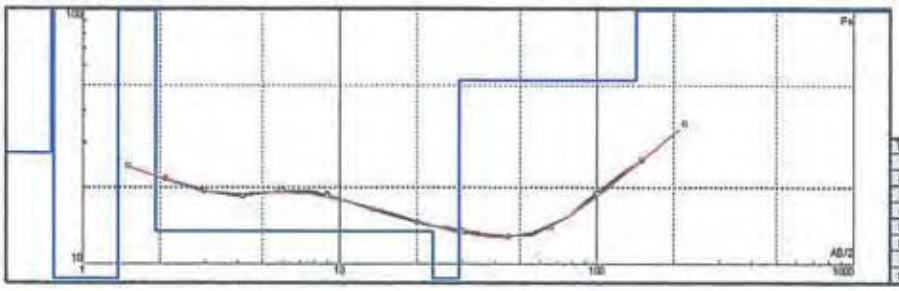
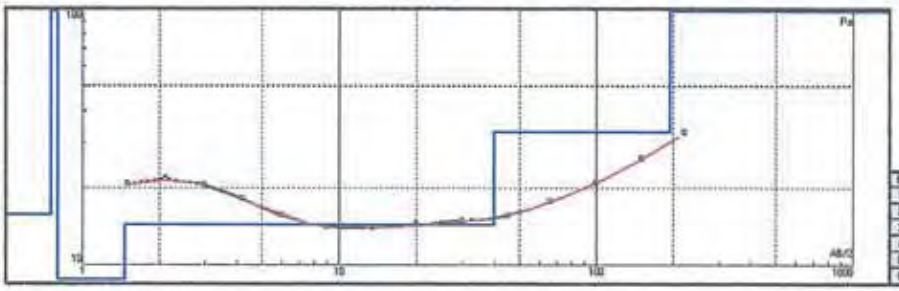


Figure 3d: Vertical Electrical Sounding results of Bubie site (Alamata wereda).



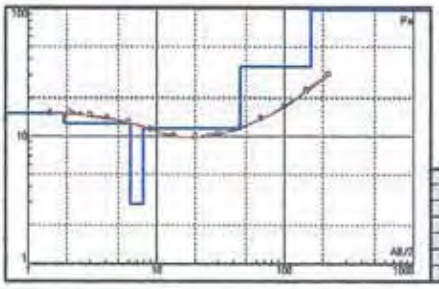
Ves-1

N	ρ	h	d	Alt
1	27.49	0.75	0.75	161
2	436.7	0.82156	0.7716	161
3	5.483	0.5097	1.371	161
4	104	8.5458	1.917	1809
5	13.47	20.68	22.91	1588
6	2.451	6.087	28.95	1582
7	53.89	113.5	142.5	1469
8	5869			



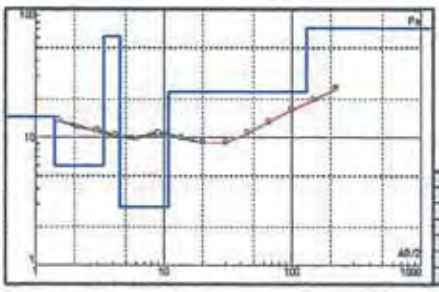
Ves-2

N	ρ	h	d	Alt
1	15.84	0.75	0.75	1578
2	602.6	3.05387	0.8031	1579
3	4.768	0.8561	1.458	1578
4	14.4	38.39	39.85	154
5	33.31	153.8	193.6	1386
6	8387			



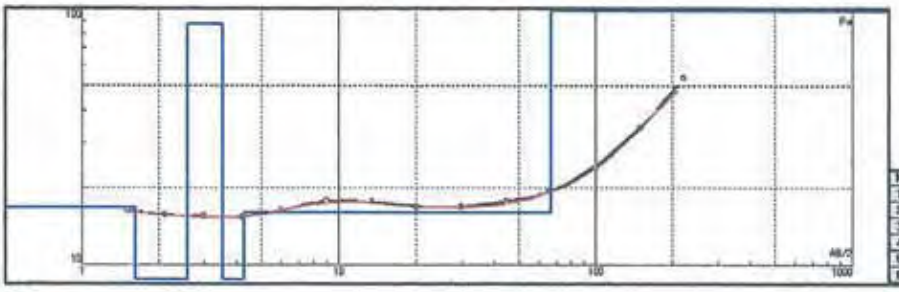
Ves-3

N	ρ	h	d	Alt
1	15.42	1.902	1.902	1574
2	12.72	4.788	6.7	157
3	2.976	1.59	7.79	1569
4	11.5	37.37	45.16	1531
5	35.33	116.8	161.8	1414
6	7058			



