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Full Length Research Paper

Geoelectric investigation of Owuruwuru Dam site, Ikere Ekiti, Southwestern Nigeria

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Geophysical investigation involving the electrical resistivity method has been undertaken along three proposed dam axes trending NNW-SSE (335° WCB) across ENE to WSW flowing Owuruwuru River at Ikere Ekiti Southwestern Nigeria. The study is aimed at evaluating the feasibility of the area for establishing a small earth dam and reservoir. The electrical resistivity method involving the Wenner and Schlumberger arrays for horizontal profiling and Vertical Electrical Sounding (VES) techniques was adopted. The study area is underlain by the Precambrian Basement Complex rocks of Southwestern Nigeria. Three Wenner profilings were undertaken along each axis with electrode separations of 10, 20 and 30 m respectively. Forty-four VES locations were occupied within the study area. The resistivity profiles showed that the northern flank of the stream (right abutment) is characterized by relatively lower resistivity values (77 to 327 Ω-m) with respect to those obtained at the central and southern (left abutment) flanks (83 to 1077 Ω-m). The resistivity profiles thus present a general morphology of the concealed basement in form of low relief on the northern flank with respect to high relief on the southern flank. Geoelectric sections generated from VES results showed that the dam site is underlain by clayey sand topsoil, sandy clay weathered basement, partially weathered/fractured basement and the presumably fresh bedrock. Materials of the overburden (topsoil + weathered basement) are generally thicker (3.4 to 19.3 m) on the northern flank of the stream channel and thinner (0.9 to 10.3 m) on its southern flank. The fractured bedrock delineated on the southern flank is confined and poses minor threat to the proposed dam. However the thicker overburden beneath the northern flank and thin overburden on the southern flank present incompatible structure that may initiate uneven settlement of the dam embankment thus making the site unsuitable for earth dam construction.

Key words: Dam axes, horizontal profiling, vertical electrical sounding, overburden, fractured bedrock.

INTRODUCTION

Dams are among the largest and most important projects in civil engineering (Coduto, 1999). For geologic, hydrologic and topographic reasons, there are limited numbers of ideal sites for dams. It is therefore very important to intensely scrutinize any proposed dam site. Pre-construction site study is a prerequisite for the construction of dams and other hydraulic structures in order to avoid locating such structures on undesirable subsurface features such as buried stream channels, near-surface fractures, joints, fissures e.t.c. The unpredictability of the near-surface ground often complicates site investigations and budgetary constraints may limit the number of boreholes. Geophysics can provide powerful tools to complement other forms of site investigation. Geophysical studies carried out prior to the intrusive investigation in form of borings and trial pits may locate anomalous areas associated with significant subsurface features. The identification of anomalies allows borings and trial pits to be appropriately targeted.

The appropriate location of borings on the basis of prior

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geophysical surveys may result in borehole data being more representative of site conditions. Essentially, geophysics may enhance the value of borehole data. On a complex site, geophysics may be utilized to determine the geology between boreholes, since interpolation between borehole logs may be ambiguous. Comparison of geophysical survey results with directly obtained geological information that permits the extrapolation of geophysical results into areas where little or no borehole information is available. On large sites in particular, the design of the spatial location of direct sampling points may be contentious (Ferguson, 1992) and important underground targets may be missed completely. Electrical resistivity method is one of the most effective and environmentally friendly approaches to evaluating engineering sites generally and particularly for evaluating dam sites. The proposed Owuruwuru dam (Figure 1) is a mini earth dam project intended at supplying potable water to the College of Education community in Ikere Ekiti Southwestern Nigeria. The Owuruwuru River is one of the tributaries of Ogbese River that drains the southeastern parts of Ekiti State and eastern parts of Ondo State into the Atlantic Ocean. To avoid drilling of numerous boreholes through the soil into the bedrock which may enhance hydraulic contact between the proposed reservoir and any fracture at depth within the site, geophysical technique which is rapid to implement and cost effective is effected. This geophysical investigation is thus aimed at delineating the geophysical/geologic features such as overburden thickness, concealed basement morphology, fractures /seepage channels(s) (where they exist) in the subsurface thus, enabling the evaluation of the feasibility of the area for establishing a small earth dam and reservoir.

The information provided by the study is expected to aid the dam embankment design process so that likely losses through seepage from the reservoir can be analyzed and prevention devices incorporated. Dams intended for water supplies require a low tolerance of seepage losses. Besides, the design of dam structures must be adapted to the existing site conditions (Ajayi et al., 2005) to minimize the losses. Failure to do any of these may invariably result in unplanned seepage and/or total collapse of the structure (Olorunfemi et al., 2000a, b). Biswas and Charttergee (1971) examined causes of dam failures worldwide and discovered that 25% of the failures were due to geotechnical problems associated with seepage, inadequate seepage cut-off, faults, settlements and landslides.

STUDY AREA DESCRIPTION

The Owuruwuru dam project site (Figure 1) is situated about 3 km west of Ikere Ekiti on the southern flank of Ikere-Igbaraodo roadway. The site is located about 1.2 km south of the College of Education campus.

Owuruwuru stream which drains Ikere Ekiti metropolitan area and flows in the eastern direction has its source from the coarse grained porphyritic granite inselbergs located west of Ikere and north of the college campus.

GEOLOGY AND GEOMORPHOLOGY

The study area is underlain by the Pan-African Older Granite series (NGSA, 2006) of the Precambrian Basement Complex rocks of Southwestern Nigeria (Figure 1). Field observations at the survey site revealed that the lithology is the coarse porphyritic granite and the undifferentiated porphyritic granite and granite, gneiss and migmatite rocks types. The bedrock occurs as outcrops and boulders within the accessible river channel at the time of field study. Massive outcrop of porphyritic granite is situated about 300 m south of the site. A characteristic feature of the Basement Complex tectonics is the widespread occurrence of fractures (Oluyide, 1988). Thus, varieties of structural features such as foliations, folds, faults, joints, fractures and fissures exist in the Basement Complex environment. The superficial deposit on the higher elevation northern flank of the river consists of sandy clay and clayey sand. Owuruwuru River flows at an angle to the general direction of strike of rocks in the area. Aina et al. (1996) observed that a stream situated within Basement Complex setting with river flow perpendicular to general strike may not be structurally controlled. Ikere Ekiti is situated within the rain forest belt of Nigeria with a climate of long wet season (April to October) and short dry season (November to March). The topography is gently rolling. The site slopes generally to the southwest in the direction of Owuruwuru River flow.

METHODS OF STUDY

Three traverses were established along NNW to SSE (335° WCB) azimuth as proposed downstream axis, main dam axis and upstream axis (Figure 2). Forty-four vertical electrical sounding (VES) locations were occupied along the traverses at intervals of 10 m. VES 1 to 16 locations were occupied along the downstream traverse, VES 17 to 32 locations were occupied along the main dam axis while VES 33 to 44 locations were occupied along the upstream axis. Preliminary studies of the proposed dam site involved the Wenner electrode array horizontal resistivity profiling. Three profilings with electrode separations of 10, 20 and 30 m were undertaken along downstream axis and main dam axis while only two profilings with 10 and 20 m separations were carried out along the upstream axis. The VES technique was adopted for detailed subsurface investigation of the dam site using the Schlumberger configuration. The universal transverse Mercator (UTM) system of coordinates was adopted using Garmin 72 Global Positioning System. However, the geodetic system of coordinates (used for referencing the traverses and the position of the project area on general map) were determined using GEOCAL. The current electrode separation (AB) was varied from a minimum of 2.0 m to a maximum of 130 m at the VES locations. R-50 Soiltest resistivity meter complete with peripherals were used for field resistivity measurements.

