HYDROGEOLOGY OF DEBRE ZEIT AREA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES

ADDIS ABABA UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE

OF MASTERS OF SCIENCE IN GEOLOGY

BY

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JUNE 1992

ABSTRACT

The investigated area is located east of Addis Ababa on the western border of the main Ethiopian rift valley. Being part of the Ethiopian rift system, it is characterized by Plio-Quaternary volcanism which gave rise to trachytic domes, rhyolitic flows, and rhyolitic ignimbrites in the highly elevated part of the area while olivine basaltic flows and surge deposits in the lower elevated plain area. The maximum point in the area is represented by Mt. Yerer with an elevation of 3100 m above sea level. The plain area has an average elevation of 1900 m above sea level.

The yearly minimum possible rainfall average in the area is 859.9 mm, the actual and potential evapotranspiration is 606.2 and 857.1 mm respectivly and the runoff that leaves the basinis 25.568 x 10^6 m^3 of water. From these determinations, the amount of infiltrated water in the area is calculated and the value is 54.39 x 10^6 m^3.

The hydraulic parameters, transmissivity and hydraulic conductivity are determined based on the pumping test information obtained for few wells, The transmissivity and permeability of the rocks found in the central part of the area is $0.9 \times 10^{-3} m^2/s$ and 4.05×10^{-3} cm/s respectively.

But for the aquifers found west of the area, the former is $8.8 \times 10^{-5} m^2$ and the latter is 1.5×10^{-4} cm/s. But the storage coefficient is not calculated because of the absence of observation wells in which the effect of further drowdown is observed.

Because of the lack of bore wells in the northern part of the area, a thorough study of the actual variation of groundwater level was not possilble. But based on the available static level data, for the central part of the area, appropriate groundwater level contour lines are constructed.

The chemical analyses result showed that most waters are calcium-magnesium-bicarbonate type.

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ACKNOWLEDGEMENT

I would like to express my deep appreciation for the constant supervision to my advisor prof. A. Vernier. I am also grateful to prof. S. Grassi for his constructive comments. Special thanks go to Ato Alula Damte, Ato Worash Getaneh, Ato Semu Mitiku, Ato Seyoum Zenebe, Ato Tesfaye Chernet, Ato Mulatu Tebeje and Ato Muluneh for their invaluable help and encouragement.

I thank prof. Getaneh Assefa for the help he rendered in solving the stratigraphic problems.

I am indebted to Mr.P.Bucci, an expert in Water Supply and Sewerage Authority(WSSA), for his constant encouragement, Ato Ezra, Ato Ayana, W/o Kibra for their help in chemical analysis, Ato Shimels (driver) and for the rest WSSA and EWWCA workers.

Finally, I acknowledge the German Academic Exchange Service(DAAD), for granting me incountry scholarship

1. INTRODUCTION

1.1 Objectives

One of the most important issues for government decision makers in developing countries is the proper solution of water supply problems through the implementation of research programmes on surface and groundwaters in order to satisify the present and future needs of population, agriculture and industry.

The most unavoidable condition for the growth and development of towns, cities etc.is certainly the progressive fulfillment of its urgent water needs of whatever kind and from whatever source.

In the Debre Zeit area, which is the subject of the present thesis, about ten farmers' village and two towns are present. According to the Central Statistical Office, the present number of population in Debre Zeit and Dukem towns is about 120 000, where as farmers which live in 10 villages are about 300 000, about 5% of them live scattered in the area.

Taking into account the growth rate of Ethiopian population (2.95% per year), a great number of residents is to be expected in the next 30 years (about 1 million). Therefore a large amount of water will be required to satisfy their necessities. Since the intermittent streams which are found in the area serve the farmers only during the rainy season, a programme for groundwater exploitation to fulfill the water demand of such fast growing population, is necessary.

From the agricultural point of view, the only crop which is largely farmed is *Teff*, while backyard vegetables and chick-pea are present only in some places. Since the area is suitable for large scale mechanized farming and crop rotation, large amount of water will be necessary, which will be provided either by surface water or groundwater.

In the area under investigation, there are few small scale industries in addition to two Flour Mills. Since Debre Zeit is close to Addis Ababa, large factories are supposed to be constructed in the future. This makes it necessary to know the groundwater potential of the area.

The aims of the present study are :

1. to verify the potential of the surface waters coming from Mt. Yerer and to evaluate the possibility of their partial utilization and suggest the most accurate methodologies to intercept them by dams or artificial channels;
2. to verify the occurrence of important groundwater reservoirs within unconfined or confined aquifers which could be

utilized in addition or an alternative to the surface waters;

3. to calculate the water budget for the corresponding hydrogeological basin;

4. to check the quality of surface waters and groundwater based on InternationalStandared Quality requirement;

5. to suggest the water management of the area.

1.2 LOCATION AND EXTENT OF THE INVESTIGATED AREA

The studied area is located 47 km. east of Addis Ababa on the main road between Addis Ababa and Nazreth. It lies on the western border of the Main Ethiopian Rift Valley.It is bounded by $8^{\circ}39'24''$N - $8^{\circ}54'12''$N latitude and $38^{\circ}53'54''$E - $39^{\circ}02'06''$E longitude.

The investigated area has a total surface of 448 sq.km, while the one referred to the main catchment basin is about 269.4 sq.km.

The western boundary is given by the water divide which passes through Dukem town, from north by Mt.Yerer, from east by the junction of Wodecha and Mojo river and from south by the rhyolite hill found nearby Mt.Sokoru.

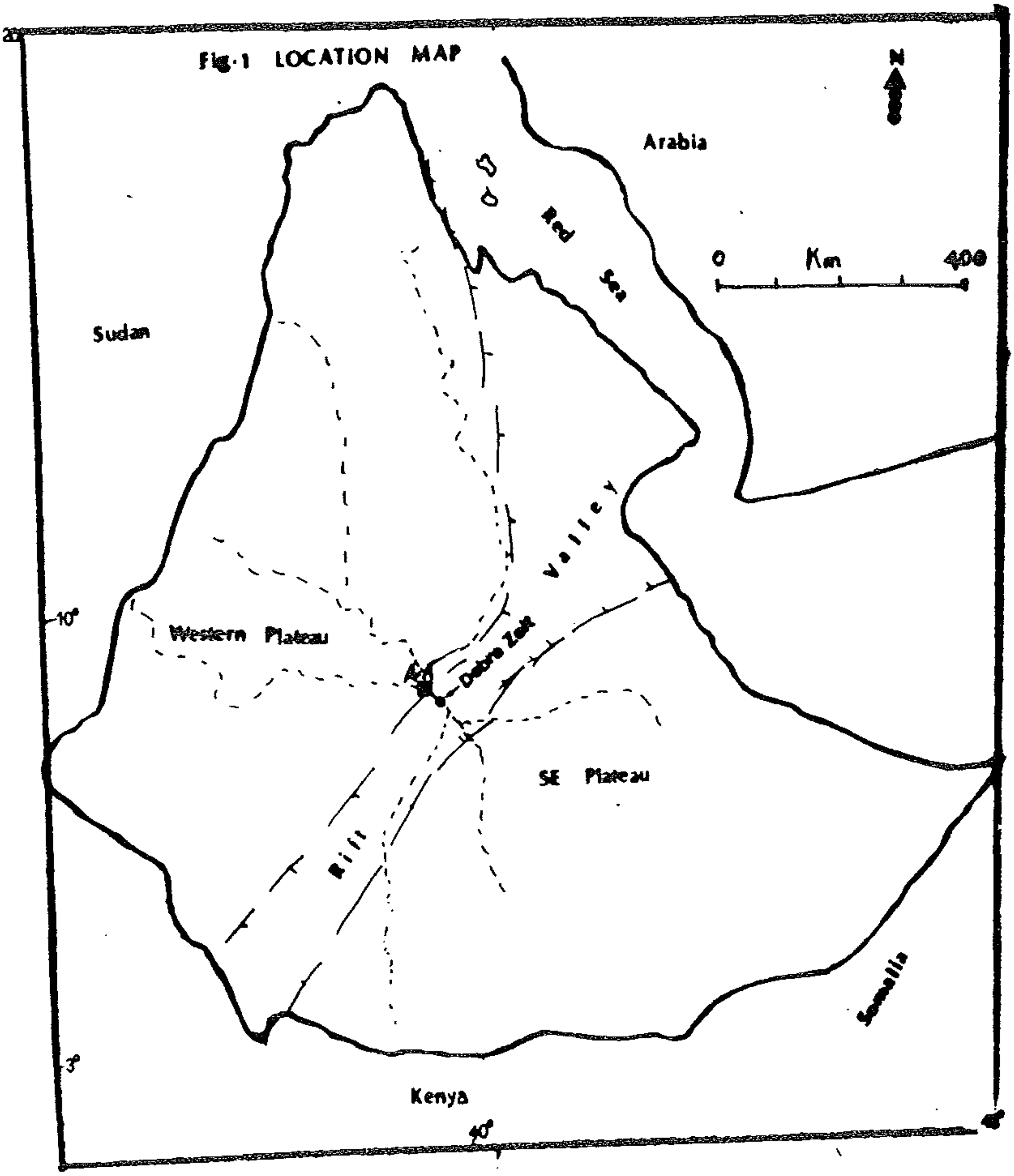


Fig.1 LOCATION MAP

1.3 PHYSIOGRAPHY AND DRAINAGE.

The studied area is characterized by an extensive Plio - Quaternary volcanism which gave rise to the peculiar geomorphology of volcanic environments and is deeply modified by alluvial deposition.

About 60% of the area is rather flat with gentle slopes,while the rest is characterized by mountains and hills. Clear elevation contrast exists between the Mt.Yerer (3100 m a.s.l.) and the flat area with mean height of 1900 m a.s.l.

The rock bodies, affected by a severe erosion, form the Mt. Sokoru and isolated hills with flat topped surface. The most important chains are found in the north western border and in the southern part of the area. In particular Mt. Yerer is characterized by steep slope and rough top surface. While some hills show steep slopes and gentle pedimont surface often covered by a thin layer of coluvial deposits.

Within the area, numerous cinder and spatter cones occur as well as craters of old major volcanic centers.

Phreatomagmatic tuff rings and lake filled maars are also frequent.They have a diameter of about 1 km, steep sides and flat bottoms.

At places, erosion cut the water shades forming gullies characterized by a large depth at the top which decreases downstream.This is due to the high concentration of runoff in the upper part which rapidly decreases towards the flat area. Mainly originated from Mt. Yerer and surrounding highlands, many intermittent streams flow down to Debre Zeit. While some of them sink in the alluvial deposits, the others are tributaries of the Wodecha river, the only perennial river which crosses the studied area collecting also the waters coming from the western branch of the wider hydrographic basin of the Mojo river.

While the northern drainage pattern shows a well developed dendritic pattern, the southern one is not well defined because the fluvial segments have not yet reached their latest stage of development.

Probably due to a local tectonical effect, all intermittent streams and Wodecha river show a southerly trend towards Debre Zeit, while all the other tributaries of Mojo river show a north-easterly trend.

The vegetation cover is mostly concentrated in the mountain sides of Mt. Yerer as shrubs and bushes, and scarcely distributed in the rest part of the area, where isolated Acacia and Eucalyptus trees together with scattered bushes and other kind of plants are found. This is mainly due to intensive deforestation carried out from immemorial time by the local people for various uses.

1.4 PREVIOUS WORK

Large number of articles have been published concerning the Main Ethiopian Rift and about the geology of Addis Ababa area. However few aspects of the geology of Debre Zeit area was discussed in these publications with connection to the Rift and its complex structure.

Geologists who worked in the immediate vicinity includes Mohr (1961), in which the geology and origin of explosion crater lakes is discussed; Haileselasie Girmay and Getaneh Assefa(1989), includes the geology and the stratigraphy of the volcanic rocks of the area, and Morton (1975), which lists the age of some of the rocks found in the area. Some others gives few idea about its geology: Merla *et al* (1973)", Mohr(1971), and Mohr (1985)".

Only one specific work on the area,by Igzaw Solomon (1974)" Short report on hydrogeology of Debre Zeit area", contains only the metereological data for the last ten years and some water chemical analysis data.

1.5 METHODOLOGICAL APPROACH OF THE PRESENT WORK

Following up a wide demographic analysis together with a detailed socio-economic study of the area and taking into account the previous literature regarding the peculiar purpose of the thesis, the present work started in the begining of 1991 with a geological investigation aimed to differentiate and map the various lithological units occuring in the area on 1:25,000 scale in addition to an accurate aerial photo interpretation in laboratory.

During the field work several rock samples have been collected for thin-section studies.

Starting from May 1991 up to February 1992 an intensive hydrogeological investigation has been carried out by means of the following operations:

- collection of the available hydrological data of the studied area and surroundings;
- delination of the catchment area and evaluation of the corresponding hydrological balance by means of the following equation: $P = E + R + I$
  where P is the precipitation, E is the evapotranspiration, R is the runoff and I is the infiltration, all expressed in mm or in %.
- identification of the hydrogeological basin on the basis of the hypothesized groundwater circulation within the various lithological units characterized by different hydraulic properties;
- inventory of the springs, dug wells and bore holes;
- phreatimetric measurements and construction of piezometric contour lines;

- evaluation of the hydraulic parameters of the occuring aquifers (K, T, and S) by means of logs and pumping and recovery tests in the available productive wells;

- characterization of the physical and chemical parameters of the surface waters and groundwater found in the area with measurements *in situ* (pH, temperature and electrical conductivity) and laboratory analysis of samples based on the quality standards given by the World Health Organization (WHO), the United States Public Health Service (USPHS) and the National Academy of Science and Engineering(NASE);

-evaluation of the total hydraulic productivity of the complex hydrogeological basin.

2. GEOLOGICAL FRAMEWORK OF THE AREA

2.1 GEOLOGICAL HISTORY AND SETTING OF THE INVESTIGATED AREA AND SURROUNDINGS

Ethiopia is subdivided into three physiographic regions: the western plateau, the Ethiopian Rift Valley and the south-eastern plateau.

The investigated area is located on the western margin of the Main Ethiopian Rift valley.

The rift system which forms the Ethiopian rift valley is known to be one of the latest structural features of the earth's crust being also related to the rift valley pattern of East Africa. The Main Ethiopian Rift runs NNE - SSW through the southern half of Ethiopia, widening out NE towards the Afar region and separating Ethiopian plateau to the west from the Somalian plateau to the east. According to Zanettin *et al* (1980), the volcanic rocks related to the rift have been outpoured after the formation of the same rift, when fissural volcanism in the related plateau had died out.

