

**AMHARA NATIONAL REGIONAL STATE
WATER ,IRRIGATION AND ENERGY BUREAU
(BWIE))**



**GEOLOGICAL & GEOTECHNICAL
FESIBILITY STUDY
OF
AWAJO INTAKE IRRIGATION PROJECT
VOLUME II: ENGINEERING GEOLOGY**



**CONSULTANT:
AMHARA DESIGN &
SUPERVISION WORKS
ENTERPRISE**

Amhara National Regional State
Water, Irrigation and Energy Bureau
(BOWRD)
Feasibility Study and Detail Design
Of
Awajo Diversion/Intake Small-Scale Irrigation Project
Engineering Geology
Final Report
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1 Introduction

1.1 General

Since agriculture is one of the principal means of bringing sustainable development in the country, it is vital to plan and modify the farming system by adopting modern agricultural practice and utilizing naturally available water resources for irrigation purpose. In this line, the regional government has planned to implement irrigation projects, with the help of various funding agencies and by its own budget in order to solve food security problems. The Amhara Water irrigation and energy Bureau is the sole agent or client to implement the engineering identification, study and design, and later construction. Supervision supported small scale irrigation schemes following various approaches; on force and/or contractual modalities. On the one force modalities, the Amhara Design and Supervision Works Enterprise (ADSWE) have received several such schemes to provide consultancy services; study and design. One of those projects that have been given attention is the Awajo river diversion irrigation project.

For the design of various stable and cost effective engineering structures in different parts of the project, the areas were investigated to gather engineering geological and geotechnical input data. This engineering geological feasibility study was carried out from May, 2007EC.

Geotechnical investigations are performed to evaluate those geologic, and soil conditions that affect the safety, cost effectiveness, design and excavation of the proposed project. The fact that insufficient, faulty interpretation of results, or failure to portray results in a clearly understandable manner may contribute to inappropriate designs, delay in construction schedules, costly construction modifications, use of sub-standard borrow material, environmental damage to the site, post construction remedial work and even failure of a structure and subsequent litigation. Hence, geotechnical investigation is usually thought of as the backbone of engineering structure design.

Investigations performed to determine the geologic setting of the project include the geology (nature and behavior of rock materials), soil and rock behaviors, and seismic conditions. This parameters influence the construction site selection through the control of the characteristics of the foundation soil and rocks, geotechnical conditions, project safety, design, and construction, critical geomorphic processes and source of natural construction materials.

Based on the above facts, the site selection criteria and factors that should be taken in to account in studying the diversion site are as listed below:

- Nature of subsurface material at the diversion axis and potential canal route with the fact that they should be sound and resistant to bear the load imposed by the weight of the overlying materials, including the structures to be built.
- Suitability (shape and depth) and stability of the valley slopes at the abutment and capability to bear the lateral pressure imposed by the nearby soil material.
- Nature of the abutment ground material in reaction with water (solution resistant rock, soil, or nature of clay material).
- Uniformity of geological formations, geological structures and their continuity.
- Topographic conditions of the river both upstream and downstream of the anticipated intake axis.
- Relation of the anticipated diversion axis with the potential canal route and the available command area.
- Availability and quality of naturally occurring construction materials within an economically justified distance from the project.

1.2 Location and accessibility

The Awajo Irrigation project headwork site is located in the National State of the Amhara Region, north showa zone, mojana wedera Woreda, quaretz Kebele. The geographic coordinates of the site are defined by the UTM location of 1099702mN, 0575992mE and river bed elevation of 2492m above sea level.

The project Headwork site is accessed through 21km dry weathered road from seladigayi town and then through 9km on foot, along steep to moderate slope ground up the head work site.

1.3 Objective

The study is focused to give sufficient pertinent information on the geologic formations and their suitability for proposed construction. Consequently, the specific objectives to be addressed within this study are:

- Developing overall approach on the geological parameters through investigation of surface and subsurface geological conditions of the site to provide geotechnical inputs needed for the design of the diversion structure and main canal, so that the project becomes cost effective, durable and socially acceptable.