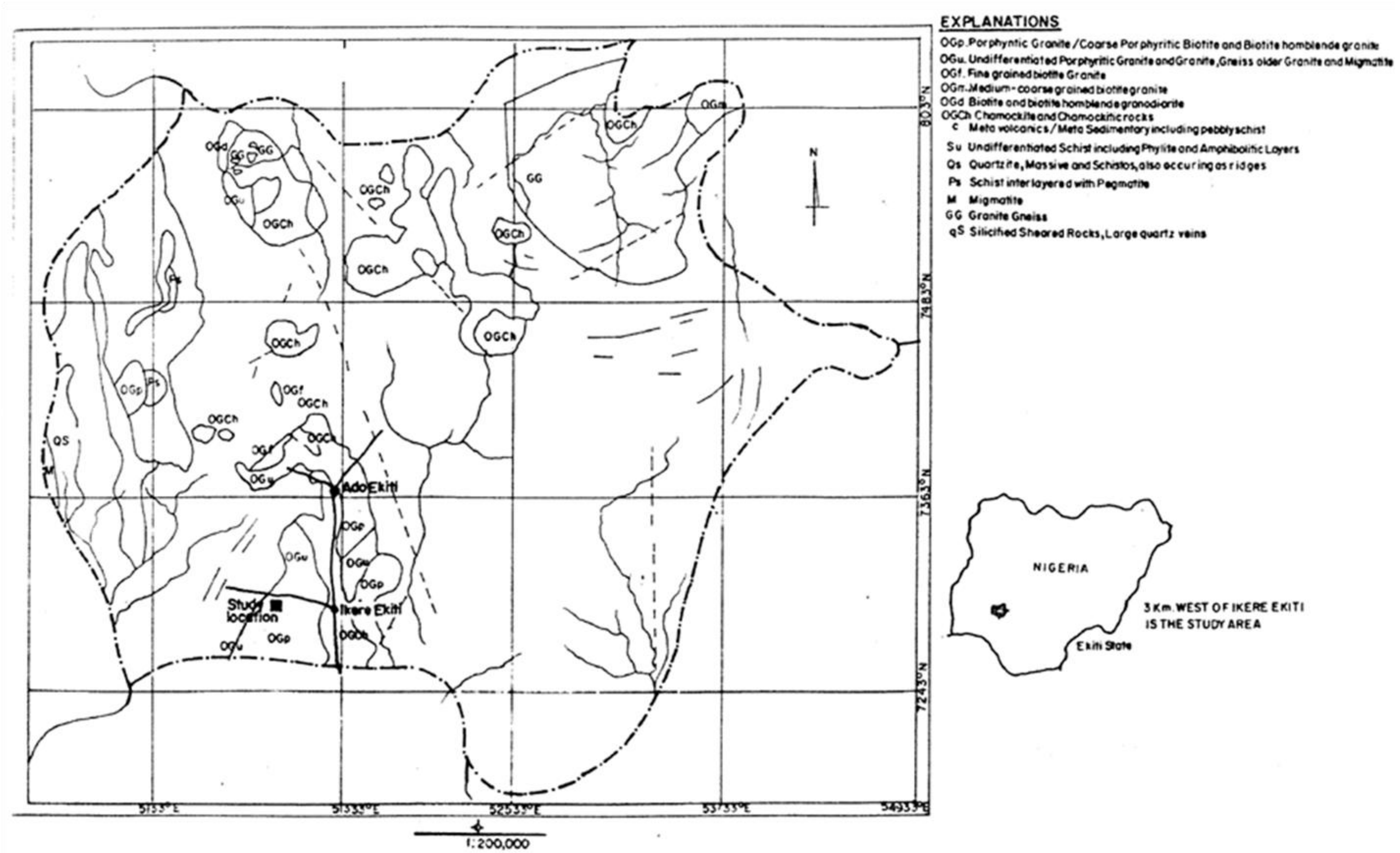


Figure 1. Map of Ekiti State showing the location of the proposed Owuruwuru dam and the general geology.

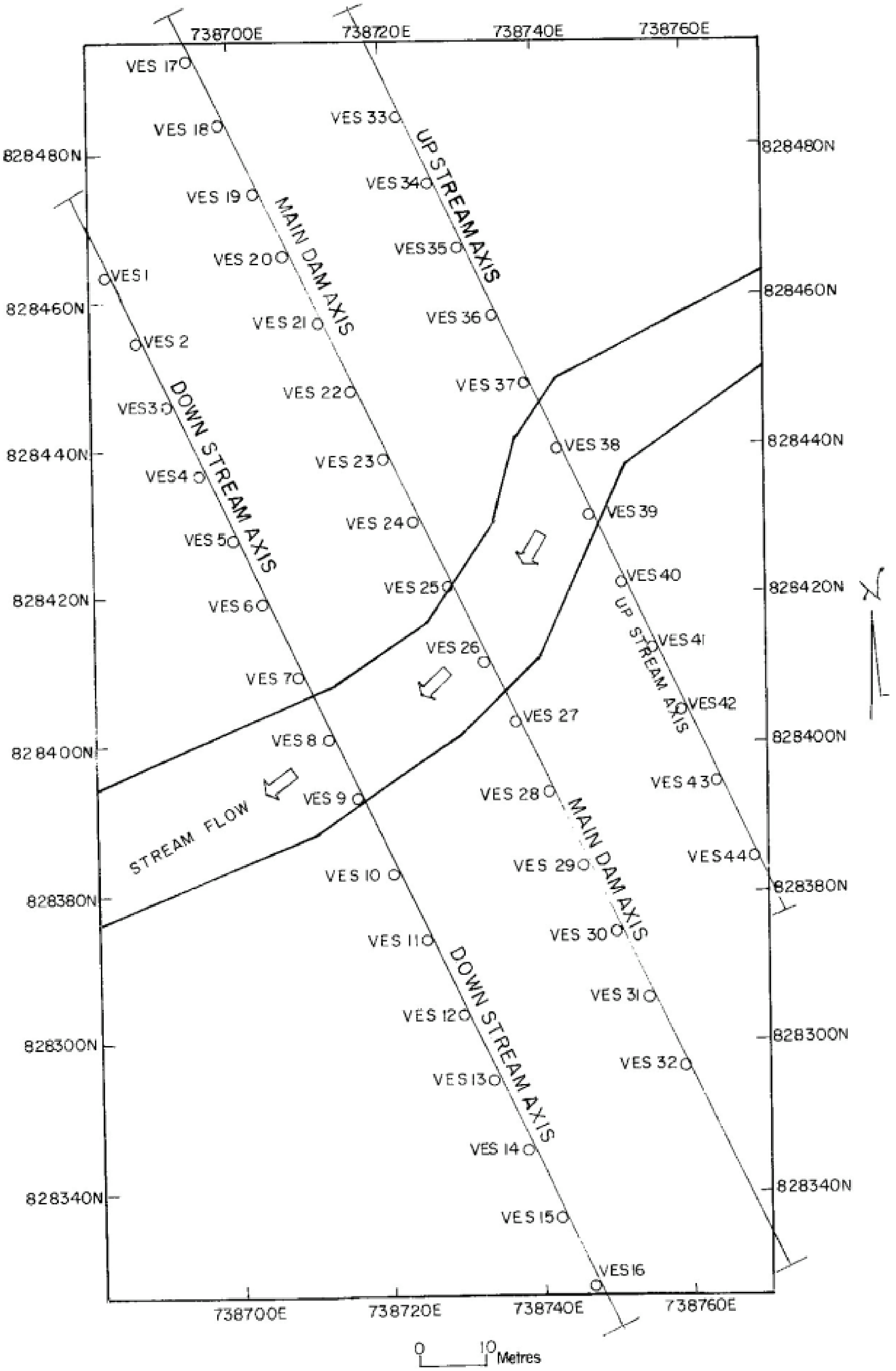


Figure 2. Layout map of the proposed Owuruwuru dam project site showing geophysical tranverses and vertical electrical points.

RESULTS

The results of the geophysical investigation are presented as resistivity profiles, 2-D inversion sections of the resistivity profiles, sounding curves, table, geoelectric sections and map. The resistivity profiles and inversion sections were interpreted qualitatively while the sounding curves were interpreted qualitatively and quantitatively.

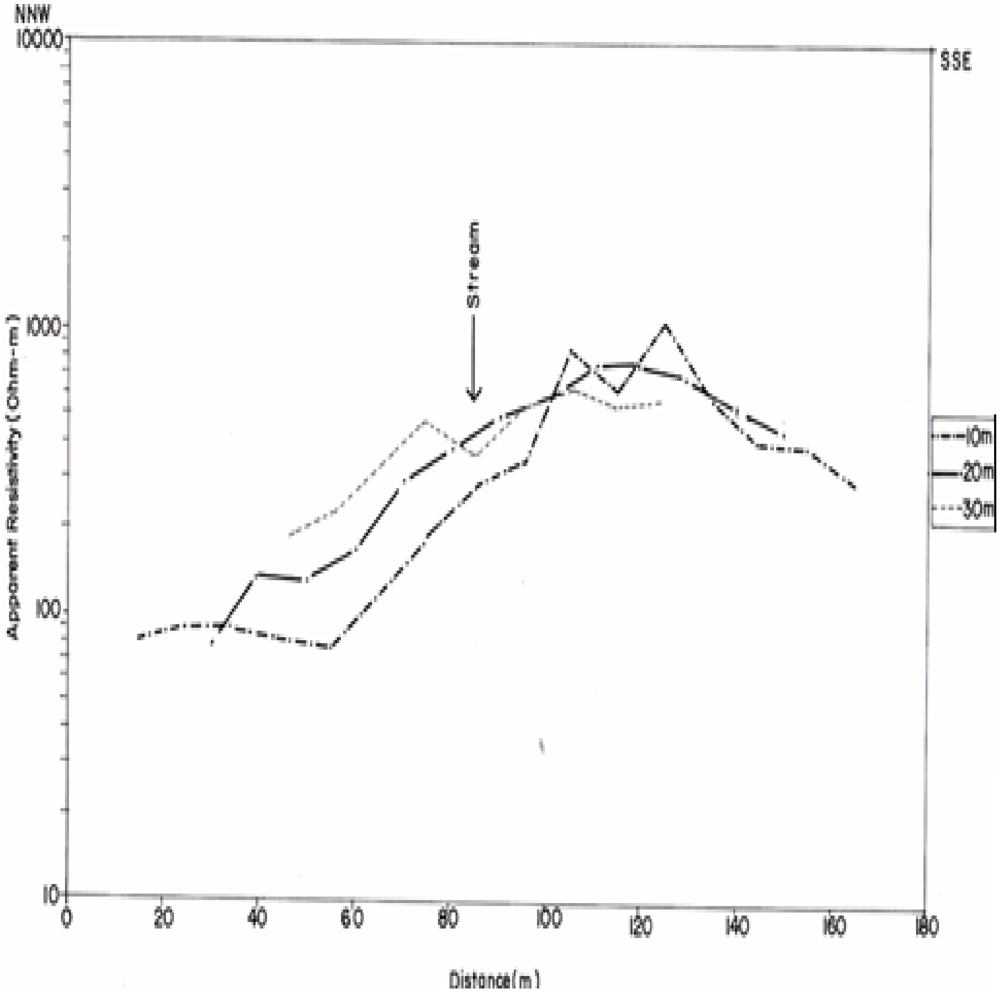


Figure 3. Electrical restivity profiles along the down stream axis with Wenner electrode seperations of 10, 20 and 30 m.