Since 8-9 myrs ago, the volcanism has shown different features in the Afar and Ethiopian rift, in accordance with their different stages of structural evolution.In fact there is a general rise in evolution of the floor of the Main Ethiopian Rift from South to North. Unlike the Main

Ethiopian Rift, Afar tends to be a featureless and monotonously flat plain, relieved only by young volcanic cones and fresh graben (Mohr, 1967).

In the Ethiopian Rift valley basalts and rhyolites are the predominant rocks with some intercalation of trachytes and pyroclastics.

From Addis Ababa down to the rift floor at Mojo,a great number of NE- SW faults occur,upthrown NW,the most important being the Dukem fault (Mohr 1967).

Mohr (1961) postulated that the basal rocks in the Debre Zeit region are probably constituted by Trap Series basaltic lavas even if not exposed in the vicinity of the area, being covered by more recent thick lavas and pyroclastics.

Climaxed about 5 mys ago and lasted up to 1.5 mys (Zanettin et al 1980), intensive volcanic activity, characterized by various periods of quiescence, occured in the Ethiopian Rift, which gave rise to a large scale acidic volcanics (trachytes and rhyolites) constituting the so called Balchi formation (Zanettin and Justin-Visentin, 1974).

Many large central volcanoes such as Wochacha (4.5mys, Mohr 1960), and Yerer (3.5mys,Morton 1975) etc.were built during Balchi volcanism. Merla *et al* (1973) confirmed that the last phase of the Trap Series was marked by the extrusion of alkaline silicic lavas of Yerer which may post date the major rift faulting.

According to Zanettin *et al* (1980), the basaltic volcanism followed the Balchi ignimbritic activity is represented by the Bishoftu formation ranging from 4 - 3 mys to 1.5 - 1 mys and is coeval with the fissural Bofa basalt (Kazmin *et al* 1979).

Furthermore, Mohr (1961) postulated the occurrence of a quaternary extensive volcanic activity which has given rise to five maars and some cinder cones.

Such a volcanic activity is supposed to be much more recent than the late Trap Series activity of the Yerer, as it has been confirmed by Mohr (1961, 1967), in his studies on the calcareous materials found in the lake Hora Hado which contains plants remains and molluscan shells, in fact he concluded that the material was deposited from evaporating water (the source of calcium carbonate was from hot spring) at the end of 2^{nd} pluvial period.It means that the age of the explosion craters is approximately 10,000 yrs. Taking into consideration the general NNE-SSW rift alignment and the occurrence of the Wonji fault belt near by the studied area, it is possible to suppose that the NNE alignment of the explosion craters may be caused due to the cracks or fractures formed by the effect of Wonji fault system.

2.2 GEOLOGY OF THE INVESTIGATED AREA

In the investigated area the following lithologic units have been mainly identified: trachytic domes, rhyolitic flows, rhyolitic ignimbrites, olivine basaltic flows,basaltic cinder cones,surge deposits, ash flows and alluvial sediments. While the mafic volcanic rocks are mainly dominated by basaltic cinder cones and olivine basaltic lava flows the acidic ones are dominated by rhyolitic flows and surge deposits with only small outcrops of trachytic domes. In the studied area, fractures and faults are mostly aligned in NE direction.

A description of the various lithological units is given below.

TRACHYTIC DOMES

From stratigraphic ponit of view, it is the oldest rock outcroping in the area and probably overlies the deepest Trap basalt. The trachyte outcrops in different places: it constitutes the long curved ridge found north of Dukem town which are aligned in NE direction, and the scattered hills which are present near by the village of Yerer-Buti and at the southern foot of Mt Yerer.

It is thought that the trachytic domes might be originated as dome structure along the rim of a curvilinear collapsed caldera. At the foot of the Dukem ridge the unit is characterized by frequent inclusions of basalt fragments ranging from some centimeters to one meter in diameter. The olivine rich basalt has a porphyritic texture with phenocrysts of plagioclase and olivine in a glassy groundmass.

Two varieties have been recognized:the pink and the pale grey trachyte. The pink trachyte is characterized by the phenocryst of feldspar which are often partially or completly weathered. At places,typical spheroidal weathering structure was observed in addition to small sized fractures. The thickness is quite variable as it frequentely forms dome structure. Generally it varies from about 40m to 100mts.

on the Dukem ridge, EW fractures have been recognized due to the presence of silicic material as effect of hydrothermal action along the fractures. The sample from the trachytic dome showed that it is constituted by phenocryst of sanidine, plagioclase, dispersed quartz, biotite and iron oxide within a glassy groundmass of feldspar lath (see photo 1a).

The pale grey trachyte which outcrops near the village of Yerer-Buti, iscomposed of plagioclase feldspar phenocrysts, small fragments of pyroxenes and iron oxides.The rock is deeply fractured, weathered and partially filled up by secondary calcite within the fissured plagioclase phenocrysts (see photo 1b).

K\Ar age determination of the unit showed a pliocene age of 3,6mys (Morton,1975).

RHYOLITIC FLOWS

The rhyolite outcrops in the most elevated parts of the area:the top and the southern flanks of the Mt Yerer and the southern most ridge of the Mt Sokoru.The exposed thickness of the unit is about 500mts.

On the SW flanks of the Mt. Yerer clear flow banding structures occur. As it has been observed in the field, this unit seems to be deeply weathered and fractured.

Coloured from pink to grey, the rhyolite is mainly composed of plagioclase phenocrysts and biotite set in a groundmass of glass and small grains of quartz and opaque minerals (see photo 2a).

According to Zanettin and Justin-Visentin (1974),the unit can be correlated with the Balchi Rhyolite.

Field observations have shown that the rhyolites of Mt.Yerer and Mt.Sokoru seems to have different eruption centers.In particular, the eruption of the second one is supposed to have prompted a caldera collapse. Inside and outside the related depression various post caldera spatter cones have been successively accumulated.

According to Morton (1975), the K/Ar age of the Yerer rhyolite is 3.3 mys.

RHYOLITIC IGNIMBRITE

The ignimbrite occurs North of Godino village and covers small part of the studied area.The unit is highly welded and shows vertical columnar jointing structures. It has exposed thickness of about 50mts.

Coloured from light grey to pale brown, this unit appears to be a highly welded ignimbrite with flattenedpumice, and deformed glass shards containg crystal fragments of plagioclase. In some varieties biotite and plagioclase feldspar phenocrysts are present together with small fragments of amphibole, iron-oxide and unidentified rock fragments (see photo 3a).

The K/Ar age of the unit according to Morton *et al* (1979), is 3.2 mys.

OLIVINE BASALTIC LAVA FLOWS

The porphyritic basalts outcrops in different places: near Bishoftu lake,south west of the Godino village and in the valley of the Wodecha river, where it shows clear vesicular structures and underlies a thick yellow surge deposit.

The unit seems to be outpoured from the various cinder cones outcroping in the area.By means of stratigraphical correlations, this basalt is proved to be older than the scoriaceous one. Generally the rock is constituted by large phenocryst set in microgranular groundmass. The phenocrysts are large fragments of plagioclase and some idingsitized olivines, pyroxenes and abundant opaque minerals. In some thin sections, a large amount of olivines of various size and small flakes of plagiclase and pyroxenes set in a very fine grained matrix have been observed (see photo 4a).

Zanettin and Justin-Visentin (1974), called it Bishoftu basalt it can be correlated with Bofa basalt(Kazmin 1979).

The K/Ar age of the unit ranges from 1.5-1mys (Mohr,1974).

LOWER SURGE DEPOSITS AND ALLUVIALS

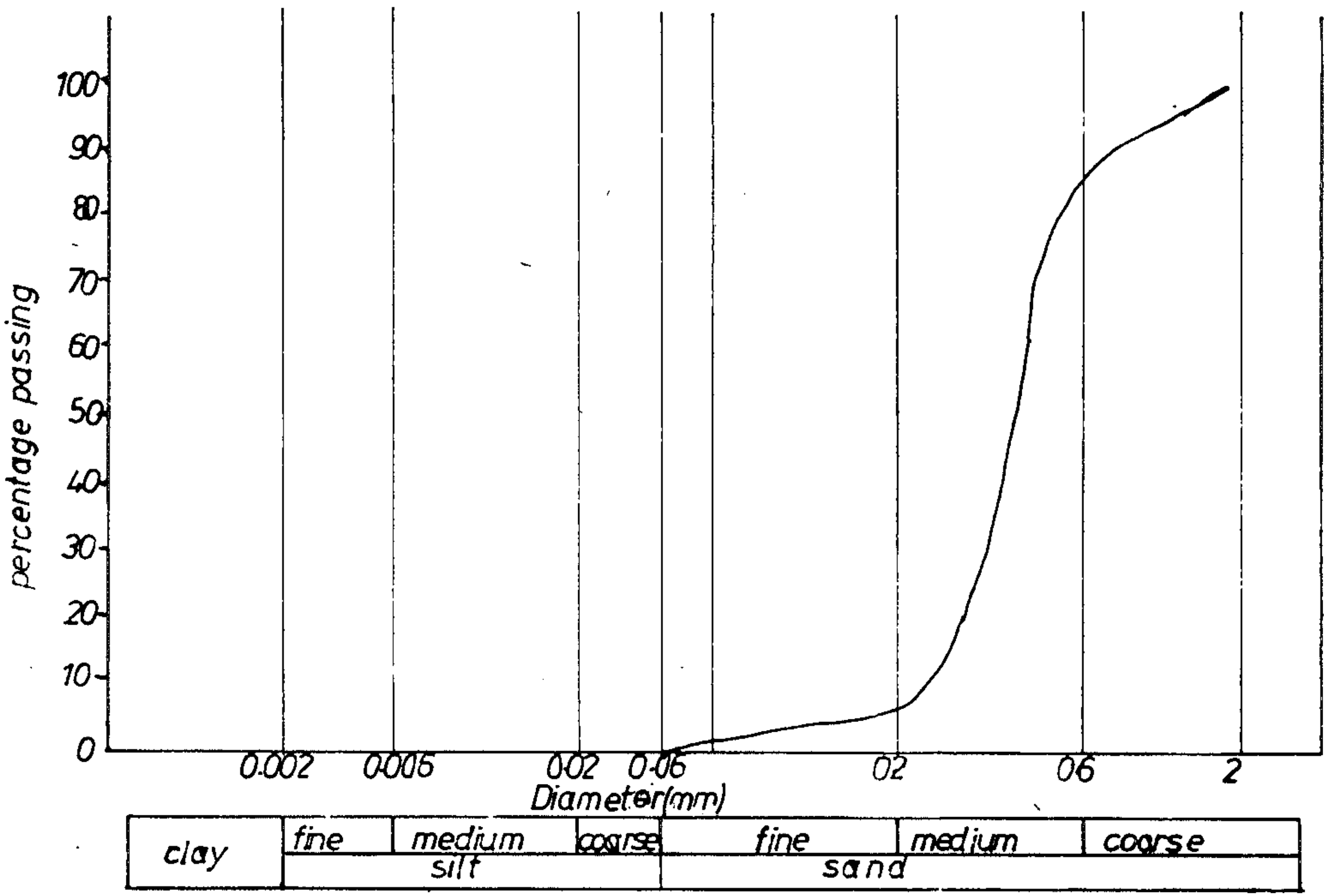
After the extrusion of Yerer rhyolitic dome, a prolonged explosive phase occured in the area, which has given rise to several pyroclastic deposits of many types emitted from vents along the steep flanks of the mountain.

The maximum thickness of the unit is about 40mts and thins toward Debre Zeit town.

The already mentioned ignimbrite is in fact the oldest pyroclastic formation which can be related to these events.

Successively several periodic depositions of base surges interbedded with ash flows, alluvium etc., have occured to form the actual stratigraphic sequence of the investigated area.

fig 2 Granulometric analysis of the surge deposit found with in the alluvlum



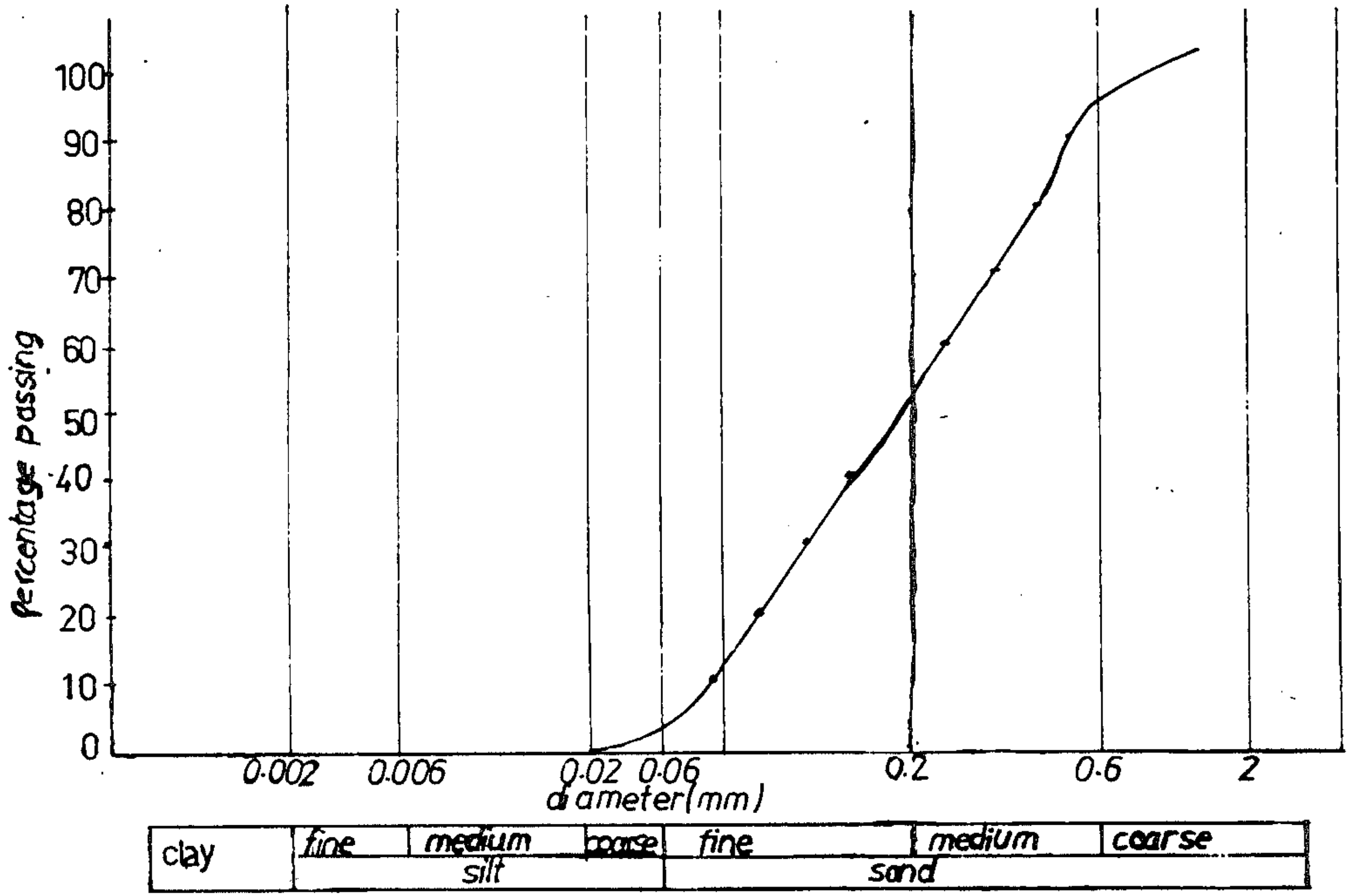
Quite continuous base surge deposits (surge 1) are present in fact in the northern and central part of the area, but mainly in the deepest fluvial gorges and gullies where they reach their maximum thickness (esp. in Wodecha river valley).The different horizons are all characterized by the same NS flow direction with a gentle gradient towards SSW and SSE in the western and eastern zone respectively. The occurrence of two vents localized on the lower slopes of Mt. Yerer are the probable sources. They have given rise to more or less coeval surge deposits, but separated by a small trachytic ridge near by the village of Yerer-Buti.