- Explaining the local geology and developing findings to the rock units and structural patterns on the context of the local area of interest.
- Locating the specific sites for the construction of the headwork and potential canal routes, which are resolute on the basis of:
 - ✓ Determining the geotechnical conditions of the headwork axis and potential canal routes.
 - ✓ Defining the distribution of formations in space.
 - ✓ Suitability of the land and stability of the foundation material for the construction and establishment of stable water tight zone.
 - ✓ Strength, workability and permeability of the existing formations.
 - ✓ Providing pertinent and reasonable information for post survey data analysis in the design and construction of the proposed structures.
- Determining the qualities and identifying the sources of naturally available construction materials within an economically feasible distance from the construction site.
- Defining ground water condition and its influence on the structures.

1.4 Approach and methodology used

A technical and systematic procedure of geotechnical investigation includes:-

- Taking Test pits along the potential canal routes, headwork axis, and taking representative samples from them for laboratory testing,
- Observing surfaces, river cuts and gully exposures to identify the nature of lithological units and their depositional history by making geological traverses.

Making several options both upstream and downstream of the headwork axis to select the best diversion site and include maximum irrigable command area, so that the project will be cost effective, durable and sanctioned by the local community.

1.5 Material used

During this feasibility stage investigation, the following methods of exploratory techniques, materials, equipment's have been implemented:

Techniques:

- ✓ By drilling and test pit boring, boreholes along proposed wire axis and around the head work site and canal route have been done.
- ✓ Soil Laboratory Testing, classification and gradation, permeability, proctor compaction. Shear strength, consolidation, natural moisture, and specific gravity tests have been conducted on different samples taken from foundation, and construction materials.
- ✓ The tests have been done in the Bureau's material Testing Service. During feasibility study the following materials are used;
 - Global position system(Gps)
 - measuring tap meter
 - digital camera
 - sample box

2 Geology

2.1 Regional geology

The Ethiopian volcanic province is characterized by two volcanic series: the Tertiary Trap Series of the high plateau and the recent (Pliocene-Quaternary) Aden volcanic series. Contemporaneous with the major uplift of the Horn of Africa, extrusion occurred from fissures and centres of immense quantities of flood lavas (Traps). These lavas covered the greater part of the Mesozoic rocks in Ethiopia.

The Trap Series consists of a very thick succession of lava flows, chiefly flood basalts (Traps), but with Trachytes and Rhyolites occurring especially near the top of the Series. The Trap Series essentially pre-dates the Rift faulting and therefore forms the great heights of the Ethiopian plateau. The Aden Volcanic Series post-dated the Rift faulting and is largely confined to the floor of the Rift System where it lies on the Trap Series (Mohr, 1962).

According to Blandford (1869), three volcanic units are distinguishable: the Trap Series of the plateau subdivided into the Ashangi and the Magdala groups; and the Aden Series. The Ashangi group includes predominantly basaltic rocks while the overlying Magdala group is essentially Silicic. Young (Quaternary) volcanic rocks were designated as the Aden Series (Kazmin, 1962).

There are three volcanic cycles for the north eastern part of the western plateau, Zanettin and Justin-Visentin (1975):

- First cycle: pre-Oligocene volcanic activity giving rise to the outpouring of the Ashangi basalts that cover the upper sandstone unit.
- Second cycle: after a long quiescence, the second volcanic cycle began to erupt in the lower middle Oligocene and cover the Ashangi penplain. This cycle started first with flood basalts (Aiba basalts) and later with large quantities of ignimbrites (alkaline rhyolites and trachytes) with variable quantities of interbedded basalts, collectively known as the Alaji rhyolites. This cycle culminated in the emission of large quantities of basalt, termed Tarmaber basalts, that cover most of the Alaji rhyolites.
- The third cycle is confined more to the rift and its periphery and also to the Lake Tana Area of Plio-Pleistocene age.

The Trap Series, consisting of Asahngi, Aiba, Alaji and Tarmaber formations, make up the regional rock units from bottom to top in the north eastern part of the western plateau.

The Ashangi formation is tholeiitic and/or basalts (Zenettin et al., 1978). The Aiba basalts, which overlie the lower Ashangi basalts unconformably, are transitional between tholeiitic and alkaline basalts. The Alaji rhyolites and basalts, which are a product of fissural volcanism, are dominantly Silicic and are made up of alkaline rhyolites and Sodic ignimbrites intercalated with variable quantities of transitional basalts. Tarmaber basalts are products of central eruption and are alkaline in composition.