The qualitative interpretation involved the evaluation of resistivity profiles and sounding curves for engineering geophysical characterization of the study site. Inversion of the field data based on linear inverse theory using the least squares method was undertaken with RES2DINV^{TM} version 3.55. 2-D resistivity model is determined for the subsurface using data obtained from electrical imaging surveys (Griffiths and Barker, 1993). A forward modeling subroutine is used to calculate the apparent resistivity values, and a non-linear least-squares optimization technique is used for the inversion routine (deGroot-Hedlin and Constable, 1990; Loke and Barker, 1996). The robust model constrain inversion method was used on the model resistivity values in this study to obtain pseudosections and inversion models. This constrain tends to produce models with sharp interfaces between different regions with different resistivity values (deGroot-Hedlin and Constable, 1990). This is apparently more suitable for basement complex terrain where a soilbedrock interface geological situation exists. The method of quantitative interpretation involved curve matching where the data were plotted on double logarithmic diagrams and matched against 2 layer master curves. By the use of auxiliary point diagrams, it was possible to interpret sequences of several layers (Dahlin, 2001). The geoelectric parameters obtained from manual interpretation of each VES data were refined using the software algorithm RESIST version 1.0 (Vander, 1988).

DISCUSSION

The horizontal resistivity profiles (Figures 3, 7 and 11) and the inversion results (Figures 4, 8 and 12) showed that the northern flank of the site is characterized by relatively lower resistivity values with respect to those obtained on the surface stream channel and southern

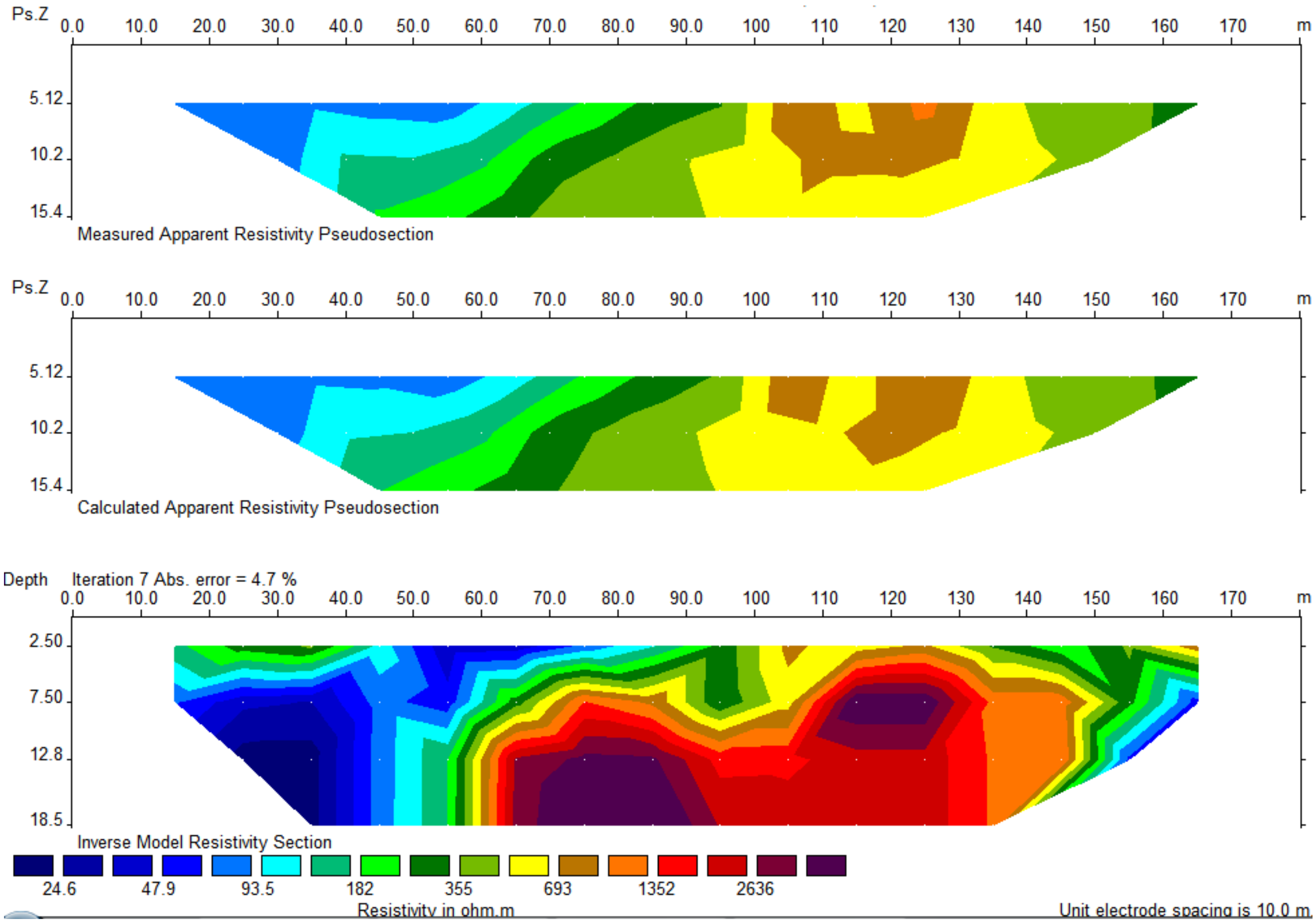
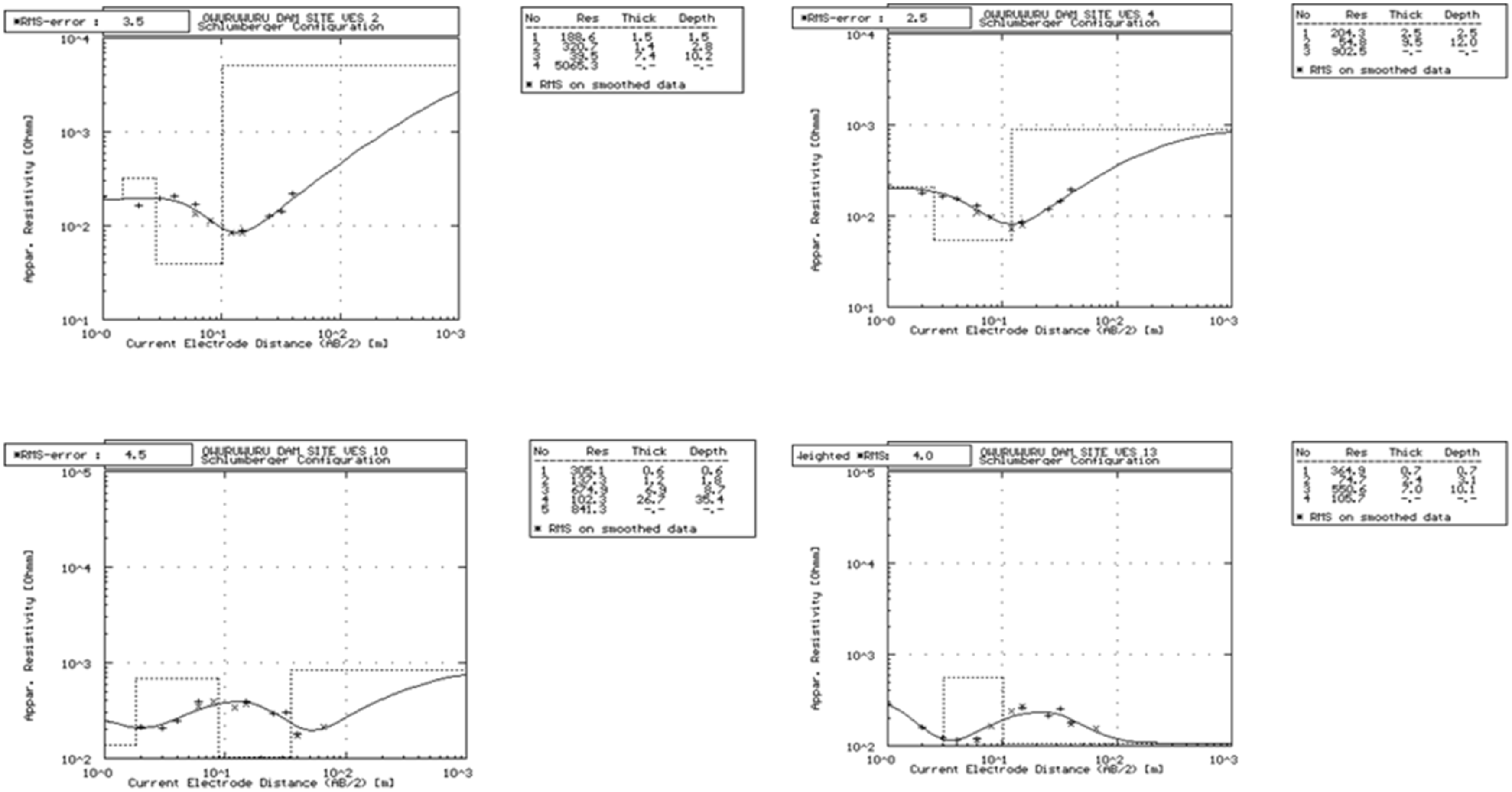