The surge of the eastern zone is younger than the olivine basaltic lava flows, as it is found to overlie them south of Godino village.

The surge deposits are characterized by different facies depending on their distance from the vent. While in the proximal facies they show well sorted granular structures with dune, antidune, cross bedding and sinusoidal lamination morphologies, in the distal facies they are mainly characterized by planar structures with very thin layers and inverse graded bedding.

Having a light yellow dominant colour, the surge deposits of the studied are strongly different from the light gray ashes, the brown alluvium and the black covering soils.

fig 3 Granulometric analysis of the surge deposit associated With explosion crater lakes



A grain size analysis of a local surge sample is shown in fig.2.

SURGE DEPOSITS ASSOCIATED WITH EXPLOSION CRATERS (surge 2)

Important surge deposits outcrop in the central part of the investigated area, mainly around the explosion crater lakes(surge 2). Characterestic dune and antidune forms occur with impact sags of porphritic basalt and scoriacious basalt near the vent besides small fragments of unidentified rocks.

The unit is composed of a repeated sequence of thin graded bedding layers, and is found to be thick near the crater rims (about 50 mts at the rim of Bishoftu lake) and then thining away from the lakes.

The general color of the unit is white-grey and the dominant grain size varies from fine sand to silty (see fig.3).

BASALTIC CINDER CONES

The unit is exposed in the form of cinder cones which are variously distributed in the area. Some of them are exposed within the collapse caldera. The exposed thickness of the unit is about 100mts.

The scoriaceous basalts are constituted by vesicular ejecta thrown out by a lava with high gas content during volcanic eruption.

The color of these basalt varies from dark to reddish-brown as a result of evident oxidation phenomena.

ALLUVIAL SEDIMENTS

The alluvial sediments are mainly exposed along the gullies of the intermittent streams occuring in the flat central part the area above Debre Zeit and in the lower course of the Wodecha river.The unit is covered by black clay horizon . Despite the great lateral variability, the unit shows a regular vertical sequence from coarse sand near the bottom to the clay at the top. Generally these sediments are very loose so that they can beeasily eroded away.

3. SURFACE HYDROLOGY

Within the investigated area two main hydrographic basins can be recognized: the Yerer-Sokoru and the Wodecha *2* basins(see the figure on annex 12). The first one, having an areal extent of 180 sq.km and a more or less oval shape, is mainly constituted of a pattern of seasonal and intermittent streams which are characterized by an endorheic behaviour in their lower course, where they approach the central part of the studied area.

It is also peculiar that it has its wide mouth in the south - western side, which is clearly open towards the Dukem river without any evidence of runoff. This basin is bounded in the NW by the trachytic domes aligned in NE direction, in the North by Mt.Yerer, in the East by some scattered spatter cones, in the South by the rhyolite ridge of Mt Sokoru.

The second one, with an areal extent of 87.4 sq.km and is elongated in N-S direction, constitutes part of the western branch of the largest Mojo catchment area (1205 sq.km).

In fact, the hydrographic net of this branch begins far away in the North giving rise to a first catchment areanamed here as Wodecha *1* (175 sq.km)then it crosses the investigated area(Wodecha *2*, 87.4 sq.km) and finally it has an evident open mouth towards the east.

The main water course in the studied area is the Wodecha river which is characterized by a perennial flow, being also supplied by several seasonal rivers coming from the steep flanks of Mt. Yerer and Mt.Sokoru.

Being adjacent, in its western side, to the Yerer-Sokoru basin, the Wodecha z catchment area is bounded to the East by a hilly ridge formed by ignimbrites and several scattered spatter cones.

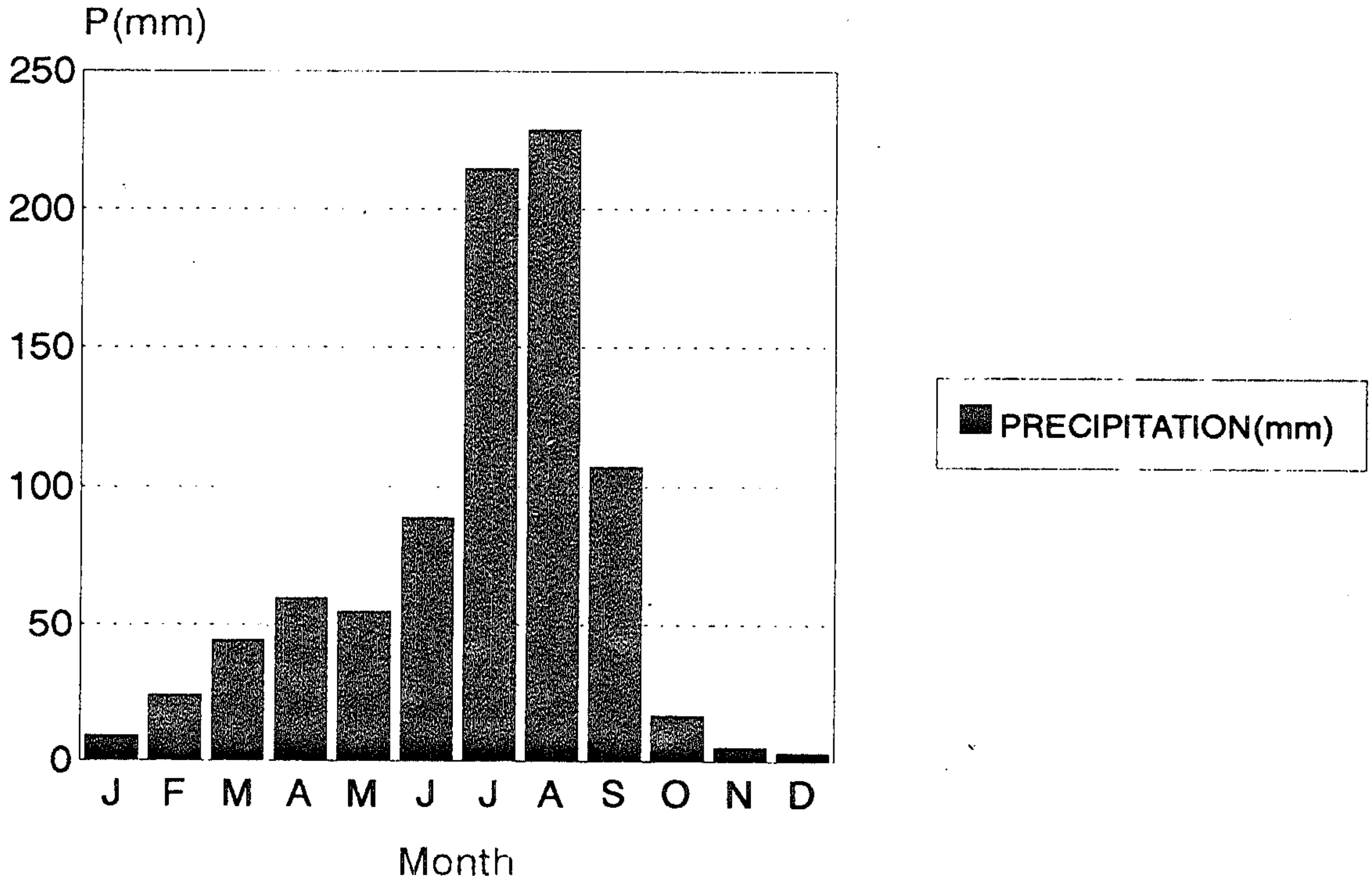
In the following discussions, the general hydrological considerations are reported together with the presently available data for the above mentioned hydrographic basins.

3.1 PRECIPITATION

Convective and orographic are the most frequent type of precipitation, the cyclonic ones being limited onlyto the wettest periods, characterized by heavy storms as a result of the monsoon cycles of Indian Ocean.

Only two rain gauge station are found in the studied area and both are located in Debre Zeit town at an elevation of about 1900 m a.s.l. These are the Agriculture Experimental Center and the Air Force Station. However,the former station does not provide a complete recored, the only station that can be used is the air force station.

Fig.4 RAINFALL DEPTH IN 39 YEARS



The station has a 39 years of complete precipitation data from which reliable annual average rainfall depth of 859.9 mm is calculated. This value can be considered as the minimum amount of precipitation depth for the whole area because of its elevation characterestics. Most of the studied basin (60%) actually found at an altitude close to that of the Air force station being the rest much higher. Since the amount of rainfall is influenced by the elevation of the area. We can believe that no value smaller than 859.9mm should characterized the average annual rainfall depth of the studied area.

According to the long record of data of the above mentoned station we can observe, see fig 4, that the annual trend is characterized by:

- a big rainy period in the months of June, July, August and September;
- a small rainy period in March, April and May and,
- almost dry period in October, November, December, January and February.

3.2 EVAPOTRANSPIRATION

The total amount of water which returns back to the atmosphere within a given time by means of the evaporation from land or free water bodies and transpiration from the vegetation cover, is called evapotranspiration rate.

the actual is the evapotranspiration that actually occurs under given climatic and soil moisture conditions. The former is temperature dependent parameter, while the later is ruled by temperature and availability of water (precipitation and soil moisture) at the place.

In the investigated area, the mean annual temperature is 19.1°Cwhile the mean yearly maximum temperature is 25.4°C and the mean yearly minimum temprature is 11.3°C.

C.W. Thornwaite carried out many experiments all over the United States in order to correlate temperature and evapotranspiration.From this work he devised a method (Thornwaite, C.W. and Mather J.R. 1957)which enables us to estimate the gross potential evapotranspiration from short, close vegetation set with an adequate water supply.

If "t" is the mean monthly temperature of the consecutive months of the year expressed in degree centigrade, the monthly heat index (j)can be expressed as:

$$j=\left(\frac{t}{5}\right)^{1.514} \qquad (1)$$

So that the yearly heat index J is given by:

$$J=\sum_{i=1}^{12} j \quad \text{for twelve months.} \qquad (2)$$

Accordingly, the gross potential evapotranspiration (PE) for any month with mean temperature t, is given as

$$PE=1.6\left(\frac{10t}{J}\right)^{a} \text{ in cm per month} \qquad (3)$$

Where $a = 0.49239 + (1792 \times 10^{-5})J - (771 \times 10^{-7})J^2 + (675 \times 10^{-9})J^3$

This potential evapotranspiration is a theoretical standard monthly value based on 30 days and 12 hours sunshine per day. It has been adjusted for the number of days per month and length of day (a function of latitude). That is, the above gross potential evapotranspiration is multiplied by appropriate latitude factors (see table 2).

To calculate different hydrologic parameters, the procedure is given as follows (leopold, B. and Dunne, T. 1978).

In table 2, row 2 (mean monthly heat index) and row 3 (gross potential evapotranspiration) have been calculated by equations 1,2 & 3 above using $T^{o}C$ (mean monthly temperature) listed in row 1. The values listed in row 5 (corrected potential evapotranspiration) have been found by multipling values from row 3 (gross potential evapotranspiration) by row 4 (latitude correction factor).

The difference between precipitation (row 6) and corrected potential evapotranspiration (row 5) gives values in row 7. This defines two seasons: a wet season lasting for four months (June, July, August and September) when rainfall exceeds evapotranspiration and a dry season lasting for the rest eight months when the water demand is not satisfied by precipitation fallen in the corresponding month.