The Tarmaber Series consists of lenticular basalts with a large amount of tuffs, scoriaceous lava flows and typical red paleosoils (Merla et al., 1973). The Tarmaber basalt is a thick sequence that reaches 1,000 m and when thicker, characterizes volcanic centres such as Guna Terara. The Tarmaber basalts, which directly overlie the Ashangi basalts (in northwestern Ethiopia), mark the Tertiary volcanic cycle in the region. Based on a few sections from the eastern and southern part of the plateau, the above was assumed to be valid until recent times for the entire western plateau. However, according to the recent works of Pik et al. (1998), this stratigraphy is not valid for the whole north western plateau. Furthermore, field observations of the group on well exposed escarpments suggest the existence of a continuous lava sequence from the base to the

top of the plateau, rather than the piling of two or more successive and stratigraphically distinct units as suggested for the north eastern part of the plateau.

Based on this recent study in the north western plateau, from samples collected from bottom to top of the lava pile in a section located north eastern of Gondar (near the study area), the lavas mostly consist of basalts, except on the top of the plateau, where ignimbrite tuffs, a few metres thick, are exposed.

2.2 Local geology

The solid geology (hard rock geology) that underlain the project area is portion of the Cenozoic volcanic formations that characterize the Ethiopian Western Highland. These formations are known to be various lava and pyroclastic flows dominated by basalt rocks and rhyolites. At the project area there are two types rock are existed. These are the result of lava flow during the Tertiary volcanic eruptions. From younger to old, the rock types are

I. Rhyolite

II. Aphanitic basalt

The younger unit of the site is observed at the upper slope and peak of surrounding hills and mountain chains. It is characterized by very fine texture. It has light yellow grey color. At most exposures in the area the unit is affected by closely spaced joints, which result in large isolated blocks of the rock.

The older rock unit presently observed at some portion of the stream bed and banks, including at headwork site, and slopes of some of surrounding hills. It has characteristic dark color, and fine texture. The rock unit has been affected by erratically oriented joints and slight degree of weathering at most places. These secondary phenomena plays significant role for its geotechnical characteristics.

Following the Tertiary volcanic basaltic rock formation, the area has been affected by different surface processes of weathering, and sediment transportation that superficial soil are developed and cover some areas of the site. These superficial soil materials observed at the site are classified into three major units for the sake of this project. These are:-

- a. Silt, with some clay, Floodplain Deposit,

- b. Sand with Gravels and boulders, recent loose alluvium,
- c. High Plastic Clay, black cotton Clay, residual soil

The distributions and geotechnical characteristics of the various superficial materials found in the project area with their influence in the engineering design of various structures are described in section 4.

3 Seismicity condition of the area

Earthquake is the result of a sudden release of energy in the earth's crust that creates seismic waves. The seismicity of an area refers to the frequency, type and size of earthquakes experienced over a long period of time.

To construct effective and long-lasting hydraulic structures, assessments on susceptibility to seismic hazards are fundamental issues. Therefore, the degree of seismicity of the area should be taken in to account with great emphasis as an important design parameter by evaluating the seismic nature of the area from history and records of previous earthquakes and knowledge of local geology. However the seismic susceptibility study is usually made with the application of secondary data from the national geophysics and geo-observatory data sources. The most famous edition in the Ethiopian context is the seismic susceptibility map of the country by Laike Mariam Asfaw, 1986. According to the seismic hazard map of Ethiopia, the country has been subdivided in to five seismic Zones as: Zone (o), Zone (1), Zone (2), Zone (3) and Zone (4), the no hazard, the low hazard, the moderate hazard, the higher hazard and the highest hazard zones, respectively. The Awajo intake project is found in Zone (2).