Figure 4. Inversion results of Wenner profile obtained from the downstream axis.

parts. Resistivity values obtained at 10 m electrode profiles are lower than the values obtained at 20 and 30 m separations. Likewise the values obtained at 20 m separation are lower than those obtained at 30 m separation. However, a contrary scenario was presented south of the stream on the downstream and dam axes (Figures 3 and 7) where resistivity values at the various separations are generally high thus indicating the closeness of the resistive basement rocks to the surface. The profiles show the morphology of the bedrock with low relief on the northern flank and a higher relief on the southern flank. The major features of the inversion sections are the low resistivity (green/blue colour scheme) and high resistivity (red/purple colour scheme) displays. The low resistivity zones in the inversion sections are prevalent on the northern flank while high resistivity zones are prevalent on the southern flank of the dam site (Figures 4, 8 and 12). The morphology of the bedrock presented in the profiles is also confirmed in the inversion sections. The curve types obtained from the VES data are 3-layer H (which constitutes the modal group) and K; 4-layer QH, HA, HK and KH; 5-layer HKH, KHK and KHA; 6-layer HAKH and KHKH (Figures 5, 9 and 13). The interpretation results are presented in Table 1. The bedrock on the northern flank is typified by rising sounding curve profiles at depth with no perceptible characteristic of fracturing. However, the bedrock within the river channel and the southern flank are characterized by resistivity patterns (K, HK, HKH and KHK) diagnostic of confined fractures. There is high probability of none existence of hydraulic contact between the confined fractures and the water in the flowing stream. The summary of the interpretation results of the downstream axis of the Owuruwuru dam site in terms of the geoelectric/geologic layering is presented as geoelectric section in Figure 6. The topsoil consists of sandy clay, clayey sand and sand with layer resistivity values varying from 63 to 497 Ω-m. The weathered basement which consists of clay/sandy clay/clayey sand is defined by resistivity values varying from 43 to 441 Ω-m and layer thickness varying from 0.9 to 29.8 m. Confined basement fracture was delineated beneath the stream to the south with resistivity values between 102 and 639 Ω-m. The fracture thicknesses vary from 2.1 to 26.7 m while the fracture thickness could not be determined beneath VES 11, 12, 13, 14 and 15 due to



VES 2

No	Res	Thick	Depth
1	188.6	1.5	1.5
2	320.7	1.4	2.8
3	39.5	7.4	10.2
4	5065.3	-.-	-.-

* RMS on smoothed data

VES 4

No	Res	Thick	Depth
1	204.3	2.5	2.5
2	54.8	9.5	12.0
3	902.5	-.-	-.-

* RMS on smoothed data

VES 10

No	Res	Thick	Depth
1	305.1	0.6	0.6
2	137.3	1.2	1.8
3	674.9	6.9	8.7
4	102.3	26.7	35.4
5	841.3	-.-	-.-

* RMS on smoothed data

VES 13

No	Res	Thick	Depth
1	364.9	0.7	0.7
2	74.7	2.4	3.1
3	550.6	7.0	10.1
4	105.7	-.-	-.-

* RMS on smoothed data

Figure 5. Typical sounding curves obtained along downstream axis.

spread limitations. The presumably fresh basement is defined by resistivity values varying from 372 to 7500 Ω-m while depth to the bedrock vary from 5.9 m on the southern flank to 30.4 m at the northern flank. The summaries of the interpretation results of the sounding curves obtained from the proposed main dam axis in terms of the geoelectric/geologic layering are presented in Figure 10. The topsoil which consists of sandy clay, clayey sand and laterite is defined by layer resistivity values varying from 131 to 1142 Ω-m. The second layer which is the weathered basement consists of clay, sandy clay and clayey sand. The resistivity of the weathered basement varies from 22 to 349 Ω-m while the thickness varies from 1.5 to 13.5 m. While the geoelectric characteristics of the bedrock on the northern flank present fresh basement signatures (H and QH), the geoelectric characteristics obtained on the southern flank of the stream present fracture signatures in form of HK, HKH

Table 1. Interpretation result.

Traverse	VES No.	Depths (m) $d_1/d_2/……../d_{n-1}$	Resistivity (Ω-m) $\rho_1/\rho_2/……../\rho_n$	Remarks
Downstream axis	1.	1.3/16.7	175/97/372	Fresh bedrock
	2.	0.6/1.4/2.8/11.3	201/173/313/45/4947	Fresh bedrock
	3.	1.3/16.8	237/103/739	Fresh bedrock
	4.	0.8/3.1/13.9	340/137/61/690	Fresh bedrock
	5.	1.4/17.6	306/76/1197	Fresh bedrock
	6.	1.6/5.9	130/53/780	Fresh bedrock
	7.	0.8/2.6/14.0	205/148/240/7500	Fresh bedrock
	8.	0.6/1.6/2.7/8.1/10.3	114/48/117/896/334/5083	Fractured bedrock
	9.	0.4/1.4/3.9/11.2/30.0	63/535/209/830/105/1110	Fractured bedrock
	10.	0.6/1.8/8.7/35.4	305/137/675/102/841	Fractured bedrock
	11.	0.8/1.8/13.0	497/441/1184/639	Fractured bedrock
	12.	0.9/11.8	238/1293/423	Fractured bedrock
	13.	0.7/3.1/10.1	365/75/551/106	Fractured bedrock
	14.	1.0/2.4/18.4	147/84/841/144	Fractured bedrock
	15.	0.5/1.6/22.6	202/43/746/210	Fractured bedrock
	16.	0.6/2.6/30.4	209/66/267/4444	Fresh Bedrock
Main dam axis	17.	1.2/3.4	316/22/2423	Fresh bedrock
	18.	0.6/1.5/2.5/8.3	194/119/220/86/648	Fresh bedrock
	19.	1.5/8.7	244/71/460	Fresh bedrock
	20.	1.3/8.3	296/74/733	Fresh bedrock
	21.	0.8/1.8/5.7/14.3	203/141/220/124/1081	Fresh bedrock
	22.	0.7/3.4/13.7	347/235/78/1115	Fresh bedrock
	23.	0.8/6.8	941/95/362	Fresh bedrock
	24.	1.1/2.6/12.6/21.6	147/54/603/237/896	Fractured bedrock
	25.	0.5/2.0/5.1/11.7	135/72/237/78/1324	Fractured bedrock
	26.	0.4/1.5/4.7/16.4	167/1048/217/886/199	Fractured bedrock
	27.	0.5/1.5/7.4/15.3	394/64/446/197/1027	Fractured bedrock
	28.	0.7/3.5	1142/300/999	Fresh Bedrock
	29.	1.0/3.7/10.8/31.1	486/1741/259/1124/315	Fractured bedrock
	30.	0.6/1.4/4.9/19.2	457/349/987/366/684	Fractured bedrock
	31.	0.8/3.7/14.2	684/108/266/75	Fractured bedrock
	32.	0.5/1.3/11.0	131/201/87/7419	Fresh Bedrock
Upstream axis	33.	0.8/1.8/13.5	461/476/201/774	Fresh bedrock
	34.	0.8/2.0/14.8	319/541/213/516	Fresh bedrock
	35.	0.8/1.8/3.7/19.3	354/212/340/180/1003	Fresh bedrock
	36.	1.5/9.9/18.4	559/181/222/916	Fresh bedrock
	37.	1.6/6.9	206/58/1024	Fresh bedrock
	38.	0.5/1.3/4.7/9.6	195/318/42/127/802	Fresh bedrock
	39.	1.0/9.6	218/43/4602	Fresh bedrock
	40.	1.4/5.2	157/38/2238	Fresh bedrock
	41.	0.5/2.1/12.9	686/24//101/∞	Fractured bedrock
	42.	0.4/3.4/8.9	1251/187/25/479	Fresh Bedrock
	43.	1.2/10.3	1722/69/3152	Fresh bedrock
	44.	0.5/1.6/7.7	79/472/48/3896	Fresh bedrock

and KHK curves. The fractured basement is typified by layer resistivity values varying from 75 to 366 Ω-m while the thickness varies from 3.2 to 14.3 m. However the fracture thickness could not be established beneath VES