TABLE 2 AVERAGE MONTHLY WATER BALANCE

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
1. T°c	17.1	19.3	20.2	20.5	20.6	19.7	18.3	18.2	22.8	18.2	17.5	17.2	
2. j	6.43	7.73	8.28	8.47	8.53	7.97	7.13	7.07	9.95	7.07	6.66	6.49	91.78
3. GPET mm	55.9	71.3	78.1	80.4	81.2	74.2	64	63.3	99.6	63.3	58.5	56.5	
4. LCF 10°N	0.97	0.98	1.00	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96	
5. CPET mm	54.2	69.9	78.1	82.8	85.5	78.6	67.2	65.8	101.6	62.7	56.7	54.2	857.1
6. P mm	9.3	24.6	44.4	60	55	89.2	215.2	229.4	107.3	16.9	5.1	3.3	859.9
7. P-CPET mm	-44.9	-45.3	-33.7	-22.8	-30.3	10.6	148	163.5	5.7	-45.8	-51.6	-50.9	2.5
8. APWL mm	-193.2	-238.5	-272.2	-295.0	-325.3	-	-	-	-	-45.8	-97.4	-148.3	
9. SM mm	6	2.8	0.9	1	1	11.6	75	75	75	43	22	10	
10. ΔSM mm	-4	-3.2	-1.9	0.1	0	10.6	63.4	0	0	-32	-21	-12	0
11. AET mm	13.5	27.8	46.3	60.1	55	78.6	67.2	65.8	101.6	48.9	26.1	15.3	606.2
12. D mm	40.7	42.1	31.8	22.7	30.3	0	0	0	0	13.8	30.6	38.9	250.9
13. S mm	0	0	0	0	0	0	84.6	163.5	5.7	0	0	0	253.8

T: mean monthly temperature
j: monthly heat index
GPET: gross potential evapotranspiration
LCF: latitude correction factor
CPET: corrected potential evapotranspiration
P: mean monthly precipitation
APWL: accumulated potential water loss
SM: soil moisture
ΔSM: change in soil moisture
AET: actual evapotranspiration
D: soil moisture deficit
S: soil moisture surplus

The severity of dry season increases during the sequence of months with excessive potential evapotranspiration, and this is expressed in row 8 (as accumulated potential water loss), which is the accumulation of negative values of row 7 (P-CPET)for the dry season.The sum begins at the end of wet month (September).

The cover of the plain area is dominated by clay and silty clay soils (in the swampy and alluvial zones)as indicated on the lithological logs (see figs.6 and 7). The available water holding capacity of these soils is approximately 30% (150mm of water depth per meter depth of soil) (Thornwaite C.W and Mataer J.R 1957). Assuming that the average root penetration of crops, grasses, shrubs etc, in the studied area, is in about 0.5m in the soil, then the root zone could hold (0.5m x 150mm per meter =) 75 mm of water at field capacity.

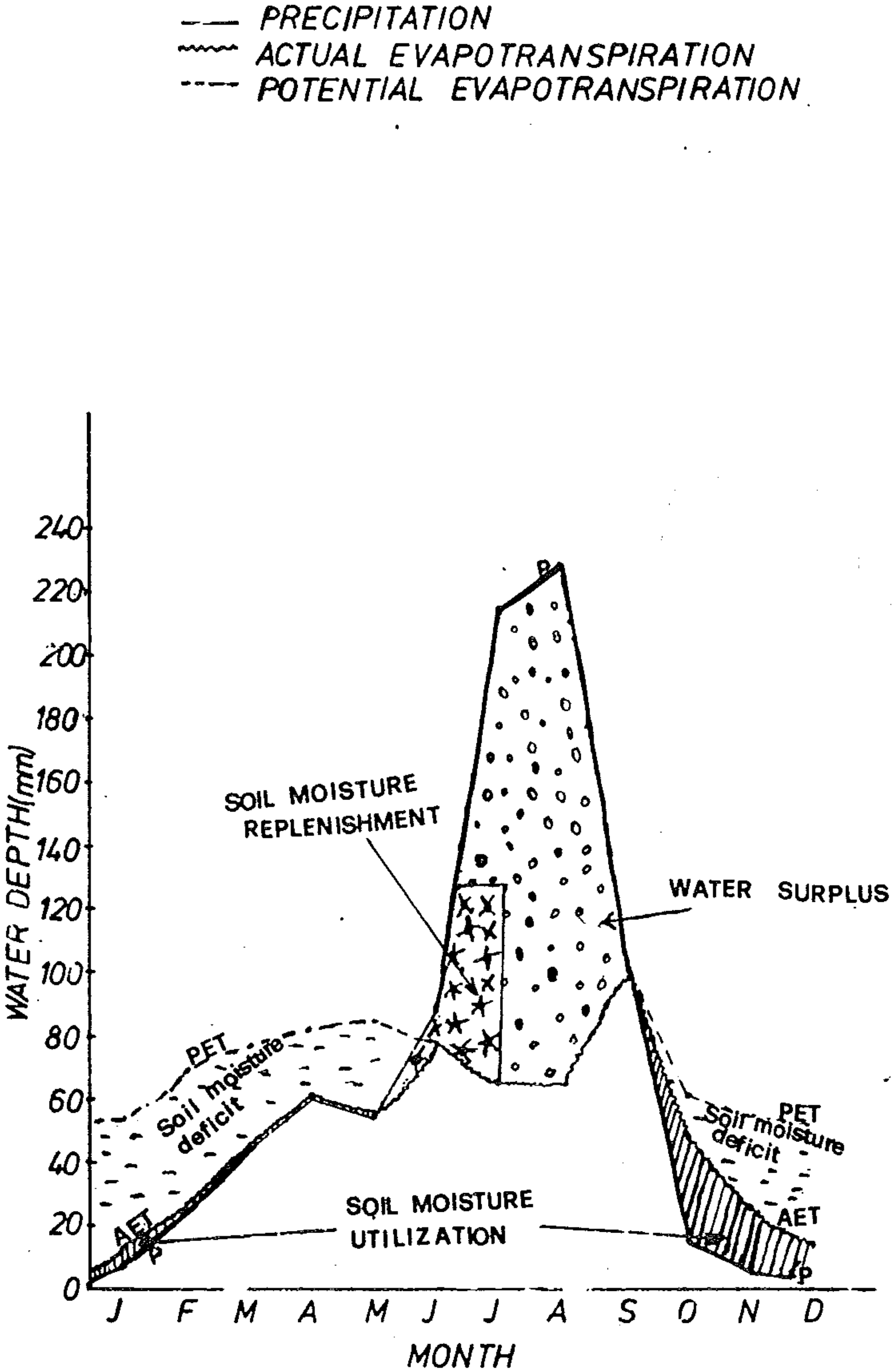
If a soil with an available water holding capacity of 75 mm is subjected to a potential water loss of 45.8 mm., the amount of water which will be retained by the soil is 43 mm. This value of soil moisture is entered for October in row 9 (soil moisture). The same was done for the other dry season months. The value of soil moisture is found by reading the graph found in annex 8 (soil moisture graph). Soil moisture values for the wet season months are obtained by adding the excess precipitation from row 7 (P- CPET) to the soil moisture level at the end of dry season month (May).

From row 9 (soil moisture)the change in soil moisture was entered in row 10.

When precipitation exceeds the corrected potential evapotranspiration, (row 5) the actual evapotranspiration (row 11) equals the potential rate(months of June, July, August and September). When corrected potential evapotranspiration exceeds precipitation, actual evapotransp- iration is the sum of precipitation and the amount of soil moisture withdrawn from storage(months of January, February, March, April, May, October, November and December). This method enables the evaluation of soil moisture deficit by subtracting actual evapotranspiration from the potential. The values of the soil moisture deficit that is mainly an agronomical quantity are listed in row 12.

Moisture surplus (Leopold B. and Dunne T. 1978) or water surplus (row 13) is the amount of water that given by the difference between precipitation and actual evapotranspiration when precipitation exceeds the actual evapotranspiration, originates both runoff and infiltration. Figure 5 shows the main hydrologic characterestics of Debre Zeit area obtained applying the above procedure.

Fig-5 MONTHLY AVERAGE WATER BALANCE



The graph indicates the seasonal pattern of:

- precipitation
- actual evapotranspiration
- potential evapotranspiration
- soil moisture deficit
- soil moisture utilization
- soil moisture recharge and
- moisture or water surplus.

The moisture deficit indicates that the plants are under stress. If the cover is a valuable crop, the whole water balance parameters would indicate the timing and magnitude of irrigation which is necessary to remove the stress.

Based on above calculation, the annual actual evapotranspiration is 606.2 mm. Out of 859.9 mm of precipitation, 253.8 mm of water is surplus and is available for infiltration and runoff.

The annual average potential evapotranspiration is 857.1mm. Generally in the area, evapotranspiration plays the most important role in the loss of surface and subsurface waters.

3.3 RUNOFF

Runoff is the total amount of water that leaves the basin flowing down through the drainage system constituted by hydrographic net.

It occurs when the rate of precipitation exceeds the infiltration demand of the soil.

Due to the peculiar character of the runoff, it has to be known that it mostly depends on the geology, geomorphology and the size of the drained area.

In the northern and western part of the study area, runoff occurs from a relatively impervious portion of highly elevated part of the area which , passes over a more pervious soil and is partly or completely absorbed before reaching the flat area close to Debre Zeit.

In the eastern part of the area all intermittent streams drains only towards the Wodecha river. Generally in the area all the rivers have a certain runoff during and immediately after the rainfall, while in the dry period, they always sink down to the river bed.

In the eight months of a year, except June, July, August and September, the runoff is very small on account of high temperature and consequent evapotranspiration. But in the four rainy months, the runoff carried by streams drains from Mt.Yerer and neighbouring hills, towards the lake Cheleleka and the large swampy area which is covered by fine grained soils.

In the central part of the area, since the topography is flat and due to clayey nature of the cover soil, the runoff is sluggish so that it gives rise to appreciable ponding or surface storage for long period and thus create opportunity for infiltration to occur.

The steep nature and impervious character of the hills accelerate the rate ofrunoff, so that there is very small chance for the runoff to percolate into the soil.

The only runoff that leaves the studied area is carried by Wodecha river. The river initially carries water coming from the northern Wodecha 1 then it receives a supplementary feeding by the small tributaries which flow down from Mt.Yerer.

Because Wodecha river is a tributary of Mojo river, in order to determine its runoff coefficient, due to absence of gauging station, a computation of the runoff value, taking in to consideration the Mojo basin, has been carried out. Also in this case it has to be observed that the runoff coefficient is the smallest possible due to the different morphological conditions of the Mojo and Wodecha 2 basins, the last one being characterized by steeper slopes and a bigger mean altitude than the first. The soil coverage and the geology of the two basins is similar. Therefore, because of the lack of runoff data in the area, the above assumption can help us to determine the runoff value for the area.

Based on the available runoff data from 1962-1989,(1981 & 1982 is missing), the calculated mean annual runoff for Mojo river is (R_M) 149.42 million cubic meter of water. The annual average precipitation in the Mojo basin is 894.5 mm with in the area of 1205 sq.km. The runoff coefficient in the Mojo river is:

$$\vartheta_M = \frac{R_M}{P_M \times A_M}$$

where P_M is annual precipitation in Mojo basin

R_M is annual runoff in Mojo basin

A_M is surface area of Mojo basin

Hence, the runoff coefficient in the Mojo basin is 0.138.

Since Wodecha river is the part of Mojo basin and carries water while entering into the area, the determination of initial runoff value is necessary. Therefore the area drained by Wodecha river before entering the studied area (A_{w1}) is 175 sq.km. Taking the precipitation (P_M) and the runoff coefficient (ϑ_M) of Mojo river, the initial amount of runoff (R_{w1}) that enters into the area is:

$$R_{w1} = (P_M \times \vartheta_M) \times A_{w1}$$

Hence, R_{w1} becomes $21.595 \times 10^6 m^3$

The surface area drained by Wodecha river in the studied area (A_{w2}) is 87.4 sq.km. The annual minimum precipitation in the studied area (P_s) is 859.9 mm. Hence, the amount of surface runoff (R_{w2}) added to the Wodecha river from the water shade of the studied area is:

$$R_{v2} = (P_a \times \vartheta_M) \times A_{v2}$$

$$= 10.365 \times 10^6 m^3$$

Therefore, the total runoff that leaves the studied area through Wodecha river is simply the sum of R_{w1} and and R_{v2} which is equal to 31.96 million cubic meter. Assuming 20% of infiltration from the river, the net runoff value will become $25.568 \times 10^6 m^3$.

The total runoff in the Yerer-Sokoru basin,with the surface area of 182.0 sq.km, precipitation of 859.9 mm and runoff coefficient 0.138, is $21.585 \times 10^6 m^3$. This value in Yerer-Sokoru basin does not leave the basin instead seeps into the soil.

4. WATER-BALANCE

The main purpose of the water balance calculation is to know the amount of water which infiltrates at different depths to recharge the groundwater circulation occurring in a given area.

In fact infiltration is one of the main factor controlling the hydrological cycle, besides Precipitation,Runoff and Evapotranspiration.

It can be calculated by means of the following equation.

$I = P - (E + R)$

In the investigated zone two main catchment areas occur. These are characterized differently by runoff and infiltration processes. Accordingly the water balance evaluation has been splitted into two parts.

YERER-SOKORU BASIN (Y-S)

A_{y-s}= 182 sq.km.

P_{y-s} =859.9 mm

E_{y-s}=606.2 mm

R_{y-s}= 118.6 mm

Then I_{y-s} = 859.9 - (606.2 + 118.6)

= 135.1 mm

It means in % : E_{y-s} =70.5% of P_{y-s}

R_{y-s} =13.8% of P_{y-s}

I_{y-s}=15.7% of P_{y-s}

In terms of water volume measured in m^3,

$V_{y-s}(E) = E_{y-s} \times A_{y-s} = 0.6062 \text{ m} \times 182 \times 10^6 m^2$

$= 110.328 \times 10^6 m^3$

$V_{y-s}(R) = R_{y-s} \times A_{y-s} = 0.1186 \times 182 \times 10^6 m^2$

$= 21.585 \times 10^6 m^3$

$V_{y-s}(I) = I_{y-s} \times A_{y-s} = 0.1351 \text{ m} \times 182 \times 10^6 m^2$

$=24.588 \times 10^6 m^3$

Due to the fact that the Yerer-Sokoru basin is properly an endorheic basin, both volumes $V_{y-s}(R)$ and $V_{y-s}(I)$ can be considered as available for groundwater recharge. So that, besides the water loss due to the evaporation processes, $V_{y-s}(E)$, the total amount of water which infiltrates within the Yerer-Sokoru basin is given by :

$V_{y-s} = V_{y-s}(R) + V_{y-s}(I) = 46.173 \times 10^6 m^3$

Going into detail, for a most precise water balance evaluation, it can be said that this total amount of water, which is available for groundwater recharge, has to be reduced to a certain value depending on two other type of water loss:

- the first one derives from the direct evaporation which takes place from thick free-water reservoirs as the crater lakes occuring in the eastern border of this basin, with a total surface of about 5 sq.km.