Ves-4

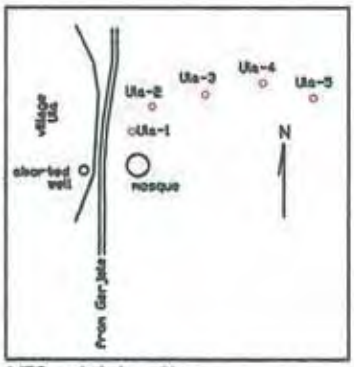
N	ρ	h	d	Alt
1	14.67	1.394	1.394	1558
2	6.15	1.883	3.307	1558
3	61.77	1.124	4.511	1554
4	2.974	6.317	10.83	1548
5	22.88	118.1	128.9	143
6	71,99			



Ves-5

N	ρ	h	d	Alt
1	16.78	1.013	1.613	1554
2	7.164	0.9573	2.57	1553
3	86.1	0.9483	3.517	1552
4	4.481	0.7419	4.259	1552
5	18.58	82.48	86.72	1469
6	8736			

	UTM-N	UTM-E	Elevation
Ula1	1382300	563760	1611
Ula2	1382374	563821	1580
Ula3	1382410	563980	1576
Ula4	1382444	564152	1559
Ula5	1382400	564302	1556



VES point location

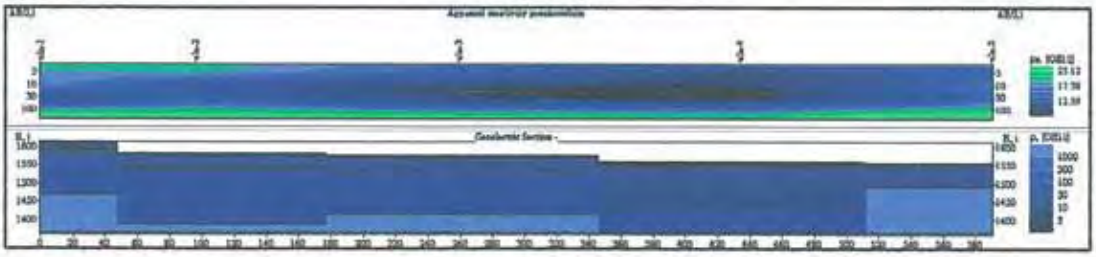


Figure 3e: Vertical Electrical Sounding results of Ula site (Alamata wereda).