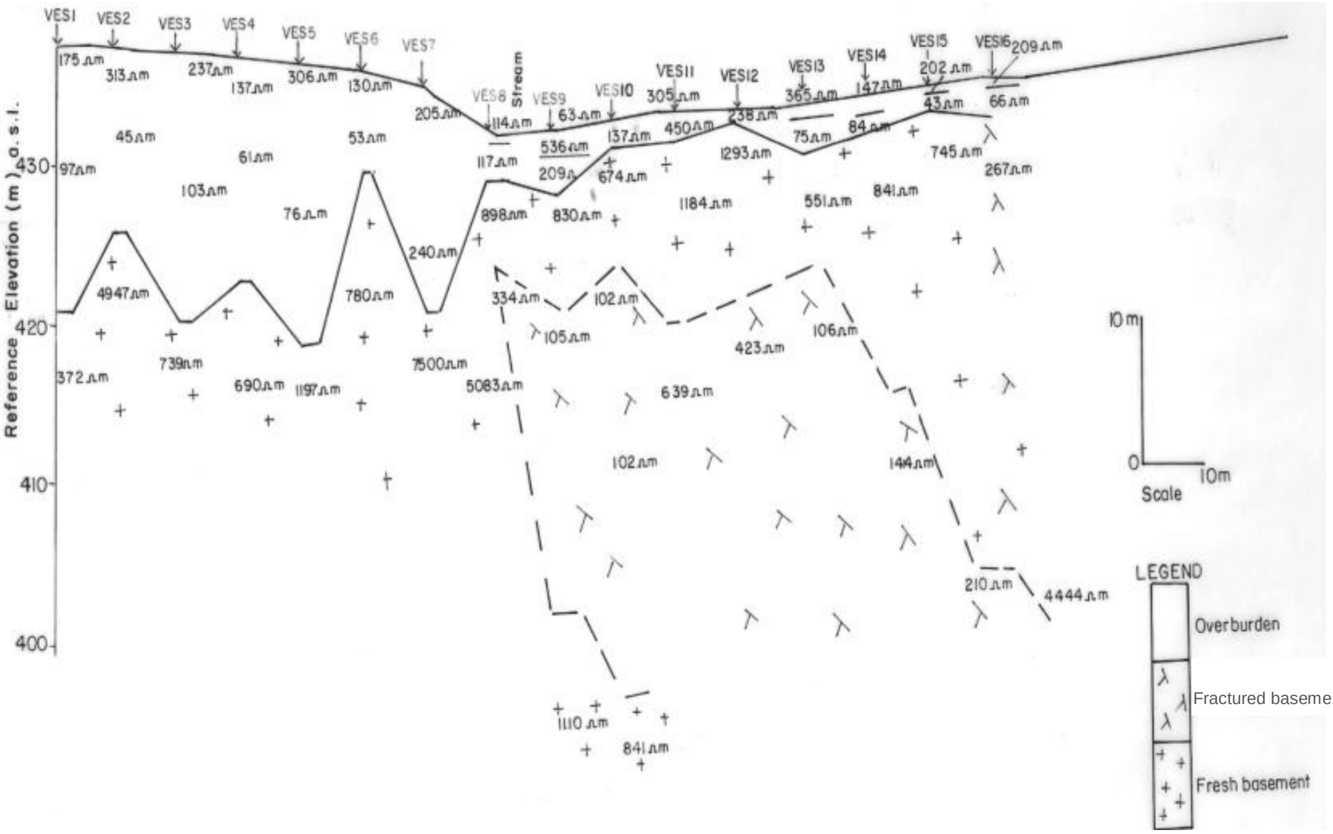


Figure 6. Geoelectric section along the down stream axis.

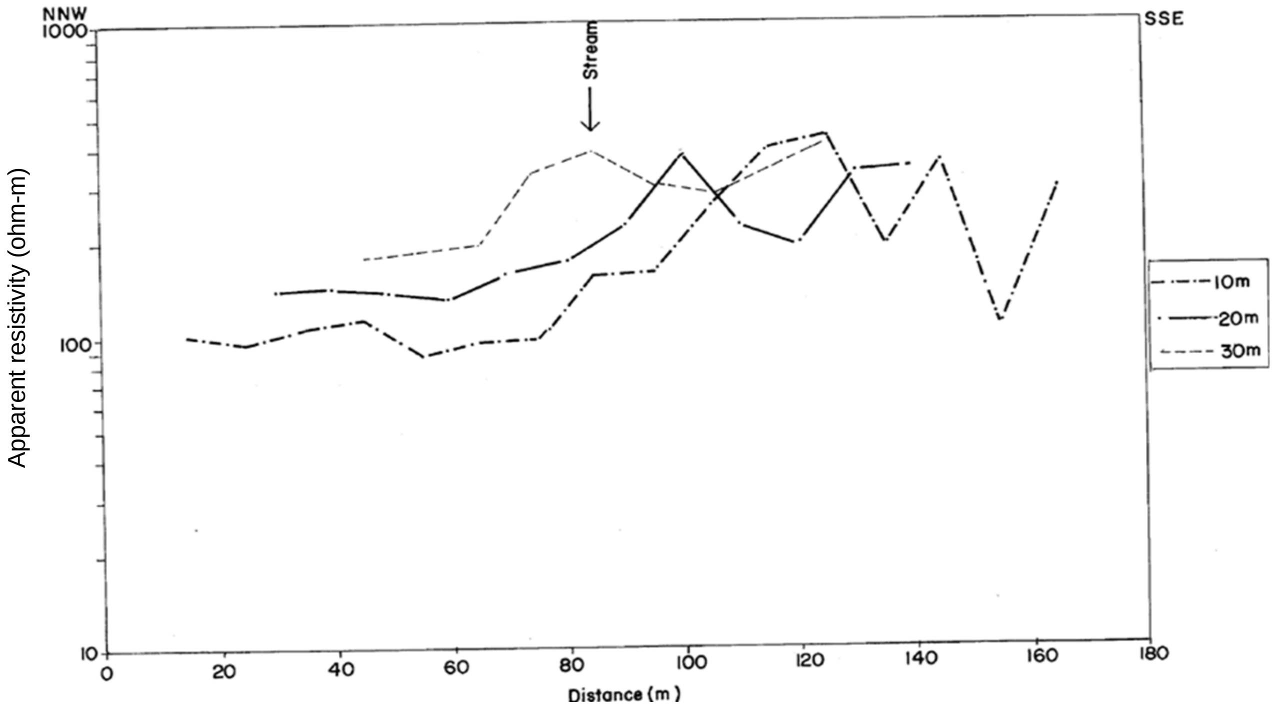


Figure 7. Electrical restivity horizontal profile of Owuruwuru dam (main dam axis) at Wenner electrode seperations of 10, 20 and 30 m.

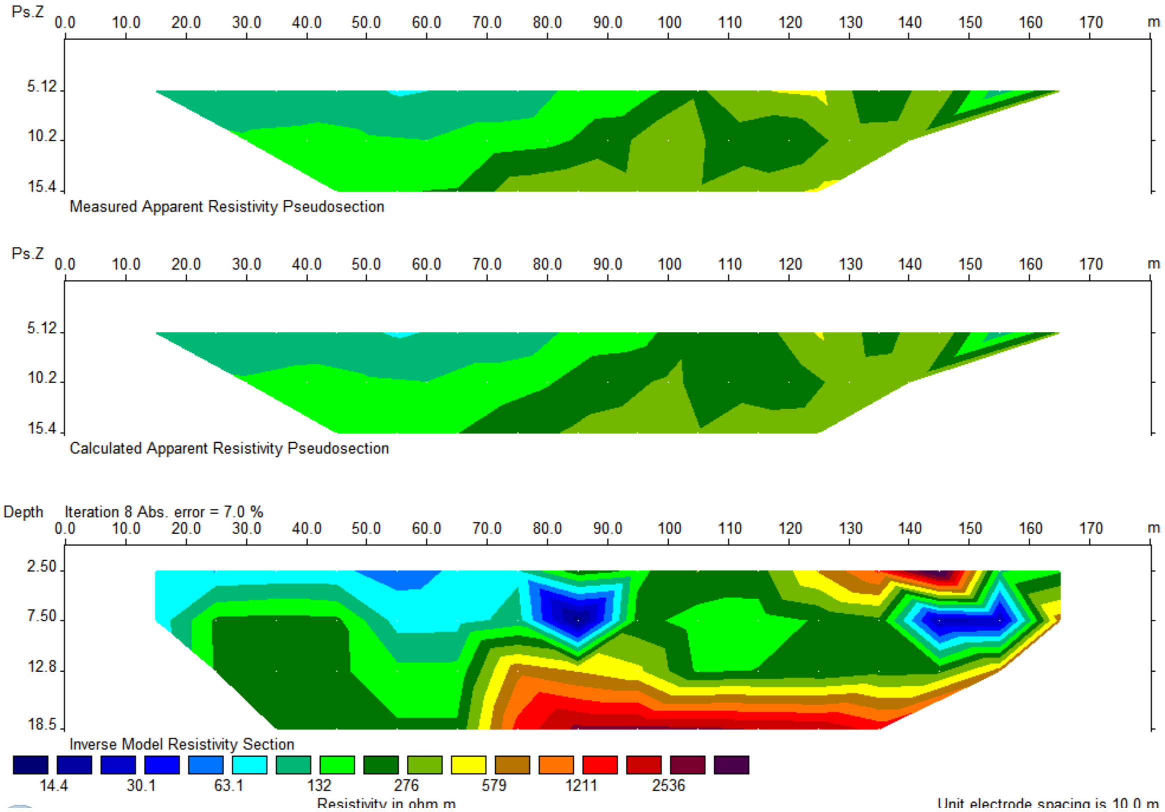


Figure 8. Inversion results of Wenner profile obtained from the main dam axis.