Given 2218 mm of the mean yearly evaporation rate for thin free water surfaces , with the reduction coefficient (0.7) for thick free water reservoirs, the water loss will be:

$V_L = 2.218 \text{ m} \times 0.7 \times 5 \times 10^6 \text{m}^2 = 7.763 \times 10^6 \text{m}^3$

- the second loss derives from the direct evaporation which takes place from very thin free water reservoirs as the swampy area and Cheleleka lake, occuring in the lower part of this basin, which are partially flooded for at least two months of the year: i.e, July and August, when high concentration of rainfalls occur. So that with 2218 mm of yearly evaporation, the mean monthly evaporation rate for thin free water reservoir becomes 2218/12= 184.83 mm.

The total area which is completly flooded during the two months is about 6 sq.km. The water loss in volume will be:

$V_{SW} = 0.18483 \text{ m} \times 6 \times 10^6 \text{m}^2 \times 2 = 2.218 \times 10^6 \text{m}^3$

Taking into account these water losses, the total amount of water which is actually available for groundwater recharge within the Yerer - Sokoru basin is given by:

$\bar{V}^*_{y-s} = \bar{V}_{y-s} - (V_L + V_{SW}) = 36.192 \times 10^6 \text{m}^3$

WODECHA 2 BASIN(W_2)

A_{W2} = 87.4 sq.km

P_{W2} =859.9 mm

E_{W2} = 606.2 mm

R_{W2} = 118.6 mm

5. HYDROGEOLOGY

5.1 GENERAL

The volcanic rocks have been always considered very important from the hydrogeological point of view.In fact most of the time, although very heterogeneous, they have been recognized as important groundwater bearing formations.

Notable is also the fact that the groundwater circulation in these units is normally not very deep, so that frequent springs or geometrically well defined productive aquifers occur.

Quite unknown are the natural processes which give rise to the occurrence and circulation of groundwater in volcanic rocks as heterogeneous and anisotropic media, moreover characterized by an extreme range of variability regarding their composition, structure, fracture pattern, weathering, etc.

In fact, the information concerning the main factors controlling these processes are often contradictory.

In general it is possible to say that unweathered lava flows have a high permeability due to peculiar flow structure as clinker or scoria beds, vesicles, lava tubes, irregular interflow openings, contraction joints formed during the solidification of lava and stream gravels and paleosols buried between successive flows .

Clinker beds, lava tubes and interflow openings are generally parallel to the flow surface, while contraction joints are normal. Therefore,the horizontal component of permeability of lava flow probably exceeds the vertical. However, permeability in both directions is so great that the difference between them are difficult to determine.

Weathering causes a decrease in the size of the openings in the lava flows and reduction of the permeability. The effect of weathering reachs greater depth adjacent to valleys or gorges.

Domes, dikes and sills are impervious while cinder and spatter cones are the most permeable units. Consolidated and unweathered cinders are very permeabile while ashes have a great range of variability.

Tuffs and ignimbrites are generally the most impervious rocks.They never act as aquifers, but over small areas they are perching members.

Hydraulic coductivitiy of sediments, based on primary permeability, is a function of the grain size, shape and sorting of the original sediment.

Recent alluvium includes highly permeabil river channel deposits through which much of the groundwater recharge occurs.

Consolidated rocks contain secondary porosity and permeability due to fracturing , Sedimentary aquifers are deposited in sedimentary basins and its variable thickness is due to the deposition of the aquifer material over the eroded surface with high relief or dissection of the top of the aquifer after deposition. Higher well yields can be obtained from thicker sections of the aquifer.

5.2 HYDROGEOLOGY OF THE AREA

The hydrogeological characterestics of the rocks outcroping in the area is discussed with particular reference to their infiltration capacity together with their availability to store or transfer groundwater downwards.

From hydrogeological point of view, the rocks exposed in the area can be divided into two groups: volcanic rocks which are relatively impervious and alluvial sediments which are pervious.

5.2.1 VOLCANIC ROCKS

The volcanic rock group includes materials having a wide range of hydrogeological properties such as trachytes, rhyolites,basalts, scoria and pyroclastic rocks.

Rhyolites and trachytes can be considered practically impervious as groundmass,even if intersected by frequent tectonic or secondary discontinuities. Since the upper part of the trachyte dome and rhyolite flow is weathered,a reduction of the size of fractures and other openings occurs, with a consequent progressive decreasing of the permeability of the complex rock bodies.

The surface water which drains from the mountain and hilly sides, constituted by impervious units, feeds the groundwater aquifers occuring downstreams; in fact no infiltration capacity of the rock bodies is expected.

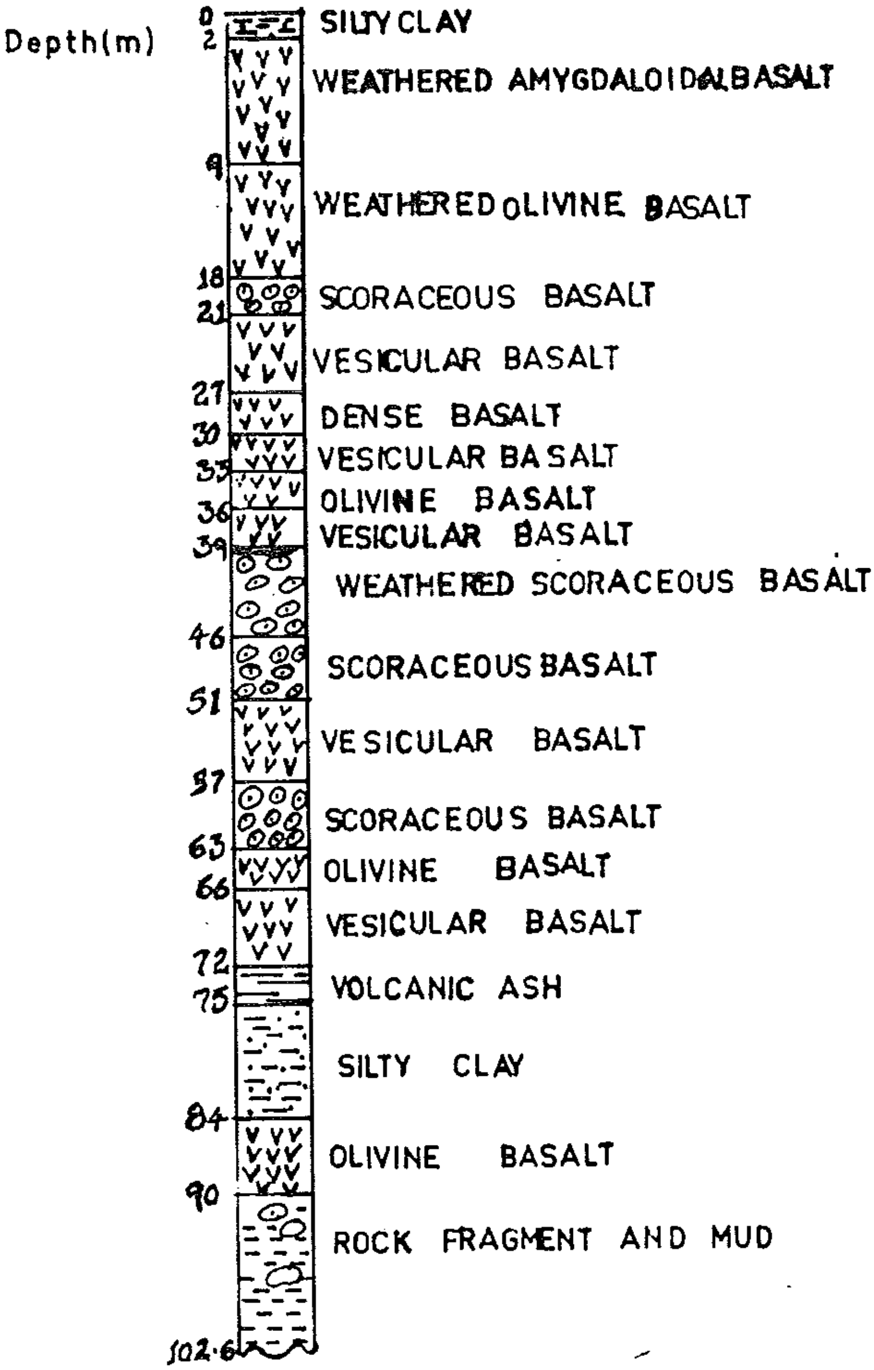
The ignimbrite which outcrop in the NE part of the area are highly welded so that they can be considered as impervious units, being only affected by a limited permeability where intersected by local vertical joints.

The spring found west of the Godino village is supposed to be properly recharged by the groundwater passing through these fractures.

Porphyritic basalts which outcrop in the upper part of the Wodecha river bed and near the Bishoftu crater lake are characterized by a vesicular texture as a result that it has a great porosity but a low permeability due to the fact that the vesicles are poorly interconnected.

Eventhough not exposed, the olivine porphyritic basalts (trap series) found as inclusions at the foot of the Dukem trachyte dome, are supposed to be the bedrock of the whole area on which pyroclastics and alluvial sediments are deposited. They are found as alternate flows of amygdaloidal, olivine, vesicular and scoriaceous basalts (see fig. 6), which are found to be heavily fractured and weathered.

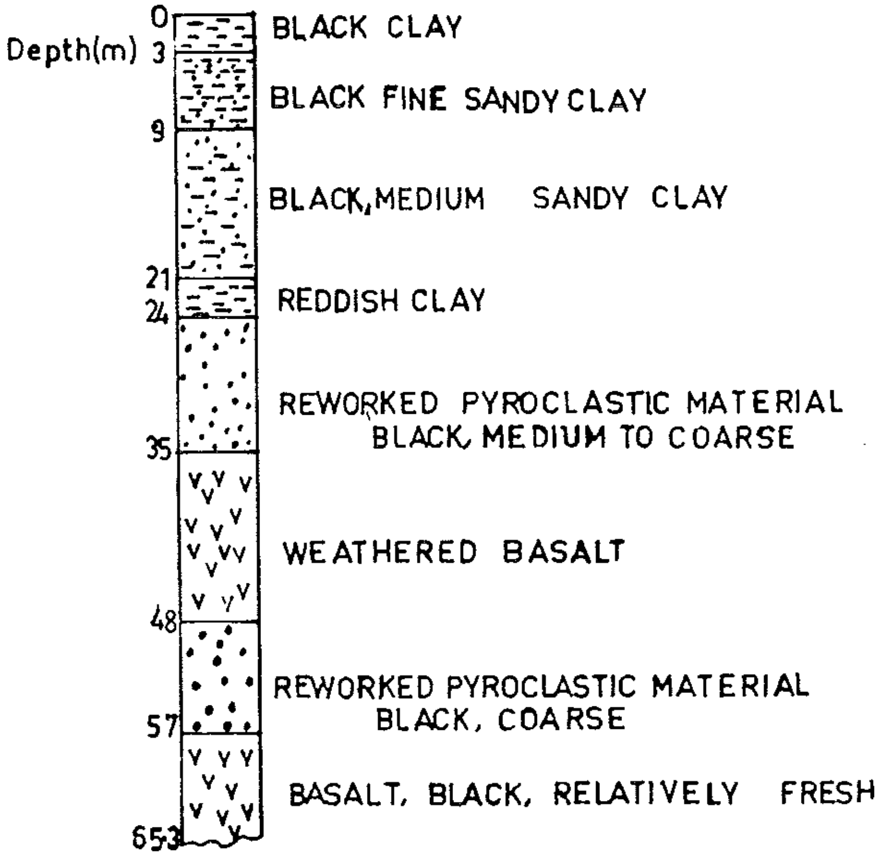
Fig.6 LITHOLOGICAL LOG FOR ADEA FLOUR MILL (№ 7)



(Source EWWCA , CENTRAL REGION)

V.S = 1:600

FIg-7 LITHOLOGICAL LOG FOR YERER-BUTI No(33)



(Source EWWCA, CENTRAL REGION)

V.S = 1:600

Due to well developed primary and secondary porosity, this complex unit is found to be the best and the most productive aquifer in the area.

These different basalts are found to be interbedded between massive basalt and clayey horizons, derived from weathering, so that groundwater occur within a multilayer aquifer under semiconfined or confined conditions, where the thin clayey layers play an important role as leaky aquitards.

Among the pyroclastic materials, surge deposits (surge 1) outcroping in the central part of the investigated area, covered by top layer of black soil, are characterized by high infiltration capacity and by moderate permeability due to their well sorted granulometric condition.

Surge deposits alternate with old alluvials, ash bed and paleosols. Because of this peculiar stratigraphic sequence, the complete unit can be considered as multilayer aquifer system, where ash beds and paleosols may act as confining beds or aquitards. The unit is found to be affected by fractures and faults which may act as easy ways for groundwater flow or storage.

The grey surge (surge 2) associated with explosion craters are characterized by a very low infiltration capacity and a low vertical permeability. This is mainly due to the poorly sorted granulometric condition and to the high weathering of the top layers. Only where thin gravelly beds are present in the sequence, a certain horizontal groundwater flow may occur fed by the lake waters during their seasonal fluctuation (see fig.15).Consequently the horizontal permeability of the unit is greater than the vertical one. Over small areas, the unit may act as perching aquifer.

The unweathered scoriaceous basalts of the spatter cones are found to be highly pervious as they may absorb greater amount of surface waters. Being too small to act as aquifers the unit can be considered as important recharging areas for the deepest multilayer aquifer systems.

5.2.2 ALLUVIAL SEDIMENTS

The alluvial sediments cover the majority of the central and lower part of the studied area, reaching their maximum thickness at the lower course of the Wodecha river, Hence they are frequently interbedded with thin layers and other coarse grained pyroclastics giving rise to peculiar erosional features.

These sediments, highly porous and permeable due to their loose nature, are moreover characterized by an extremely high infiltration capacity which allows the river water and rainfall to seep directly in to them down to the bed rock at great depths. Their grain size constitution, which varies from coarse to silty and clayey , give rise to the occurrence of highly yielded unconfined, semiconfined and confined aquifers together with local perched ones.

Only when the clayey material constitutes the top soil (swampy area and Cheleleca lake) a lower infiltration capacity occurs, allowing the rainy waters and runoff to form ponding areas of great extent.

The different hydraulic properties of the solid rocks and the loose pyroclastic and alluvial sediments, together with their areal distribution make it possible to identify the occurrence of important hydrogeological basins in the area. These basins have comparable areal extent, and boundaries of the two catchment areas of Yerer-Sokoru and Wodecha 2, so that it collects all their groundwater which move towards the open mouth occuring south of Dukem town. This is confirmed by the results obtained by means of a phreatimetric study carried out in 1991 which has allowed the construction of the groundwater level contour lines of the lower part of the area which contains several productive wells (see hydrogeological map).