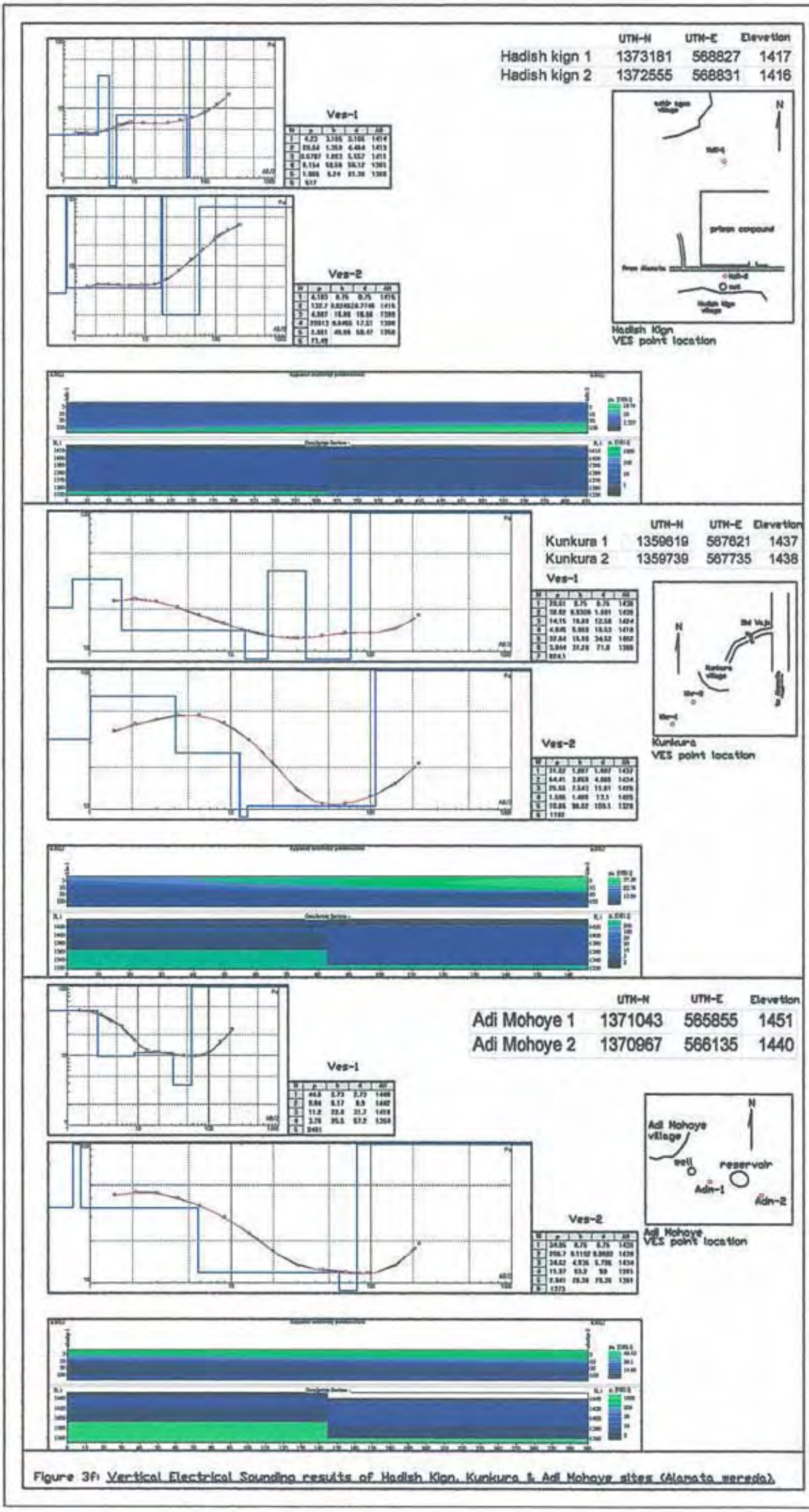


Figure 3f: Vertical Electrical Sounding results of Hadish Kign, Kunkura & Adi Mohoye sites (Alamata woreda).

8.3 HINTALO WAJIRAT WEREDA

Key Hamed

Results for Key Hamed site are presented on Figure 4a. Prospects for groundwater in Key Hamed area generally seems not so good. The relatively better location for drilling, where there seems to be a distinct potentially water bearing strata, is in the vicinity of VES-1 (target depths between 20 - 34m), and is recommended for borehole construction. The target depth should be intersected sufficiently during drilling. Total depth of drilling is recommended to be at least 40m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 4a for UTM coordinates of the relevant VES points.

Chekom

Results for Chekom site are also presented on Figure 4a. Prospect for groundwater in Chekom area generally seems ok, but problem of wet clay may be encountered. The relatively better location for drilling, where there seems to be a distinct potentially water bearing strata, is in the vicinity of VES-2 (target depths between 10 - 100m), and is recommended for borehole construction. The target depth should be intersected as much as possible during drilling. Total depth of drilling is recommended to be at least 120m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 4a for UTM coordinates of the relevant VES points.

Netae

Results for Netae site are presented on Figure 4b. Prospect for deep groundwater in Netae area generally seems bad. Drilling at Netae is not recommended. However, constructing a hand dug well may be possible there (note that there are 3 abandoned hand dug wells there). The relatively better location for a hand dug well, where there seems to be shallow and distinct potentially water bearing strata, is in the vicinity of VES-4 or VES-5 (target depths between 3 - 15m), and is recommended for borehole construction. The target depth should be intersected as much as possible during digging. Total depth of digging is recommended to be at least 15m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 4b for UTM coordinates of the relevant VES points.

Azeba

Results for Azewa site are presented on Figure 4c. Prospect for deep groundwater in Azewa area generally seems bad. Drilling at Azewa is not recommended. However, constructing a hand dug well may however be possible there. The relatively better location for a hand dug well, where there seems to be shallow and distinct potentially water bearing strata, is in the vicinity of VES-2 (target depths between 10 - 16m), and

is recommended for borehole construction. The target depth should be intersected as much as possible during digging. Total depth of digging is recommended to be at least 20m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 4c for UTM coordinates of the relevant VES points.

Adi Hudug

Results for Adi Hudug site are also presented on Figure 4c. Prospect for groundwater in Adi Hudug area generally seems ok. The relatively better location for drilling, where there seems to be a distinct potentially water bearing strata, is in the vicinity of VES-2 (target depths between 11 - 27m), and is recommended for borehole construction. The target depth should be intersected as much as possible during drilling. Total depth of drilling is recommended to be at least 35m. The top few meters of the well should be grouted and sealed after drilling in order to avoid contamination while abstraction of water from deeper layers. Refer to either Table 3 or figure 4a for UTM coordinates of the relevant VES points

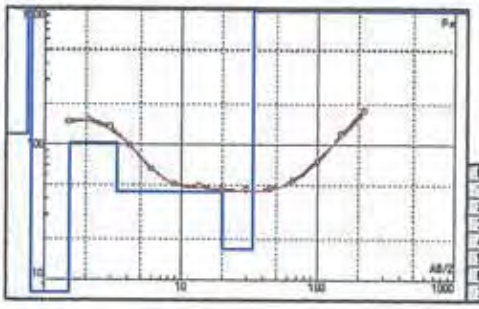
Mai Silas

Results for Mai Silas site are also presented on Figure 4c. Prospect for groundwater at Mai Silas area generally seems bad. Drilling at Azewa is not recommended. Refer to either Table 3 or figure 4c for UTM coordinates of the relevant VES points.