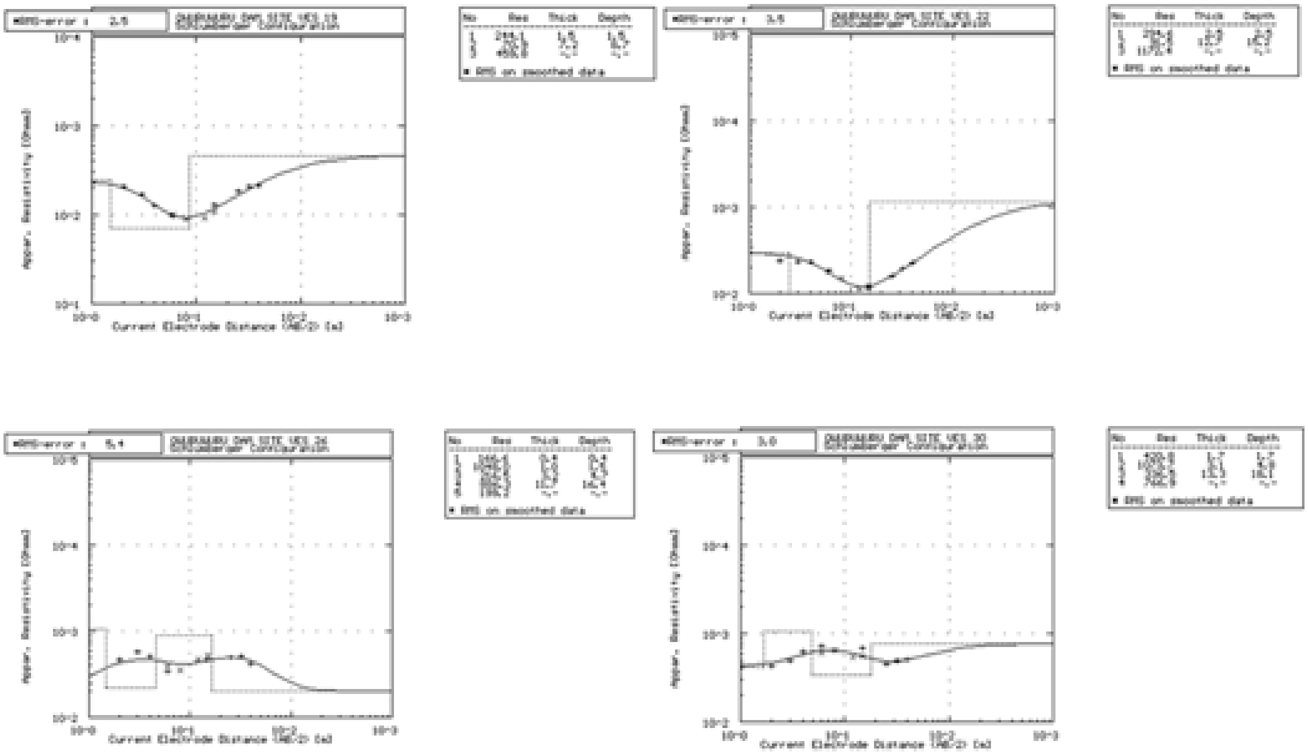


Figure 9. Typical sounding curves obtained along the main dam axis.

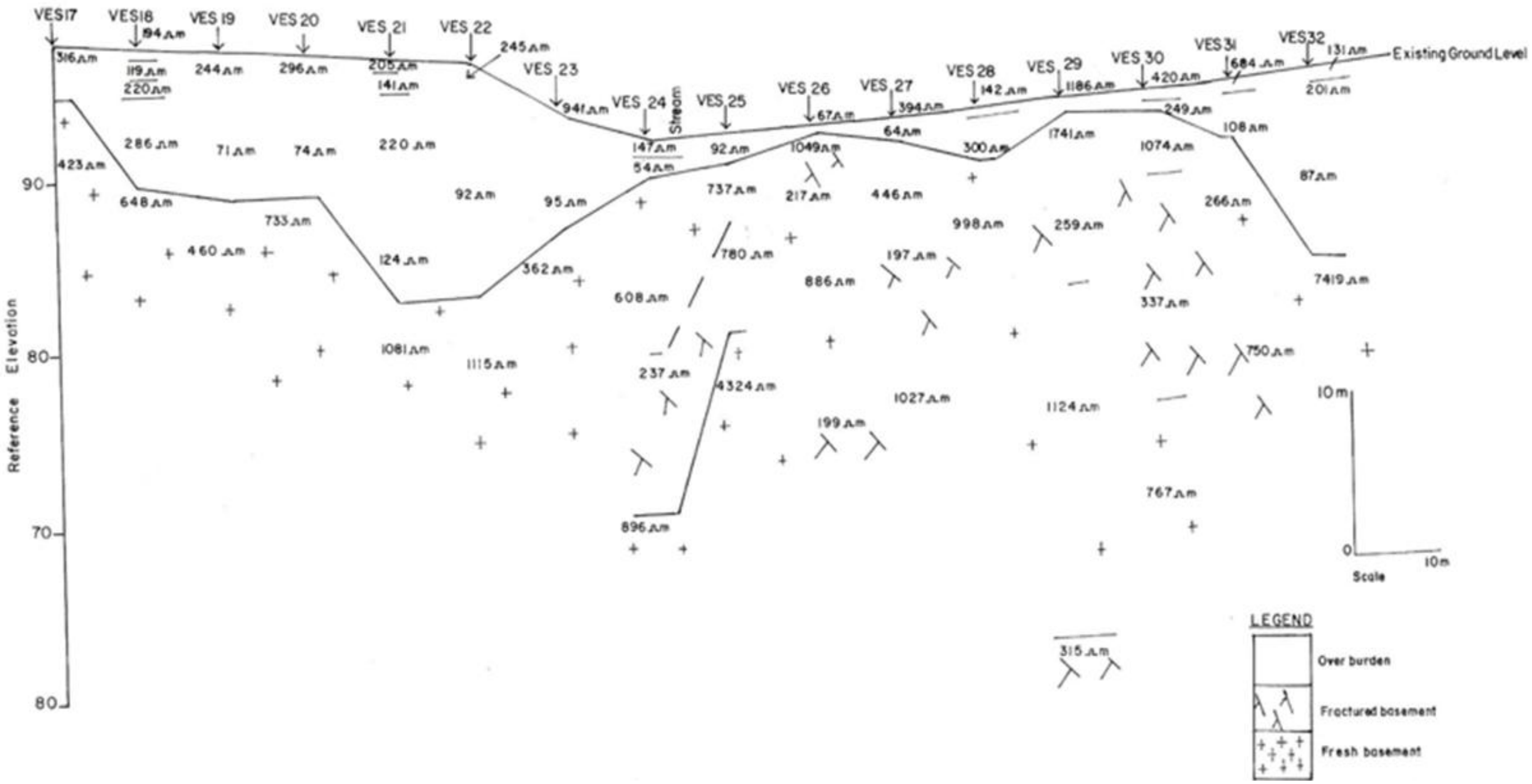


Figure 10. Geoelectric section along the proposed main dam axis.

26, 29 and 31 due to spread limitations. The fresh basement is defined by resistivity values varying from 362 to 7419 Ω-m while depth to bedrock varies from 3.4 to 21.6 m. The summaries of the interpretation results of the upstream axis in terms of the geoelectric/geologic layering are presented in Figure 14. The topsoil consists of sandy clay, clayey sand, sand and laterite with resistivity values varying from 79 to 1722 Ω-m. The topsoil is underlain by the weathered basement which consists of clay, sandy clay and clayey sand. The weathered basement within the proposed reservoir is characterized by layer resistivity values varying from 24 to 541 Ω-m and layer thickness varying between 1.6 and 18.5 m. Geoelectric characteristics indicative of fractured basement was obtained at one sounding location (VES41) on the entire traverse. The fracture column

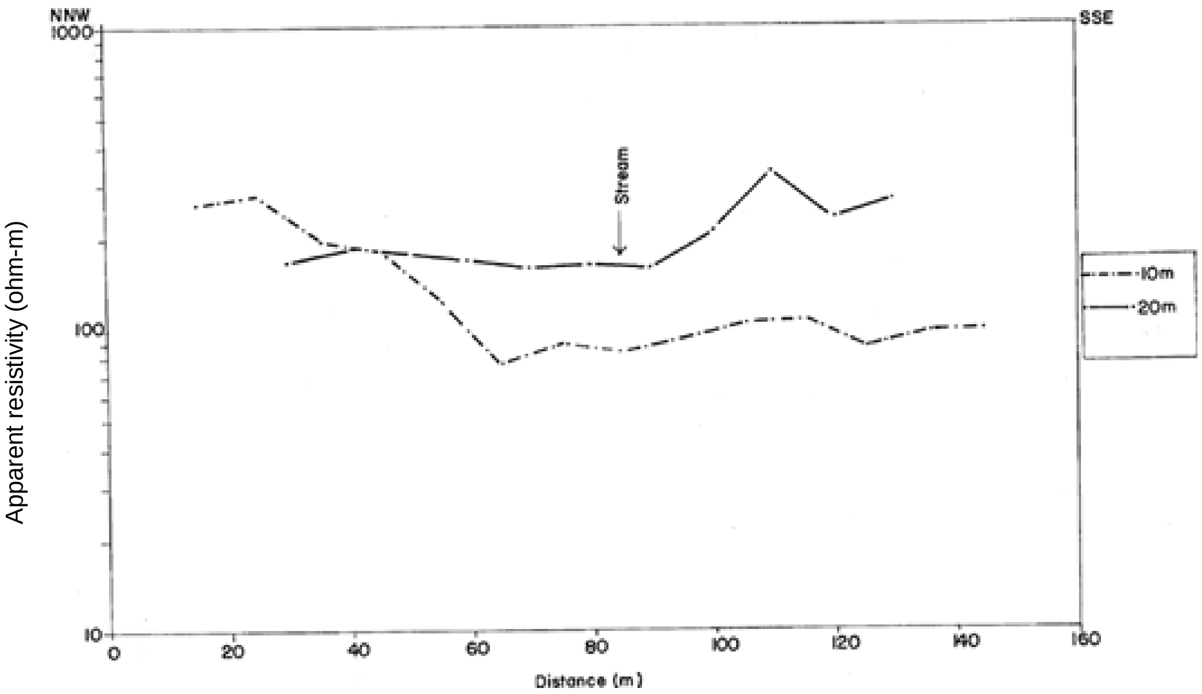


Figure 11. Electrical restivity horizontal profile of Owuruwuru dam (upstream axis) at Wenner electrode seperations of 10 and 20 m.