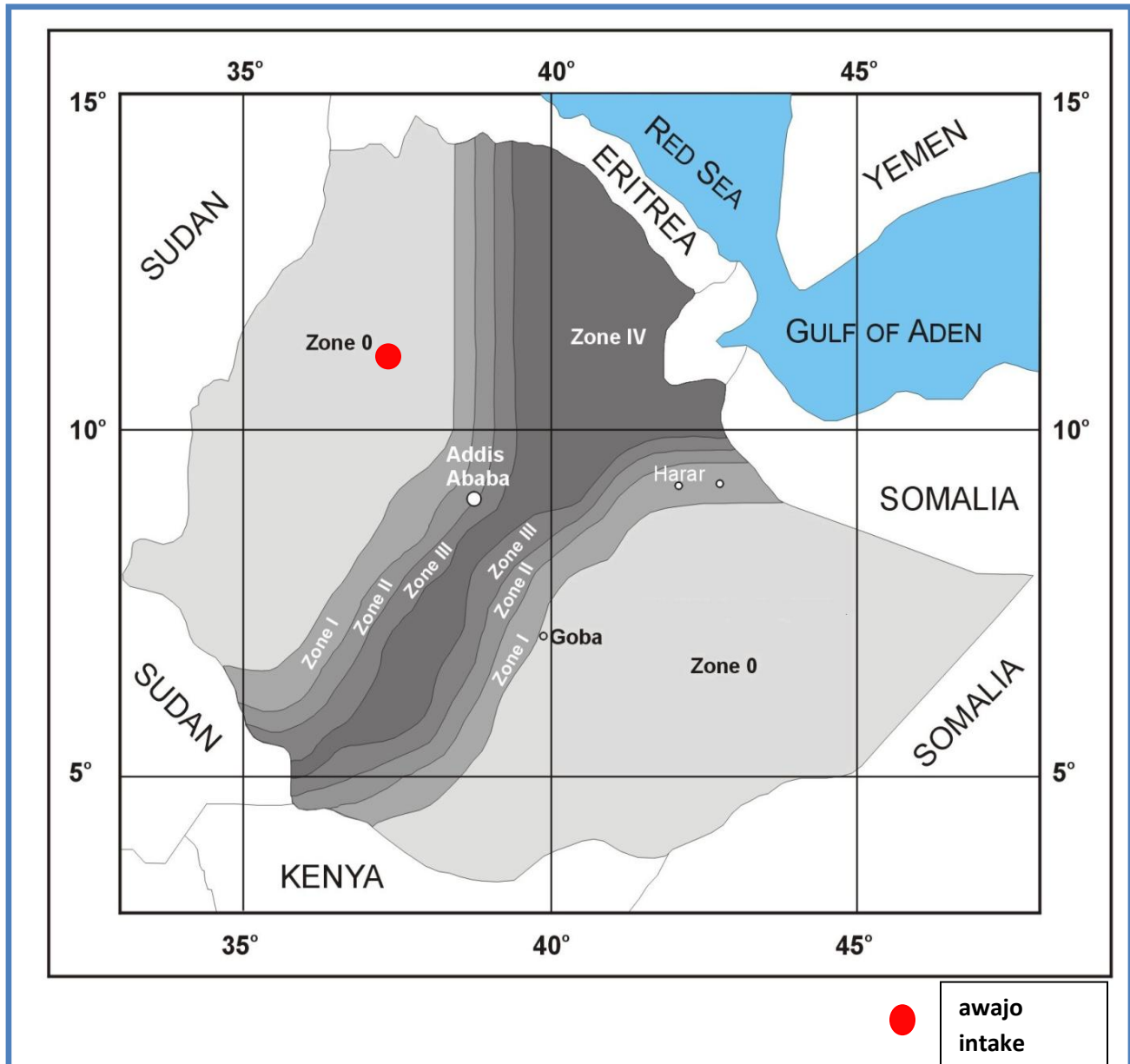


Figure 1 Seismic Risk Maps of Ethiopia, 99 Year of Return Period

4 Engineering Geological and Geo-technical Investigation

This part emphasizes on the details of engineering geology and geo-technical aspects of the project focusing on strength and permeability characteristics of the underlying formations over which proposed structures lies, mainly at headwork and along main canal route. In addition to this, required natural construction materials' source areas and their suitability conditions are discussed.

4.1 Headwork Site

For this project a simple river bed level intake structure has been proposed for diverting the water to the main canal. The headwork site geological surface and subsurface conditions have been investigated based on the nature of the proposed structure. At the site and immediate vicinity, the stream flows along moderate slope course and its bed is mainly covered with recently deposited alluvial sediments. These sediments are dominated with cobbles and boulders at the top and become sand and gravel size fragments to depth. On the other hand, the banks of the stream at the headwork site are made up of different geologic materials; most part of the right bank is made up of old alluvial sediment of pebbles and cobbles cemented by silt/clay materials. The left bank, on the contrary, is made up of mainly rock body; basalt. The detail geologic nature of the banks, and bed of the stream along the headwork axis and immediate vicinity are described and their potential geotechnical influence on the proposed structures also discerned/detected below, with remedial measures.