Dengolat

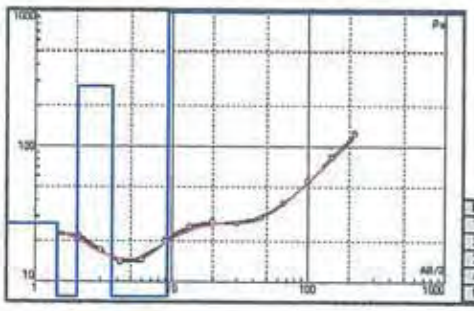
Results for Dengolat site are presented on Figure 4d. Prospect for groundwater at Dengolat area generally seems bad. Drilling at Dengolat is not recommended. Refer to either Table 3 or figure 4d for UTM coordinates of the relevant VES points.

	UTM-N	UTM-E	Elevetion
Key hamed 1	1440779	561243	2331
Key hamed 2	1440742	561273	2340



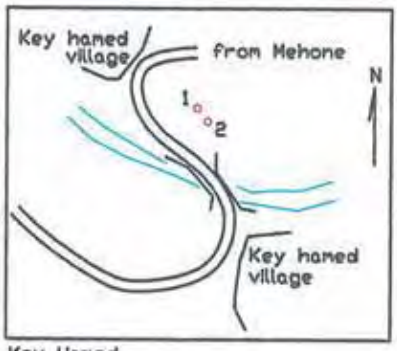
Ves-1

N	ρ	h	d	Alt
1	120	0.75	0.75	2330
2	5737	0.8427	0.793	2330
3	8.22	0.718	1.51	2329
4	184	1.83	3.37	2328
5	44.9	16.5	20	2311
6	17.2	13.5	33.6	2297
7	25757			

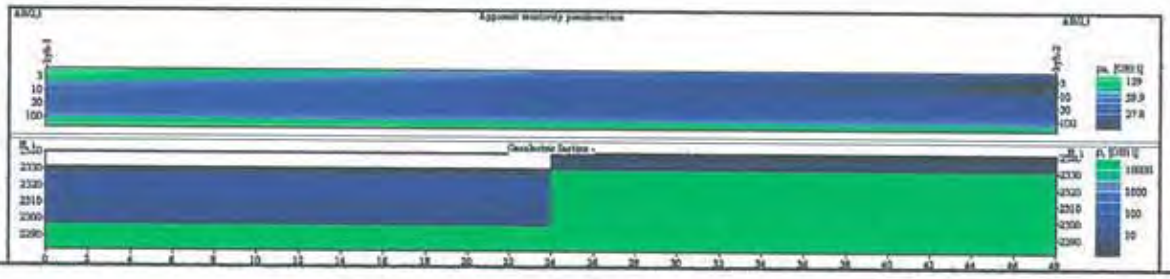


Ves-2

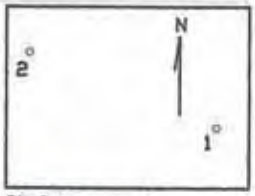
N	ρ	h	d	Alt
1	27.1	1.44	1.44	2339
2	1.99	0.587	2.03	2338
3	279	1.61	3.64	2336
4	3.52	5.61	9.25	2331
5	4398			



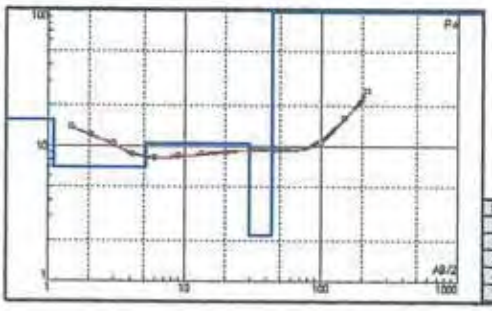
Key Hamed
VES point location



	UTM-N	UTM-E	Elevetion
Chekom 1	1464810	562321	2106
Chekom 2	1465022	561795	2088

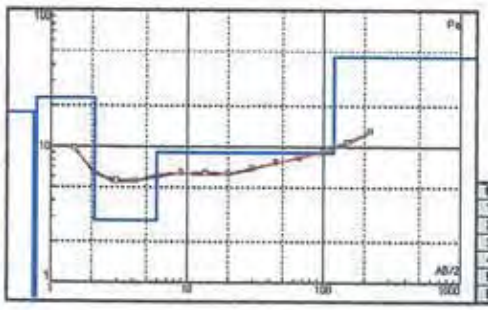


Chekom
VES point location



Ves-1

N	ρ	h	d	Alt
1	15.8	1.1	1.1	2105
2	7.87	4.1	5.2	2101
3	10.6	24.6	29.9	2076
4	2.23	13.9	43.7	2062
5	4282			