Due to this peculiar configuration of the groundwater flow, for a more detailed discussion about the main hydrogeological basin, it is convenient to split it in to three sub-basins: the Yerer, Sokoru and Wodecha 2.

occuring both from the wild water films coming from the rhyolite ridge of Mt. Sokoru (infact no runoff at all occurs) and from the very frequent spatter cone structures.

The moderate groundwater potential of this aquifer, due to its small areal extent, is confirmed by the occurrence of one productive well which has the yield of about 6 l/s.

3. *WODECHA 2 SUB-BASIN*

This sub-basin, which is located in the eastern part of the studied area, gives rise to the main discharging area of the above mentioned most productive aquifer, as it is confirmed by the shape of the groundwater level contour lines.

This sub-basin is characterized by a complex aquifer occuring within the alluvial sediments limited in depth by basalt and ignimbrite bed rock.It is mainly fed by the Wodecha river especially during the flood periods, but also by the scattered spatter cones and by the groundwater flow coming from the multilayer system of the eastern part of surge 1.

This aquifer seems to be hydraulically interconnected with the lake waters particularly with (Kuriftu, Bishoftu-Guda and Hora) which are found along the main groundwater flow direction .

Infact the level of fluctuation all over the year, of both lakes and groundwater are quite correspondent.

The static level measurement taken in August 1991 showed1 meter increament as compared to that of May 1991.

The high groundwater potential of this aquifer is confirmed by the occurrence of several well fields (WSSA,central region), where yields of about 15 l/s maximum and 5 l/s minimum values are common.

As it is shown by the shape of the groundwater level contour lines, all these three sub-basins converge towards the main aquifer occuring in the lower part of the investigated area. This area can be considered as the medium through which the discharge of the whole hydrogeological basin takes place.

Although there are several well fields in the area, which are affected by a significant groundwater exploitation, the actual hydraulic potential of this important aquifer has not yet been ascertained, especially if the total available discharge volumes, evaluated in the chapter of the water balance, are taken into consideration.

6. WELL AND SPRING HYDRAULICS

The main source of groundwater supply is from dug wells and bore wells and small amount from springs.

DUG WELLS

Dug wells are usualy of 1 to 2m in diameter and 9 to 13mts in depth excavated in weathered volcanic material.They are more than 50 in number and are generally circular in plan. They have concrete and wood linings and are abundant in Debre Zeit town. Some of them are fitted with surface pump which can discharge less than 1 l/s. The majority are equiped with pully. In a day, the wells can notdischarge more than 5 barrels but the amount of water is large in the morning.

Depth to the static water level varies from 8.5 to 10.5mts. In rainy seasons the wells are rich in water and the static level become shallow but during dry season some wells dry up. Generally they are located in an unconfined aquifer which is the first upper aquifer in the area.

BORE WELLS

Bore wells have been successful mainly for the supply of drinking water to Debre Zeit, Dukem and some village dwellers.

Bore wells located in recharging zones have very low yield. The diameter of the bore wells vary from 15cm to 20cm and the measured maximum depth is 138m. The yield of the wells varies from 0.7 to 15 l/s.

Pumping test data are available only for very few wells. All wells are well equiped with steel casings and electrical submersible pump. One bore well was abandoned in the area. While 29 are functional.

Bore wells are located in the semi-confined aquifer which is made of basalt.They showed one meter increament in static water level from may to august 1991.

SPRINGS

Only three perennial springs are found in the area.The Godino and Buti springs are used for various purpose in the domestic consumption. Concrete reservoir is built on Godino spring from which water is tapped by local population through out the year.

However, the Buti spring is located in the gully cut out surge, it is covered by flood during rainy season. Buti spring is recharged by water that percolates through surge deposit. Thus, its discharge is smaller than Godino spring.

The main recharge of the Godino spring is provided by the water that percolates through the fractures developed in the ignimbrite and it seems to be a contact spring.

Tebel spring was discoverd while quarring the scoria cone for construction purpose. The appearance of the water is very clear because of the high filtration capacity of the scoria.

6.1 HYDRAULIC ANALYSIS

Under natural conditions, an aquifer is usually in a state of dynamic equilibrium,i.e a volume of water recharges the aquifer is equal to the volume of discharged water.

The aquifers which are found north,west and south of the area are poor in water and the resulting water table is very deep indicating a deficiency in the amount of potential recharge. As shown in table 4, a lot of bore wells are tabulated, but for 90% of wells, pumping test, recovery test and lithological log data are not available.

For the present discussion, two bore wells, the most representative of the whole basin, are selected with their lithological logs, pumping testand recovery test data.

Since there was no observation well nearby the discharging well to measure the effect of drawdown further away, no measures of storage coefficient were possible.Transmissivity and hydraulic conductivity have been calculated using the Jacob's straight line method.

$$T=\frac{2.3Q}{4\Pi\ \Delta S} \qquad (1)$$

Where T = transmissivity(m^3/day/m)

Q = discharge(m^3/day or l/s)

ΔS = change in drawdown per log cycle(m)

Applying this equation for Yerer-Buti well knowing that Q = 2.5 l/s (or 216 m^3/day) and from fig 8, ΔS = 0.5m

Thus $T = \frac{2.3 \times^{3} 216 \text{ m /day}}{4 \times 3.14 \times 0.5\text{m}}$

$=79.1\text{m}^3$/day/mwhich is equivalent to $0.92 \times 10^{-3} \text{m}^2$/s.

The hydraulic conductivity can be calculated by dividing transmitivity by the saturated thickness of the aquifer.

Hence $k=T/M$ (2)

where k= permeability or hydraulic conductivity of the medium

T= Transmitivity(m^3/day/m)

M= saturated thickness of the aquifers(m)

=22.71m.

Thus $k= \frac{79.1\text{m}^3\text{/day/m}}{22.71\text{m}}$

=3.5m/daywhichisequivalentto4.05×10^{-3}cm/s.

From the above value,the transmissivity and permeability of the rocks

in the central part of the catchment basin is $0.9 \times 10^{-3} \text{m}^2$/s and 4.05×10^{-3}cm/s respectively. These values are in agreement with those of unconfined aquifers.

The pumping test and recovery test data plotted on fig 11 showed that the recovery is slow. Because of the shortage of water, at the end of recovery test, the water level did not reach the original static water level. This is attributed to the phreatic nature of the aquifer and shortage of potential recharge.The pumping season, October which is dry, has its contribution on the shortage of the recharge.

Applying equations (1) and (2) for this well, the transmissivity is $7.6m^3/day/m$ (i.e $8.8x10^{-5}m^2/s$) and the permeability is 0.13m/day i.e $1.5x10^{-4}cm/s$ (fig 10). This values are in agreement with those of semi-confined aquifers.

According to Johnson (1966), transmissivity values of an aquifer with $14.9m^3/day/m$ is sufficient to meet domestic needs while the value greater than $149.2m^3/day/m$ can be used for industrial and irrigation purposes.

The yield of the springs found in the area increases during rainy months of June, July, August and September, eventhough there is a time lag between precipitation and increase in the discharge of the spring.

The hydrogeological hypothesis of the most indispensable aquifers in the area is discussed taking into account the porosity and permeability of the rock. Both porosity and permeability of basaltic rocks decrease with time. Part of this reduction, however, is only apparent because the more porous and permeable part of the rock is easily destroyed by erosion and, therefore, may not be preserved in geologic time. The primary porosity and permeability of the rock at depth can be minimized by weathering and compaction of weathering products. The accumulation of secondary minerals in the voids also decreases the porosity and