4.2 Left Bank

At the proposed headwork axis and immediate vicinities, the left bank forms relatively moderately to gentle slope topography. From surface observation, the bank is made up of two basic geological units. The unit is silt- sand and aphanitic basalt. For geotechnical purpose, there are two distinct layers observed at the bank. These are top silt sand deposit and underlain massive basalt rock. The slope and peak areas of the bank are covered by the silt sand deposit material. This top unit has thickness ranges of 1m to 1.5m, decreasing towards the bank foot. It is weak and loose horizon. It is flood plain deposit having gray- brown color. It has stiff consistency and dry moisture content. The bank is now affected by flood erosion that active eroded surfaces are visible. So, it is necessary to provide some bank protection structures to prevent ongoing bank erosion.



Plate 1 Left Bank of Awajo Intake

4.3 Stream Bed

At the proposed headwork site the stream bed or course is well defined, nearly straight, and shows rough surface due to recent sediment accumulations and undulating appearance of bedrock outcrops. Along the intake axis, the bed is made up of two basically different geologic materials, as seen from surface observation. These are **recently deposited alluvial coarse grained sediments**, and **underling bedrock**.

The central and left areas of the bed are totally covered with the alluvial deposits. The bedrock is totally covered with the sediments at the central and left areas of the stream bed. The alluvial sediment observed at the center, left and right beds are composed of silt-sand with significant amount of gravel, boulder and cobbles. It is loose, dry (at the time of study) and easily workable. From surface geological understanding of the area, the thickness of this sediment is expected in the range 2 to 2.5m. This coarser sediment is believed to be underlain by the bedrock extension that exposed at the right bed which is clearly observed in the downstream beds. On the other hand, the bedrock found at stream beds bed is affected by slight degree of weathering and

erratically oriented joints. The foundation of the proposed intake structure; therefore, can be lie on the bedrock after removing the top 2m to 2.5m deposits of silt sand at left side. In addition to this, the foundation of the bed bar (if proposed), along the axis should lie on the bedrock, after excavating the top alluvial deposit covering the center, and left bed of the river.



Plate 2 Awajo Intake River Center

4.4 Right Bank

At the proposed headwork axis and immediate vicinities, the right bank forms relatively moderately to gentle slope topography. From surface observation, the bank is made up of two basic geological units. The unit is silt- sand and aphanatic basalt. For geotechnical purpose, there are two distinct layers observed at the bank. These are top silt sand deposit and underlain massive basalt rock. The slope and peak areas of the bank are covered by the silt sand deposit material. This top unit has thickness ranges of 1.5m to 2m, decreasing towards the bank foot. It is weak and loose horizon. It is flood plain deposit having gray- brown color. It has stiff consistency and dry moisture content. The bank is now affected by flood erosion that active

eroded surfaces are visible. So, it is necessary to provide some bank protection structures to prevent ongoing bank erosion.