Ves-2

N	ρ	h	d	Alt
1	17.8	0.75	0.75	2087
2	0.0633	0.0267	0.777	2087
3	22.8	1.3	2.08	2086
4	2.87	3.85	5.93	2082
5	0.12	112	118	1970
6	45.4			

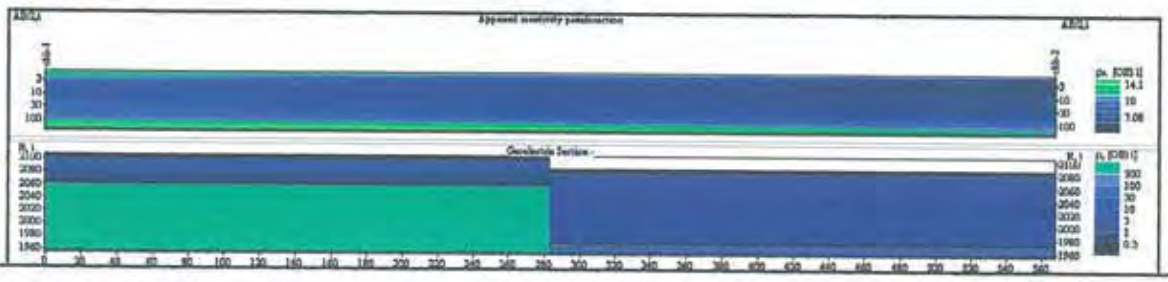
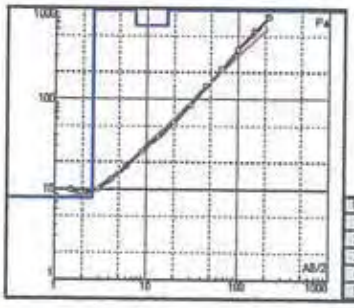


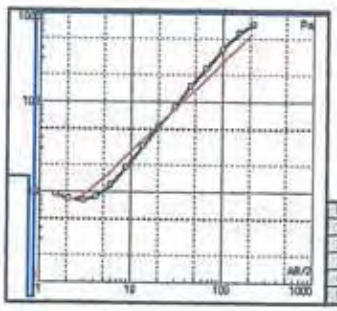
Figure 4a: Vertical Electrical Sounding results of Key Hamed & Chekom sites (Hintalo Wajirat wereda).

	UTN-N	UTN-E	Elevetion
Netae 1	1479878	536560	2162
Netae 2	1479875	536326	2153
Netae 3	1480112	536177	2144
Netae 4	1480250	536044	2133
Netae 5	1479818	536894	2163



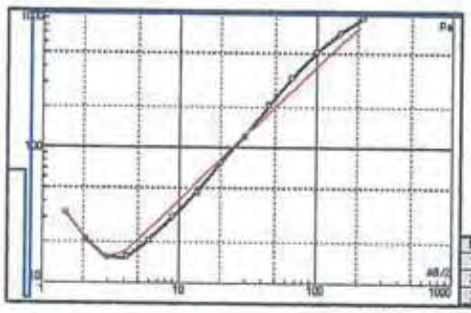
Ves-1

N	ρ	h	d	Alt
1	8.11	2.6	2.6	2159
2	1.3E+6	1.54	4.14	2158
3	31259	3.32	7.46	2155
4	666	8.1	16.6	2145
5	1452			



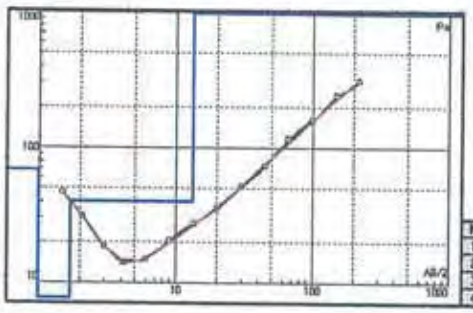
Ves-2

N	ρ	h	d	Alt
1	19	0.75	0.75	2152
2	0.43	0.127	0.877	2152
3	1292	6.27	7.15	2145
4	1087	16.2	23.3	2138
5	3.3E+5			



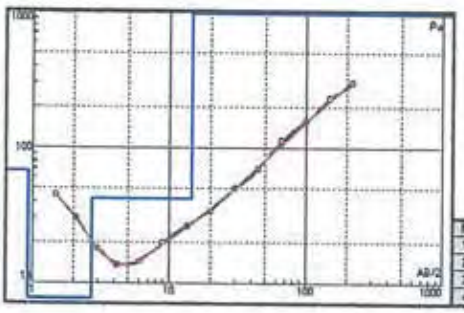
Ves-3

N	ρ	h	d	Alt
1	67.1	0.75	0.75	2143
2	0.325	0.0746	0.825	2143
3	9335			



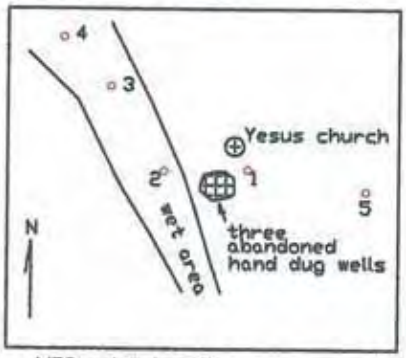
Ves-4

N	ρ	h	d	Alt
1	69	0.907	0.907	2132
2	2.53	0.784	1.69	2131
3	40.2	11.5	13.2	2120
4	1806			