FIG-8 YERER BUTI, GRAPHICAL SOLUTION: PUMPING TEST

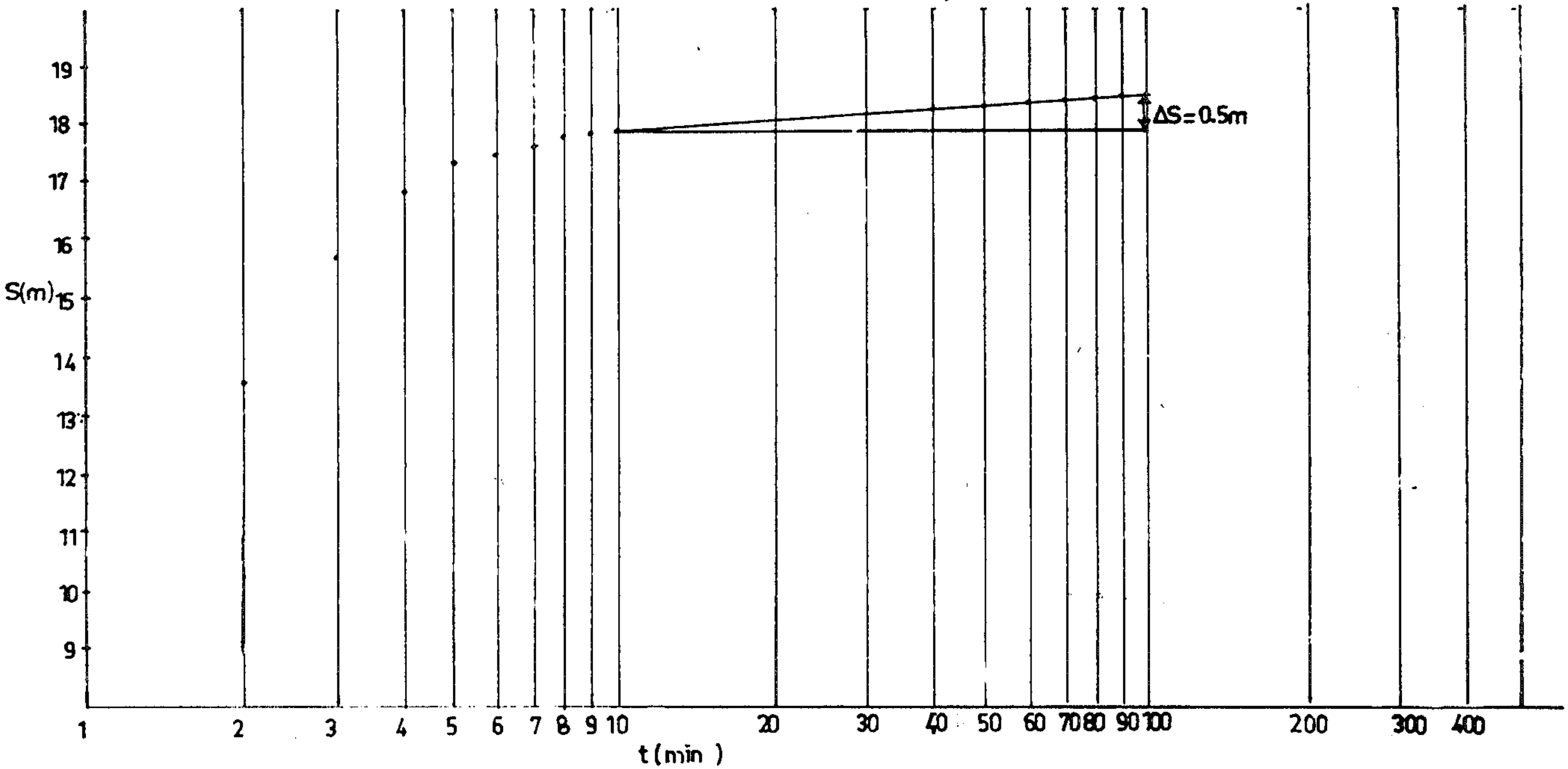


fig. 9 – YERER BUTI PUMPING–RECOVERY TEST

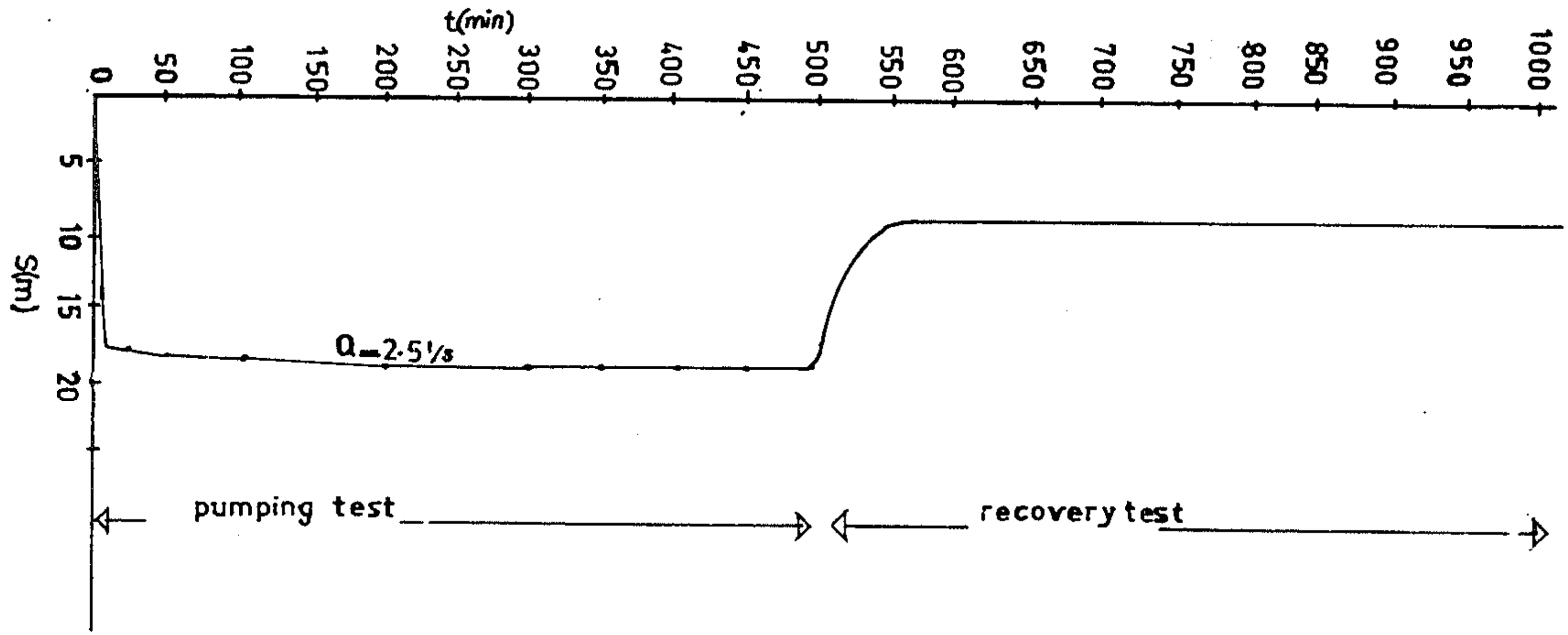


FIG-10 TEDECHA . GRAPHICAL SOLUTION: RECOVERY TEST

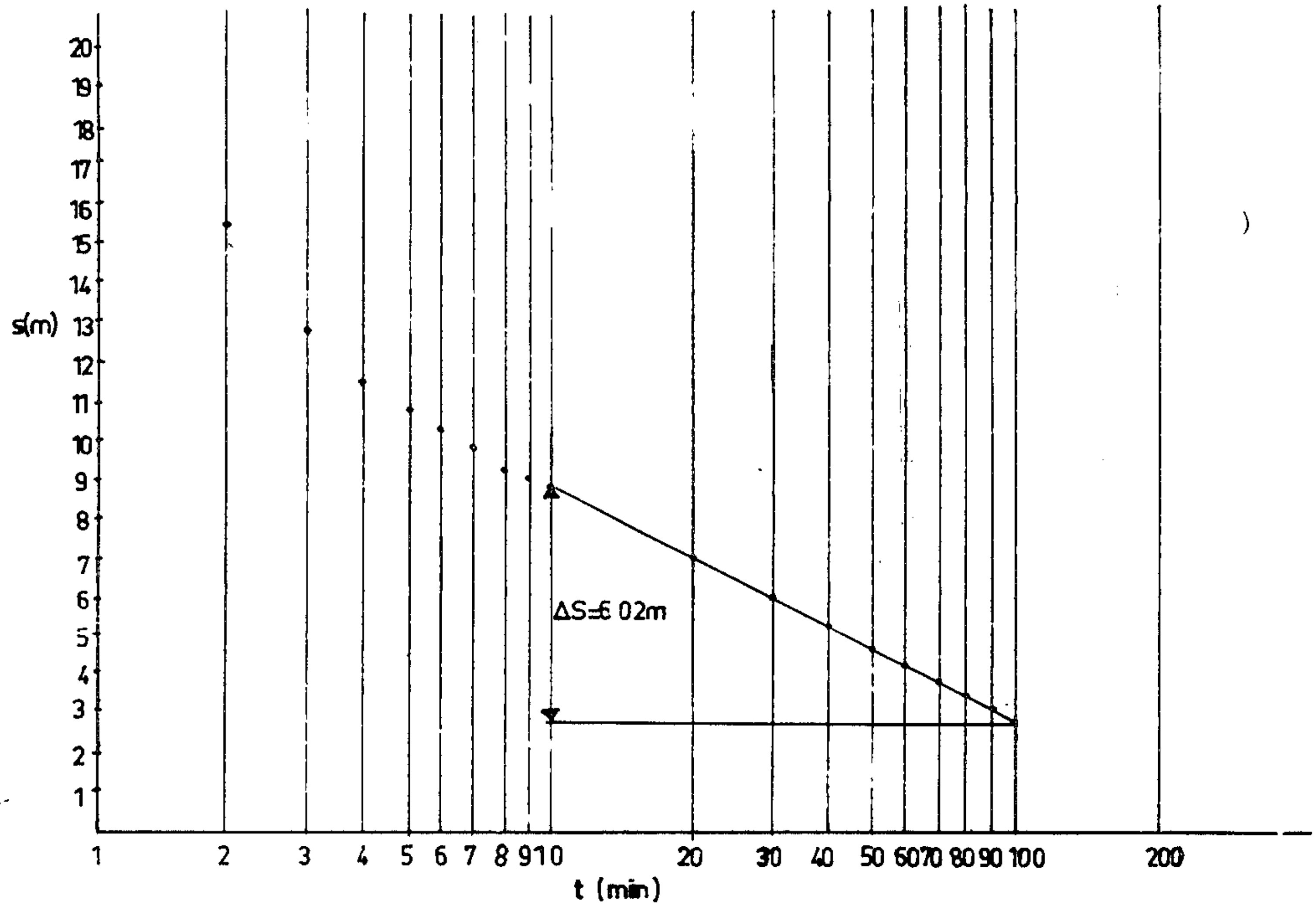
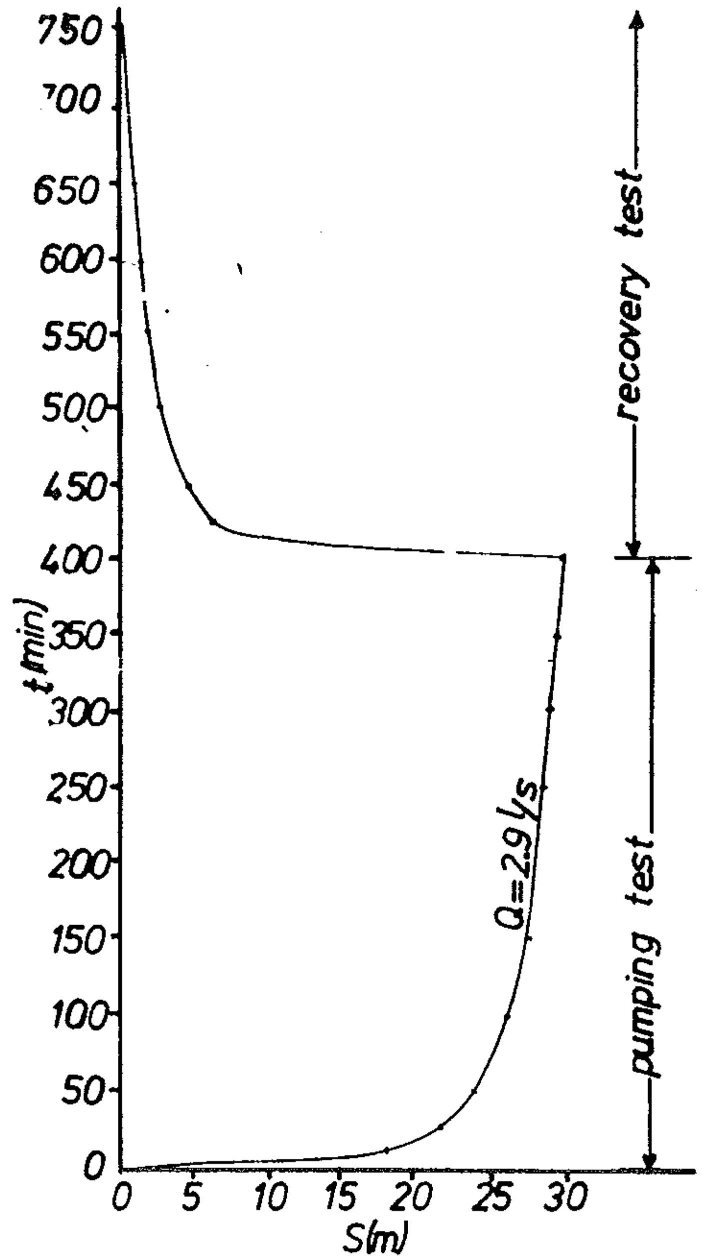


fig.11 Tedecha, Pumping – Recovery curve



permeability of the rock i.e the porosity of amygdailoidal basalt is smaller than that of vesicular basalt. But the permeabilty can not be easily determined because the voids may or may not be interconnected.

The water rich aquifer in the area is located at depth and is made of basaltic material of different flow units which possess different permeability value. Hence, the permeability of scoriaceous basalt will be very high in the sequence if the fracture or crack size in the rest basalt is small. If the fractures are wide enough to increase zenital and azimutal permeability, the scoriaceous basalt will have low permeabilty.

TABLE 3 DUD WELL AND BORE WELL INVENTORY

Code	Location and/or owner of the well	Map reference	Ele. a.s.l(m)	Date comp (G.c	cas.d. in	Tot. dep. (m)	Pump pos. (m)	Static water level (m)	Dynamic level (m)	Type of pump	Yield l/s	Water use
1	D.Z swine farm	1:25000	1910	1981	6	90	45	57.4	-	sub.	-	for pigs plant.
2	Poultry devp't feed pro.	,,	1900	1960	6	-	65	55.22	-	,,	-	for poul. food pro. plant.
3	,,	,,	,,	1988	6	130	75	54.49	-	,,	-	,,
4	,, (Lemlem tabia)	,,	1910	1979	6	120	-	54.44	-	,,	0.83	,,
5	,,	,,	1910	1980	6	120	75	54.43	-	,,	0.7	,,
6	WSSA (DCA)	,,	1895	1990	6	80	65.25	42.64	-	,,	3.5	constr.
7	Adea flour mill	,,	1860	1983	6	102.6	57	39.5	40.43	,,	4	domestic factory.
8	,,	,,	1860	1987	6	75	65	39.1	-	,,	3.3	,,
9	D.Z maize mill	,,	1890	-	6	-	40	-	-	,,	3.3	factory
10	DCA ketena2	,,	1890	1985	6	-	81	37.58	-	,,	-	domestic constru.
11	DCA ketena3	,,	1890	1991	6	-	-	37.75	-	,,	-	,,
12	Ato Tilahun (dug well)	,,	1890	1990	-	9.15	-	8.72	-	-	-	domestic cattles
13	WSSA	,,	1895		A	B	A	N D	O	N	D	
14	Ato Megersa (dug well)	,,	1895	1982	-	10	-	8.86	-	-	-	plantati. cattle
15	Ato Gizaw (dug well)	,,	1890	1987	-	10.4	-	8.6	-	-	-	domestic planta.
16	Blata Admasu (dug well)	,,	1895	-	-	13	-	10.55	-	-	-	domestic
17	Ato Tekle	,,	1870	1960	-	10.3	10.1	9.1	-	surface	-	domestic planta.
18	Veterinary collage	,,	1880	1966	6	-	-	18.26	-	sub.	-	domestic, planta. cattle
19	Animal & Fisheries Resource devp't	,,	1880	1986	6	-	-	19.9	-	,,	-	medicine
20	,,	,,	1880	1963	6	50	-	20.2	-	,,	-	,,
21	WSSA shimbra meda	,,	1892	1987	6	86.17	55.68	23.1	38.68	,,	5	domestic
22	,,	,,	1892	1987	6	91	43.59	18.39	-	,,	15	,,
23	,,	,,	1892	1987	8	77.82	43.18	21.23	38.4	,,	15	,,
24	,,	,,	1890	1987	8	79.39	50.75	17.97	33.8	,,	15	,,
25	,,	,,	1890	1987	8	78.94	47.71	16.56	33.64	,,	15	,,
26	,,	,,	1890	1997	6	78.49	40.61	15.13	32.17	,,	5	,,
27	Management inst.	,,	1880	-	8	36	-	21.38	-	,,	-	,,
28	Air force (mang.inst.)	,,	1880	-	6	-	-	20	-	,,	-	,,
29	Hero's center	,,	1880	1979	6	71	47	-	-	,,	5.8	,,
30	,, (dug well)	,,	1880	1953	-	18	9	8.7	-	surface	-	domes. planta.
32	Tedecha	,,	1945	1987	6	139.6	124.48	45.42	-	sub	2.9	domes

...conti. table 3

32	Dukem	,,	1946	1986	6	138	133.5	96.5	-	sub	3.5	domes.
33	Yerer-Buti	,,	1916	1987	6	66.3	61.1	29.59	-	,,	2.5	,,
34	A.F food proc.	,,	1890	-	6	-	-	18.2	-	,,	-	food pr
36	Air force	,,	-	-	-	-	-	-	-	-	-	-

TABLE 4 SPRING INVENTORY

code	Name of the spring	Map refere.	Ele. asl	To ec m p	mode of imergence	Rock type	perenn or interm	flow l/s	metho of measu	kind of developmen	water use
1	Godino spring	1:25000	1995	23	slope 9break	ignim.	perenn	1	observation	concrete	dome.
2	Tebel	,,	1800	20	-	scoria	,,	-	-	none	drink
3	Buti spring	,,	1920	20	cntact	surge	,,	-	-	none	dome.

7. WATER CHEMISTRY

7.1 Sampling and analyses

Chemical analyses were carried out for representative samples collected from bore wells, springs, dug wells, lakes and river water. In August and May 1991, 1 liter of water was collected within plastic bottels.

For the bore hole water, samples were collected in the mornings after the static level measurement has been taken.

For the lakes and the river, samples were collected as near to from the central points as possible.

The chemical composition of the ground and surface waters have been assessed leaving behind the bacteriologcal test because of the short time needed to transport incubated water samples to the laboratory.

Chemical determination was carried out on major cations like sodium, potassium, calcium, magnesium, iron, manganese and on major anions like chloride, nitrate, nitrite, flouride, bicarbonate, carbonate, sulphate and phosphate. Other minor components like aluminium, ammonium and silica have been determined besides bicarbonate alkalinity, carbonate alkalinity and total hardness as $CaCo_3$ of the water.

Chemical analyses were carried out in the laboratory of type. The sampled groundwaters cluster in a group which has practically constant percentage of bicarbonate and carbonate ions and variable cation content that ranges between 60 and 90% in Ca+Mg. The relative abundance of these elements can be related to dissolution processes of minerals such as olivine, pyroxenes and plagioclase as well as from the dissolution of volcanic glass.

Among lake waters, only the Bishoftu Guda and Kuriftu samples clearly fall within the groundwater group in Fig 12 suggesting probable interconnection between groundwater circulation and lake waters. The other lakes are found in quite different position. Hora lake is shifted to the left side of the diagram because of the presence of rather larger amount of Cl probably due to pollution (derived from the settlements around the lake) as suggested also by the relatively high nitrate content. Hora lake could simply represent a polluted product of water similar to those of the groundwater group.

Quite different characterestics are shown, on the contrary, by Bishoftu lake. In fig. 12 this lake water has a HCO_3 + CO_3 percentage similar to that of the groundwater group but with Na + K contents clearly prevailing over Ca +Mg which classify this fluid as water of the sodium bicarbonate type.