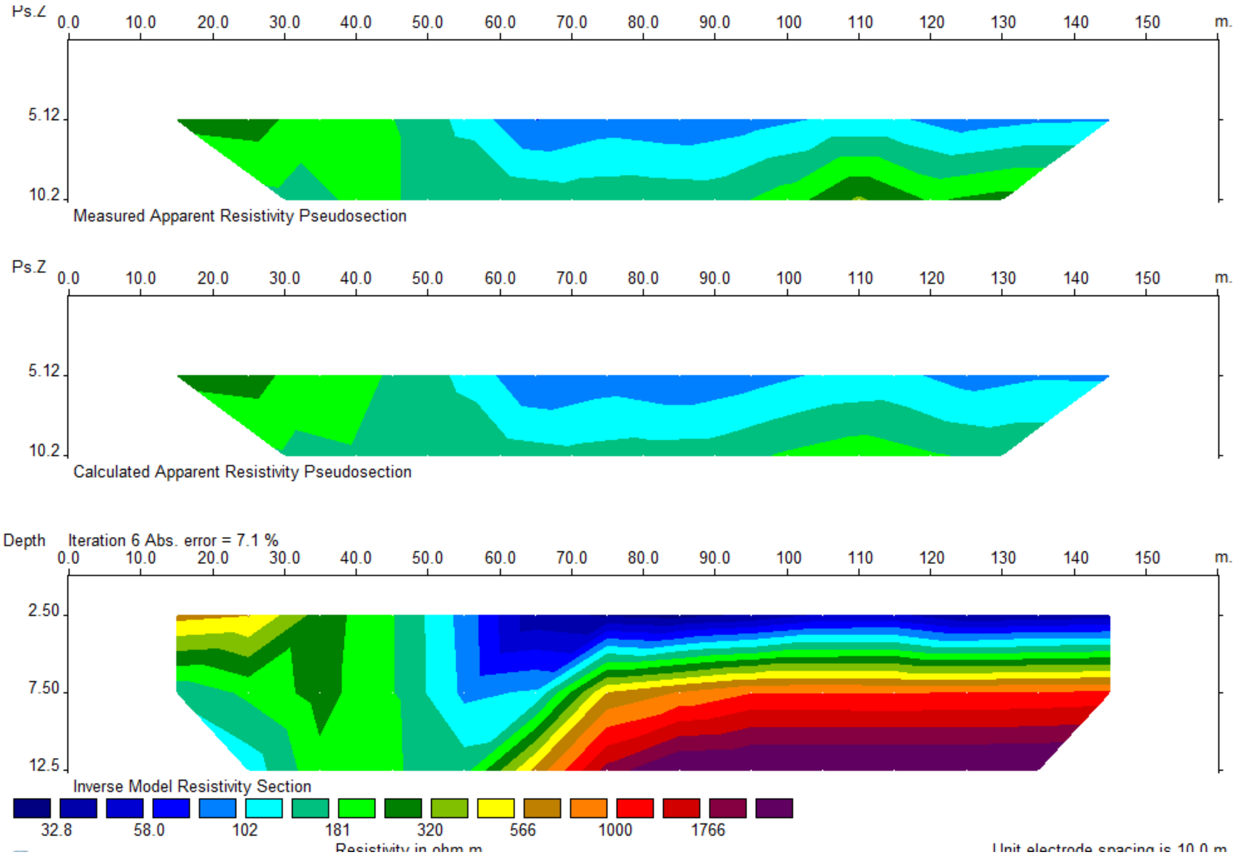
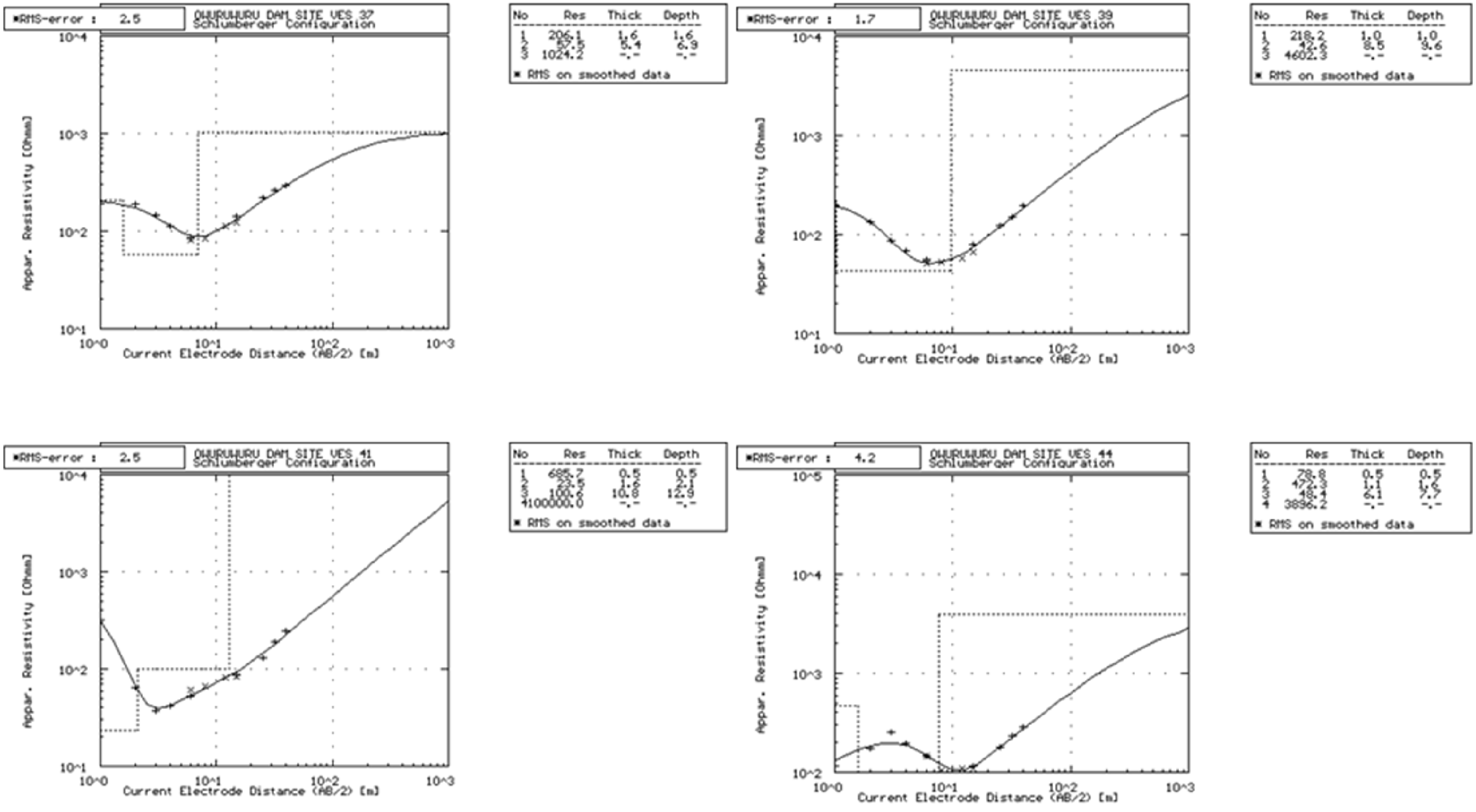


Figure 12. Inversion results of Wenner profile obtained from the upstream axis.



No	Res	Thick	Depth
1	206.1	1.6	1.6
2	57.5	5.4	6.9
3	1024.2	-.-	-.-

■ RMS on smoothed data

No	Res	Thick	Depth
1	218.2	1.0	1.0
2	42.6	8.5	9.6
3	4602.3	-.-	-.-

■ RMS on smoothed data

No	Res	Thick	Depth
1	685.7	0.5	0.5
2	22.5	1.6	2.1
3	100.6	10.8	12.9
4	100000.0	-.-	-.-

■ RMS on smoothed data

No	Res	Thick	Depth
1	78.8	0.5	0.5
2	472.3	1.1	1.6
3	48.4	6.1	7.7
4	3896.2	-.-	-.-

■ RMS on smoothed data

Figure 13. Typical sounding curves obtained along the upstream axis.

is defined by resistivity value of 101 Ω-m with layer thickness of 10.8 m. The presumably fresh basement is generally characterized by relatively high resistivity values (479 Ω-m to ∞ Ω-m). Overburden thickness within the reservoir channel varies from 5.2 to 19.3 m. The interpretation of the results of the geophysical studies undertaken at the proposed Owuruwuru earth dam project site has shown that the northern flank (proposed right abutment) of the stream intended for water impoundment is underlain by thicker overburden materials than its southern flank (proposed left