Ves-5

N	ρ	h	d	Alt
1	68.4	0.932	0.932	2162
2	6	1.78	2.71	2160
3	42.2	11.8	14.5	2148
4	1852			



VES point location

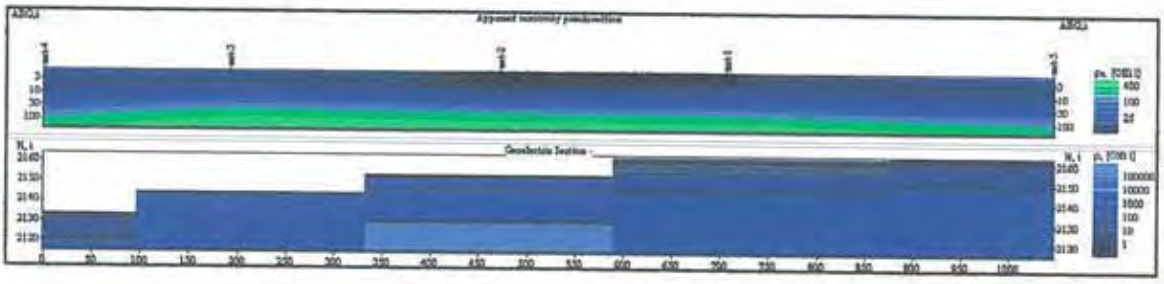
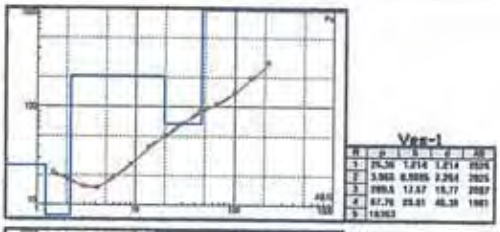
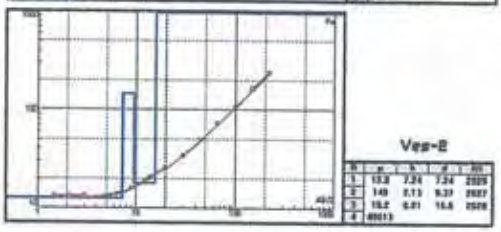


Figure 4b: Vertical Electrical Sounding results of Netae site (Hintalo Wajirat wereda).



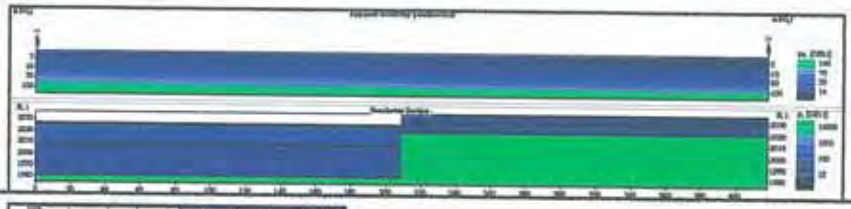
Ves-1

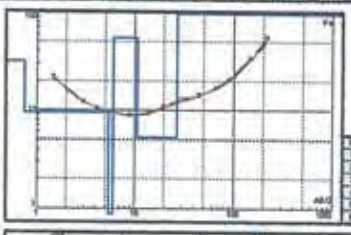


Ves-2

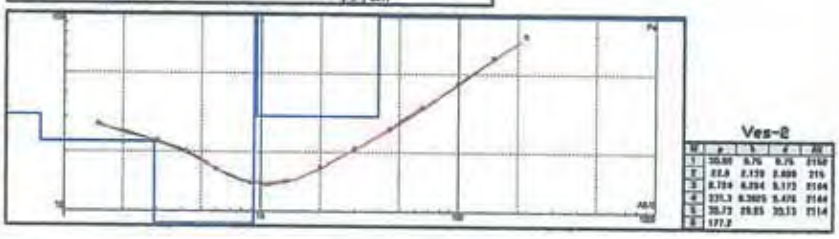
	UTM-N	UTM-E	Elevation
Azeba 1	1457694	540614	2027
Azeba 2	1457618	541025	2036