Plate 3 Right Banks of Awajo River

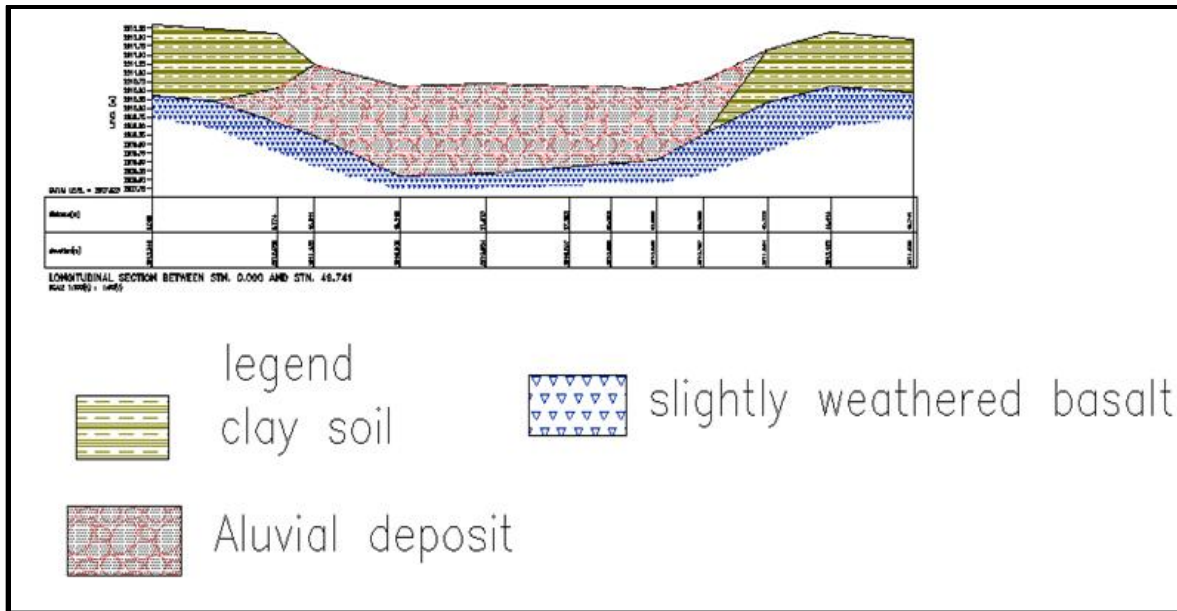


Figure 2 Geological X-Section of Awajo Intake Axis

5 Main Canal Route

For this particular project, the main canal route has length of about 3.6km and outlets in the left side of the river. Within this length, the canal passes different geologic materials, which varies both surficial and to depth. The distribution of the geologic materials with respect to the canal route, and their characteristics, especially permeability, stability and workability have been investigated during the field work using only visual inspection due to the rocks are exposed at the surface and natural cuts of exposures as these features reveals mostly the depth to bedrock.

Based on the findings of the surface geological investigations and with reference to design chain ages and also natural existing features, the canal route ground conditions have been described in the succeeding sections.

- **From outlet (0+000m) to about 0+113m** (within the left bank), the canal passes a foot of a ridge, which is portion of the left bank of the river. This route is characterized by low plastic clay soil and an out wash deposit which comes forms the hill side at the left bank direction with instable slope and there is an out wash deposit the comes from nearby ridges and needs protection work protect the canal from the flood. It is easily workable, loose, and pervious only for the top section of the soil units. The thickness of this layer is in the range of 2m to 2.5m. It is stiff, dry, workable and imperious horizon. It is underlain by jointed rock of

aphanatic basalt. If the canal section lies below the top soil (2 to 2.5m from surface) significant seepage is expected through the jointed and weathered rock units, and so lining is required.

- **From about 0+113m to 0+2203m** the ground surface is covered with low plastic clay soil intermixed with some colluvium boulders coming from nearby hill slopes. The thickness of this layer is in the range of 1m to 1.5m. It is stiff, dry, workable and impervious horizon. It is underlain by jointed rock of rhyolite. If the canal section lies below the top soil (1m to 1.5m from surface) significant seepage is expected through the jointed and weathered rock units, and so lining is required. Along this particular reach especially the last 200m (from the above ranges) there is observed land instability. Within these range the canal needs protection work. Within this sub-reach, two gullies will be crossed by the main canal. The first gully is located at co-ordinates of about 575520mE and 1099935mN with elevation of 2496m). Both banks of the gully are made up of similar geologic materials. The top about 2m is characterized by low plastic clay soil having stiff consistency. It is dry and impervious horizon. It is underlain by highly weathered Rhyolite rock. Both banks are now not affected by active flood erosion. On the other hand, the gully bed is covered with gravels and transported deposited by the gully. The second gully is found at co-ordinates of 575297mE and 1100146mN). Both banks of the gully are made up of similar geologic materials. The top about 2m is characterized by low plastic clay soil having stiff consistency. It is dry and impervious horizon. It is underlain by highly weathered Rhyolite rock. Both banks are now so stable that there is no active bank erosion. On the other hand, the gully bed is covered with gravels and transported deposited by the gully.
- **From 2203-2353m.** The route is covered by low plastic clay soil having brown color. It is 0.5 to 1m thick, stiff, easily workable and impervious. It is underlain by closely jointed and highly weathered Rhyolitic bedrock. This lower unit is pervious, stable and workable at least some 2 to 3m thickness. If the canal section lies within the lower jointed and weathered rock, lining is required.
- **From 2353m to end.** The route is covered by medium plastic clay soil having dark brown color. It is more than 2m thickness and the bed rocks are may be existed after 3m. It is stiff, easily workable and impervious. Within these canal route range stable slope, pervious, and workable at least some 2 to 3m thickness. If the canal section lies within the lower bed rock,

lining is required, whereas it is designed within the top clay soil, an earthen type can be proposed.