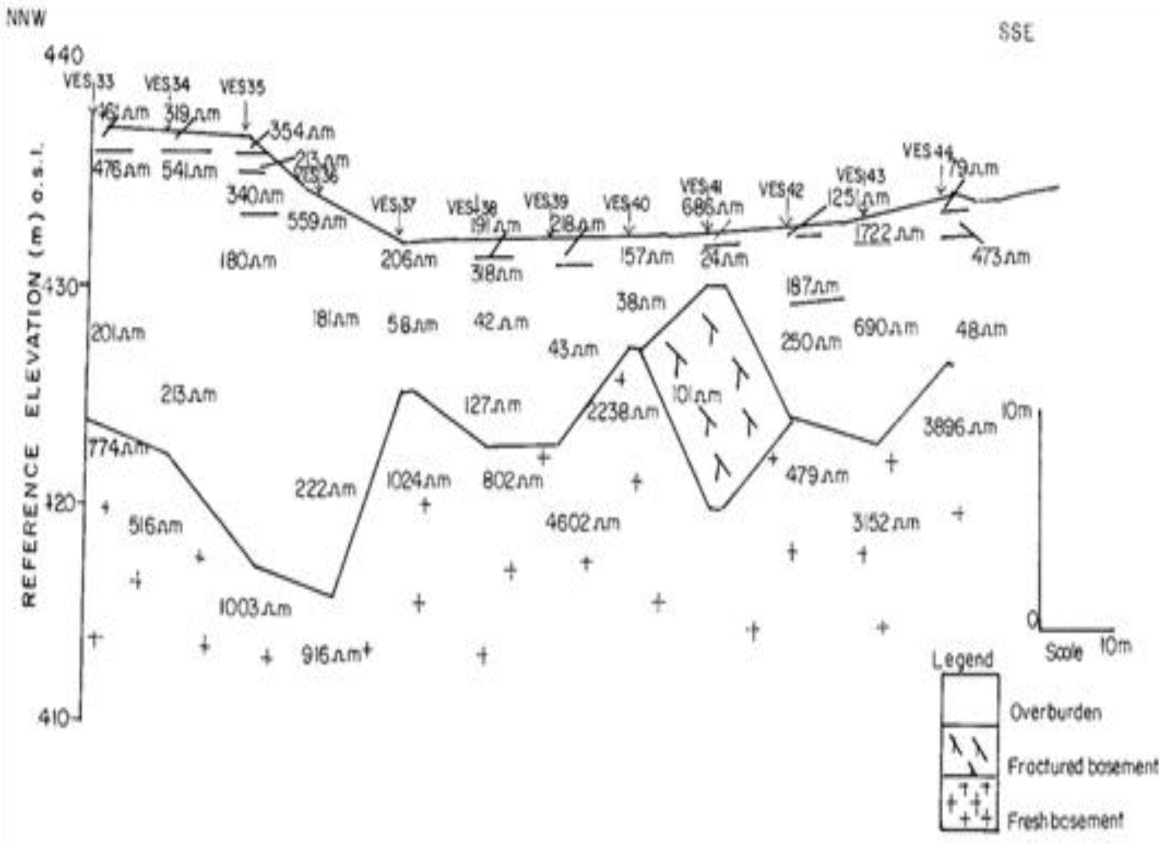


Figure 14. Geoelectric section along the proposed main dam axis.

abutment). The inversion model resistivity and geoelectric sections (Figures 4, 6, 8, 10, 12 and 14) show that the dam site is underlain by clayey sand topsoil, sandy clay weathered basement, partially weathered/fractured basement and the presumably fresh bedrock. Materials of the overburden (topsoil + weathered basement) are generally thicker on the northern flank of the stream channel and thinner on the southern flank of the stream. The inversion model resistivity and geoelectric sections along the downstream and main dam axes (Figures 4, 6, 8 and 10) show that the bedrock on the northern flank of the stream channel presents no perceptible fracturing characteristics while the bedrock on the southern flank present fractured/partially weathered basement characteristics. The upstream axis section (Figures 12 and 14) shows very few evidences of fracturing characteristics throughout its study length.

The structural map (Figure 15) that was generated from delineated fracture boundaries on the geoelectric sections of Figures 6, 10 and 14 showed that the seepage flow path widens south-westwards parallel to the stream flow direction. Thus the western flank of the site (upstream axis) is apparently underlain by fewer fractures compared with the main dam and downstream axes. The results of the geophysical investigation conducted on three proposed dam axes showed that the northern flank of the stream presented no appreciable seepage characteristics within the bedrock. The contrary is the case on the southern flank along the downstream and main dam axes. However, the upstream axis has more overburden thickness and less fracturing characterizing its bedrock when compared with the downstream and main dam axes.

CONCLUSIONS

The geophysical investigation conducted on the proposed Owuruwuru dam site at Ikere Ekiti shows that the northern flank of the stream is underlain by fairly thick superficial soil (overburden) materials while the southern flank of the stream is underlain by fairly thin superficial soils. The bedrock is closer to the surface on the southern flanks of the three axes (southeastern area of the site) investigated. The overburden materials consist of clay, sandy clay and clayey sand. The topsoil is generally dry as shown in the relatively high resistivity values. The bedrock is intensely fractured beneath the downstream axis, slightly fractured beneath the main dam axis and relatively fresh beneath the upstream axis.

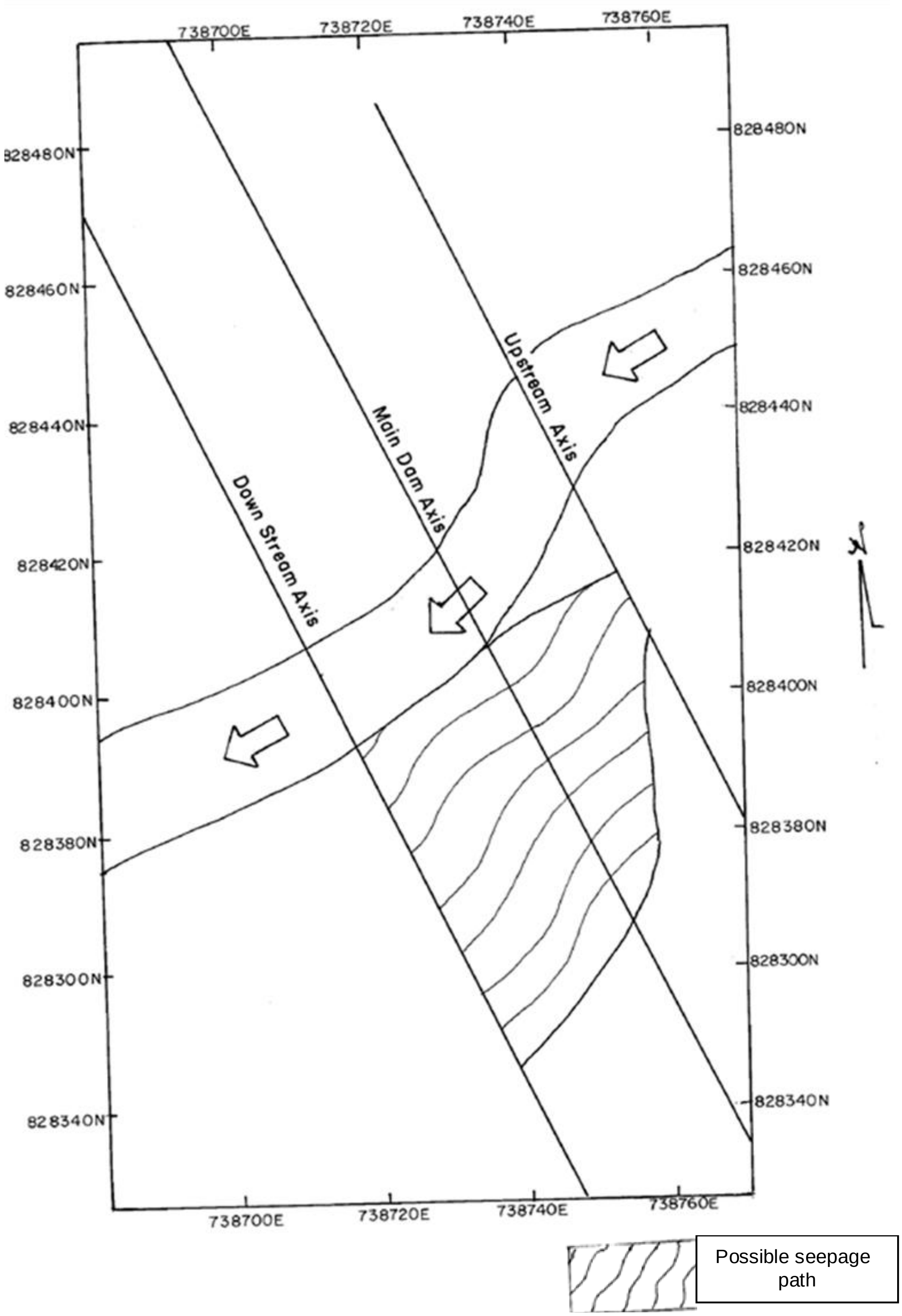


Figure 15. Structural map of the study area.

The fractures beneath the downstream and main dam axes are confined and may pose no serious threat since limited hydraulic contact presumably exists between the confined fractures and the overlying stream and the proposed reservoir area. The general characteristics of the materials within the dam project site in form of resistive and shallow bedrock indicate that they are competent. However, some form of remediation in the design process is required for reducing the threat posed by the existence of fractures which are possible subsurface seepage channels. The difference in overburden thickness beneath the banks of River Owuruwuru may prompt future uneven settlement of the dam embankment. Rapid settlement may occur from elastic compression of the thicker overburden of the northern flank. Uneven settlement is unfavourable to the function of an earth dam. Thus, the site is not ideally feasible for an earth dam and reservoir.

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