Azeba
VES point location
- access bad





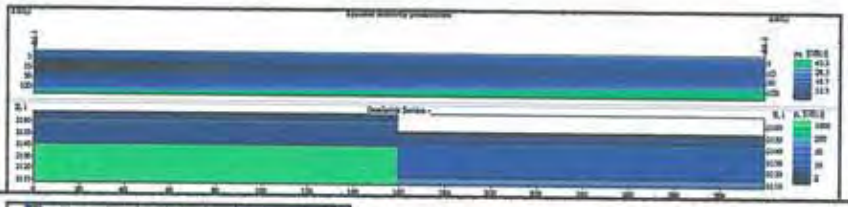
Ves-1

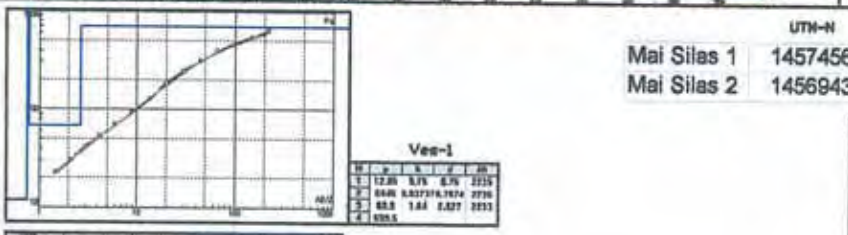


Ves-2

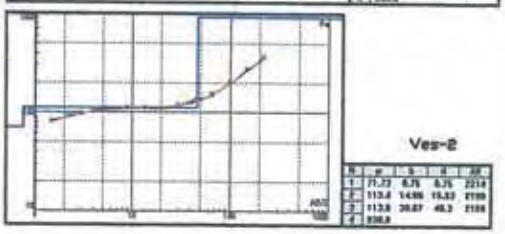
	UTM-N	UTM-E	Elevation
Adi Hudug 1	1466428	543622	2168
Adi Hudug 2	1466228	543871	2153

Adi Hudug
VES point location
- access bad



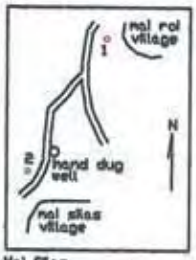


Ves-1



Ves-2

	UTM-N	UTM-E	Elevation
Mai Silas 1	1457456	552641	2236
Mai Silas 2	1456943	552338	2215



Mai Silas
VES point location

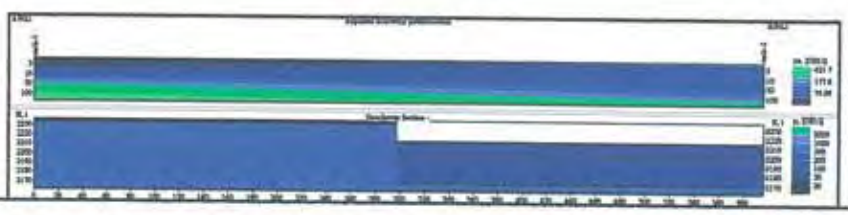
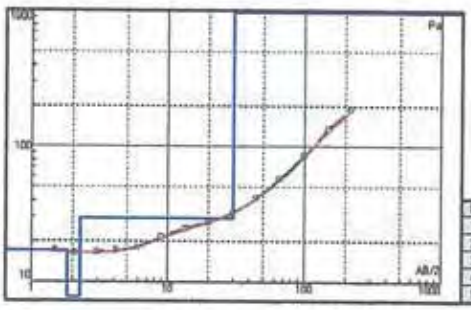


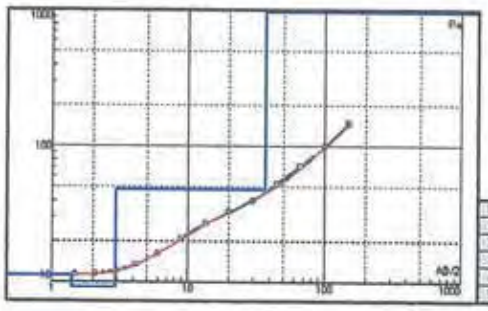
Figure 4c: Vertical Electrical Sounding results of Azeba, Adi Hudug & Mai Silas sites (Hintalo Wajirat woreda).

	UTM-N	UTM-E	Elevation
Dengolat 1	1470637	535751	2324
Dengolat 2	1470446	536132	2329
Dengolat 3	1469648	536992	2343
Dengolat 4	1470044	536684	2338
Dengolat 5	1470285	536546	2340