6 Natural Construction Materials

During the site investigation, natural construction materials required for the construction of the various proposed engineering structures at the headwork and within the farmland have been assessed, and possible quarry sites and borrow areas have been identified within the vicinity of the area as much as possible. In addition to the identification, the quality, quantity, accessibility condition and ownership of each proposed production sites have also been studied and described in this report; on separate sub-sections below. The natural materials required for the construction of the proposed hydraulic structures include rock for masonry stones, aggregates (both coarse and fine), impervious soil for fill and/or lining, backfill soil, and water.

6.1 Rock Quarry

Quarry site that can be used for production of rock for masonry stone and crushed coarse aggregates has been assessed during the field work session within the vicinity of the project area at economic distance for hauling. One possible quarry site has been identified along the right side ridge following the main canal route from chain age 100m to 2000m. Here moderately weathered rhyolite rock exposed and forms a continuous ridge parallel to the main canal. It is believed that below this weathered rock, fresh portion of the rock is found and can be used for the intended purpose.

In this field study, another sources for rock also proposed. The first one is from the stream bed of awajo River. The bed is covered with very large quantity of boulders to cobble sized rocks of different types. From the headwork to about 1 to 2km distance especially in the up-stream direction large amount of such sediments can be collected by considering only strong black cored basaltic rock fragments. These fragments are strong, fresh and used for intended purpose.

6.2 Fine Aggregates

Borrow areas for fine aggregate or natural sand have been assessed starting from the project stream itself. Natural deposits of such materials couldn't be found when assessed within the beds of the stream in the project area; rather very coarser sediments and rock exposures are found covering almost the entire bed of the Awajo stream. Seeing to this nature of the stream, other

distant streams have been explored to identify the best source areas for fine aggregate or natural sand that can be used for this particular project. During exploration of this natural sand, at a distant one stream was identified as a possible source of fine sand. The stream is known as 'Jewuha'. It is located at about 120km from the project site, within Kewuat Woreda. A potential source area within the Jewuha stream bed is located alongside the main Showa Robit-Ataye Asphalt road, near to a small village of Jewuha. Here, there are local legalized sand miners associations, and the sand is acquired from them through negotiation and agreement.

Both visual investigation and laboratory testing of the sand deposit found in the proposed area have been done. In the area good quantity, which suffices the need of this project, is available. The deposits are dominated by sand sized transported alluvial sediments, though some amount of fines and over sizes are also observed. The individual grains of sand are mainly originated from basalt rock and reveals high crushing resistant that the sand has good quality in this respect.

6.3 Water

Water for construction purposes can be getting from the project stream, awajo itself. The stream is perennial that throughout the year there is some amount of water flow along its course. During this field time the stream flow was about 200L/second. The stream water originates from mainly fractured basaltic rock aquifer, which is portion of the Ethiopian western highland that is known to discharge good quality potable water.

7 Conclusions and Recommendation

7.1 Conclusion

- Geological and geotechnical conditions of the foundation area at the headwork site, along the proposed main canal route and associated drainage crossing sites are the most relevant parameters which are useful for the design of hydraulic structures. Accordingly this investigation has been conducted for awajo diversion Small scale irrigation project. Furthermore, nearby source areas for natural construction materials have also been assessed, for the specified project.
- This geological and geotechnical investigation has been carried out by gathering sub surface information: by taking traverse along existing canal, test pits, exposure at gullies and river banks.

7.2 Recommendation

- At the proposed headwork site, the bedrock is expected at a reasonable depth (2 to 2.5m). The bed rock has sufficient bearing capacity to support such proposed intake structure. Hence the structure can be founded on the basaltic bedrock.
- During the site investigation the actual depth of this deposit material thick varies from center to banks and more than 2m diameter size boulder material deposited with active river bed. So that, with active stream bed 2.5, right bank 1.5 to 2m, left bank 1 to 1.5m have this deposited material thickness and below this deposit layer basaltic rocks are exposed. Due to this the cutoff trench should be lies on this basaltic rock accordingly the overburden deposit thickness.
- The left bank of Awajo River is characterized by erodible clay soil. It is now affected by flood erosion. It is necessary to provide bank protection work.

8 ANNEXTURE-1

Geologic X-Section along the Intake Axis