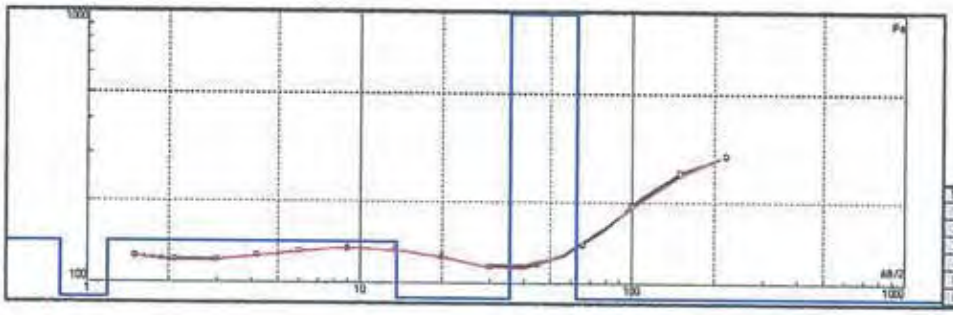
Ves-1

N	ρ	h	d	Alt
1	17.2	1.815	1.815	2322
2	5.295	0.4425	2.258	2322
3	23.53	27.84	30.1	2234
4	2293	37.37	67.57	2256
5	22794			



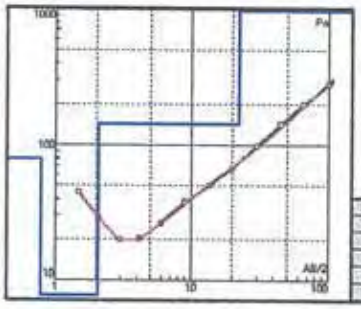
Ves-2

N	ρ	h	d	Alt
1	11.26	1.393	1.393	2329
2	0.289	1.516	2.909	2326
3	48.83	33.79	36.7	2292
4	2274	30.86	67.56	2261
5	22602			



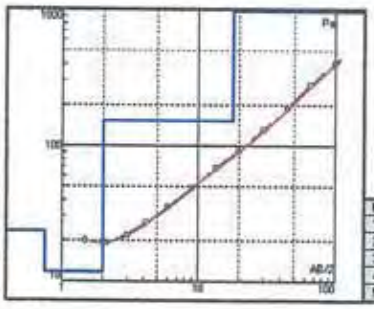
Ves-3

N	ρ	h	d	Alt
1	141.8	0.7966	0.7966	2342
2	69.86	0.3891	1.186	2342
3	142.7	12.37	13.56	2329
4	63.61	21.91	35.47	2308
5	36.48	27.38	62.85	228
6	39.3			



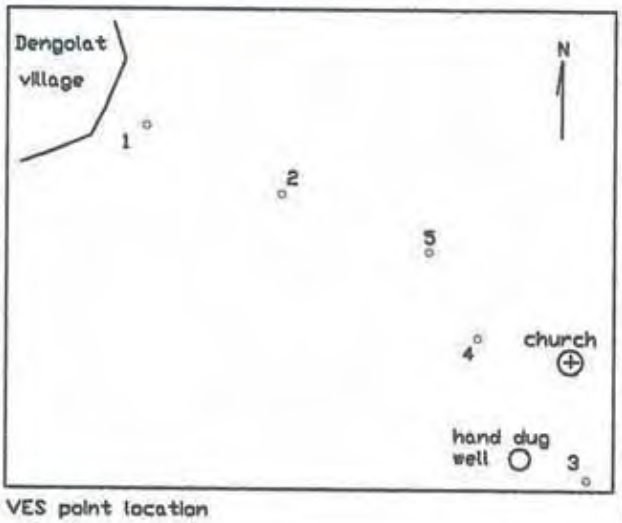
Ves-4

N	ρ	h	d	Alt
1	79.9	0.784	0.784	2337
2	7	1.28	2.06	2336
3	145	20	22.1	2316
4	5287	45.5	67.6	2270
5	58367			



Ves-5

N	ρ	h	d	Alt
1	23.6	0.75	0.75	2339
2	11.83	1.255	2.005	2338
3	154	15.83	17.83	2322
4	43685	49.72	67.56	2272
5	58655			



VES point location

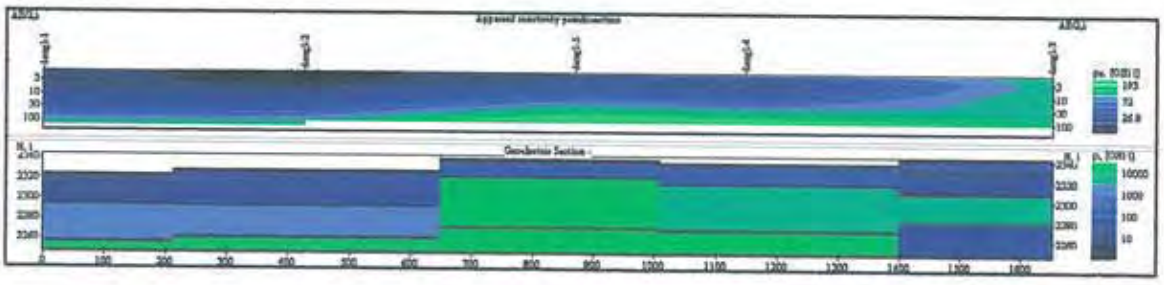


Figure 4d: Vertical Electrical Sounding results of Dengolat site (Hintalo Wajirat wereda).