Figure 13, in which bicarbonate content is plotted vs TDS for the different water points, stresses the difference

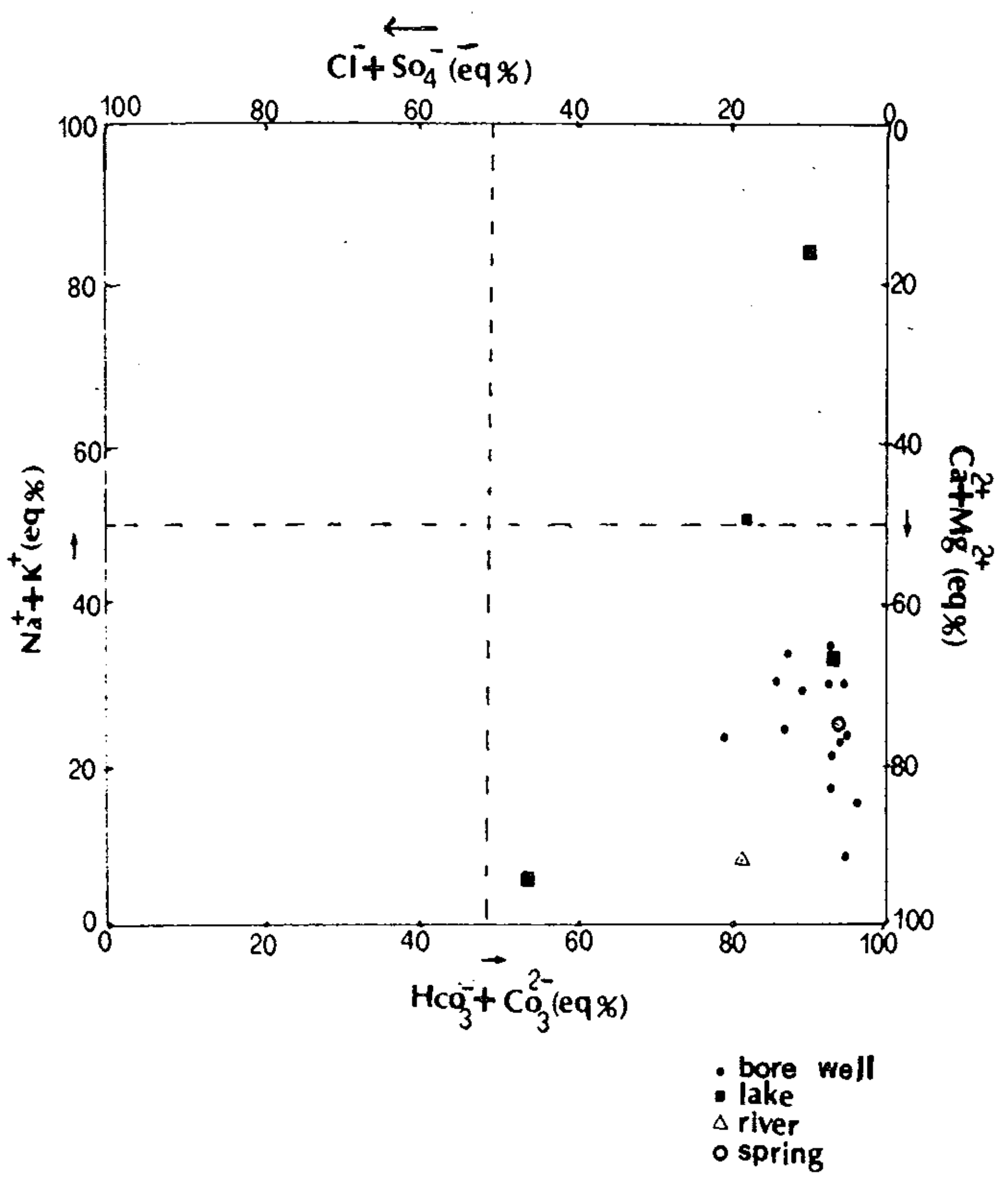


Fig. 12 Water chemical analysis plot on the square piper diagram

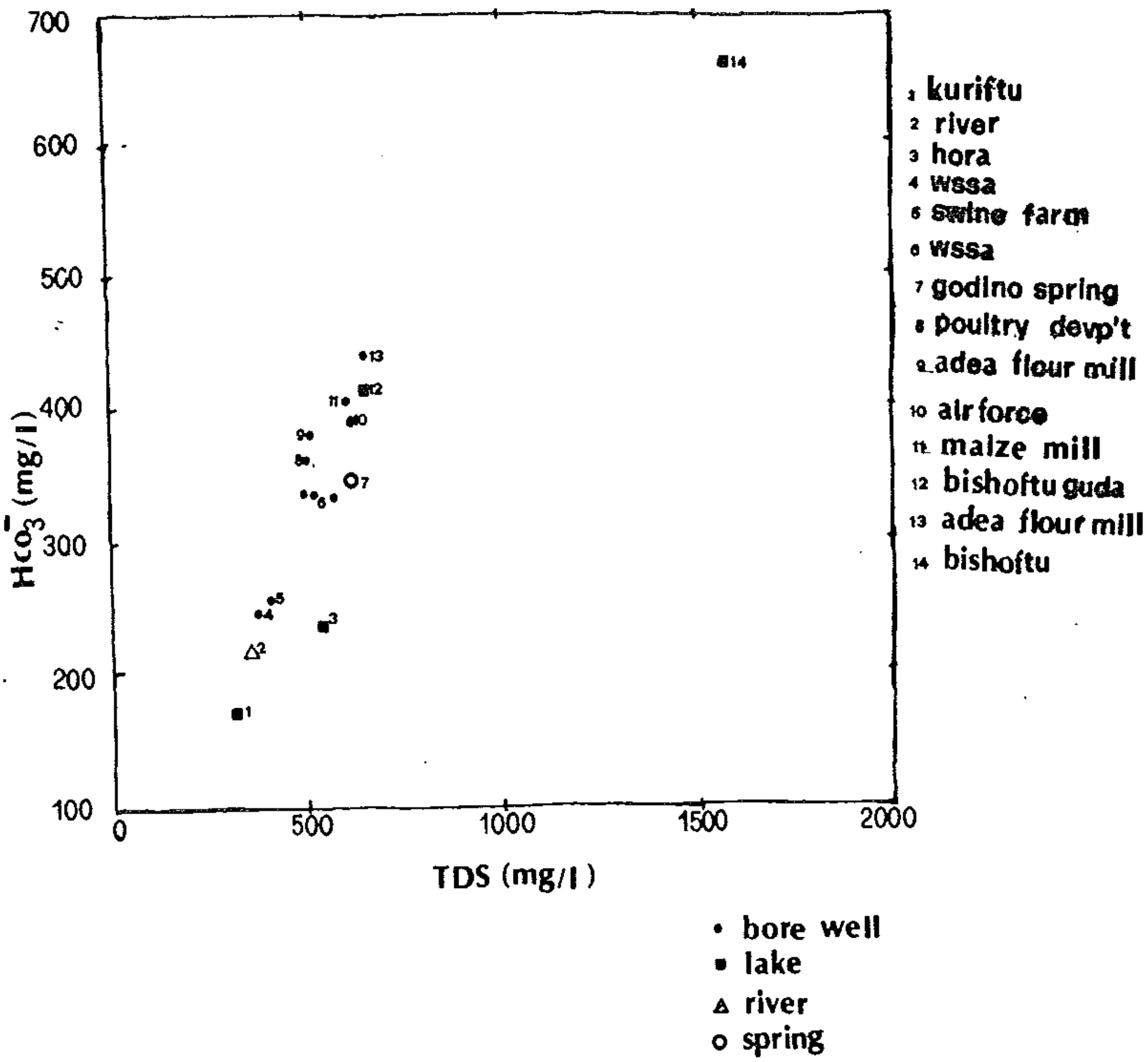


Fig.13 Bicarbonate., vs TDS

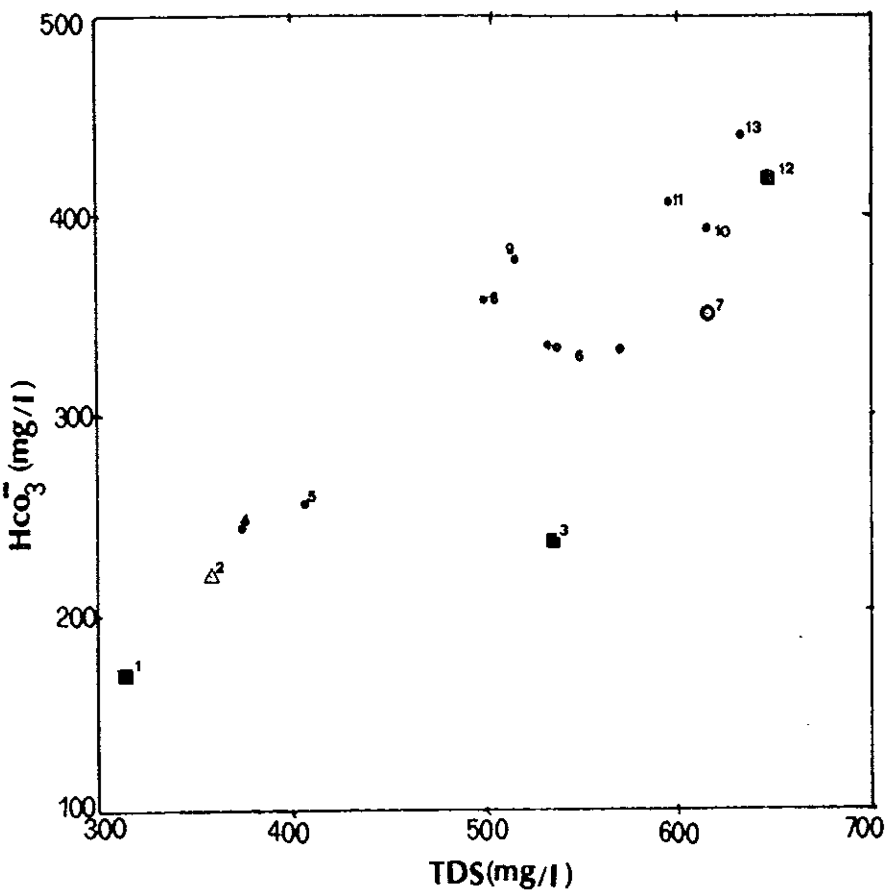


Fig.14 Bicabonate vs TDS

better the relationships between groundwater and water from the lakes.

As a final observation, the magnification of the lower left side of fig.13 is given on figure 14. It shows the occurrence of less saline waters in recharging zone and relatively saline waters in the discharging zone.

7.3 WATER QUALITY CRITERIA FOR DOMESTIC USE

The suitability of waters for domestic purpose is checked comparing with the international standard values set by WHO (1962), USPHS (1962), NASE (1972). The standard values given by the above organizations are based on two criteria:

1. by the presence of objectionable tastes, odour , or color and

2. the presence of substances with adverse physiological effects

The chemical constituents of all waters fall within the standared limits (see table 5). Taking into consideration only the chemical composition, there is no objection concerning the quality of water for domestic consumption.

But lake waters, because of pollution it recieves from various source, are not used as a source of water for potable supply purposes.

High sodium waters are generally unsuitable for drinking.

The most hazardous ion to health, flouride, which is abundant in the rift valley waters, is very small in all waters found in the area with average value of 0.76 mg/l ascompared to waters found in Metehara (2.4 mg/l), Nazreth (4.6 mg/l), Bulbula (14.75 mg/l), Koka (29.5 mg/l), etc. (source WSSA central region water quality control service).

The lower concentration of flouride in the studied area can be explained as a consequence of mild volcanic activity and faulting in the area investigated.

The overall ammonium and nitrate aboundance in the area is small which indicates the presence of small amount of contaminants.

All waters are found to be hard waters with the total hardness greater than 150 mg/l as $CaCO_3$ (Kashef, 1986).

parameters	Maximum acceptable	Maximum allovable
Taste	Tasteless	-
Odour	Odourless	-
Color	Colorless, 5	50
Turbidity	Clear, 5	25
Settleeable Solids	Absent	
Floating Solids	Absent	
Suspended Solids	Absent	
Filtreable residue dried at 105 ^{o}c	500mg/l	
pH	7-8.5	9.2
Total solids	500mg/l	1500mg/l
Dissolved solids	500mg/l	1000mg/l
Total hardness as $CaCo_3$	100mg/l	500mg/l
Carbonate alkalinity as $CaCo_3$	-	120mg/l
Bicarbonate alkalinity as $CaCo_3$	-	150mg/l
Ammonium (NH_4^+)	-	0.5mg/l
Sodium (Na^+)	10mg/l	200mg/l
Potassium (k^+)	-	2000mg/l
Calcium (Ca^{2+})	50mg/l	150mg/l
Magnesium (Mg^{2+})	50mg/l	150mg/l
Iron (Fe^{2+})	0.3mg/l	1mg/l
Manganese (Mn^{2+})	0.05mg/l	0.5mg/l
Chloride (cl^-)	200mg/l	250mg/l
Flouride (F^-)	0.6mg/l	1.4mg/l
Nitrite (No_2^-)	1mg/l	2mg/l
Nitrate (No_3^-)	10mg/l	45mg/l
Bicarbonate (Hco_3^-)	150mg/l	500mg/l
Carbonate (Co^{2-})	-	20mg/l
sulphate (so_4^{2-})	200mg/l	400mg/l
Total silica (sio)	40mg/l	50mg/l

Table 5, Drinking water standard according to WHO, NASE, & USPHS

WHO=World Health Organization ,1962
NASE=Nationa Academy of Science and Engineering, 1972
USPHS=United States Public Health Service, 1962

7.4 WATER QUALITY CRITERIA FOR AGRICULTURE

As the salt harms the growth of plants, sodium concentration has been used to check the suitability of the waters for agricultural purpose. The two important effects of the sodium are a reduction in soil permeability and a hardening of the soil. Both effects are caused by the replacement of calcium and magnesium ions by sodium ion.

A simple method of evaluating the effects of high sodium water is expressed assodium-adsorption-ratio (SAR) as recomended by Richards (1954).

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}}$$

where the concentration of the constituents are expressed in meq/l.

The above formula has been used to classify the waters found in the area for irrigation. The values are presented in table 6.

A low SAR (2 to 7) indicates little danger for sodium;medium hazards are between 7 and 18, high hazards between 11 and 26 (Fetter, 1986).

Well Owner or Location	Well code	SAR
1. Debre Zeit Swine farm	1	1.0
2. Poultry Devp't and Food P.En.	4	0.5

3. Adea Flour Mill	7	0.6
4. Adea Flour Mill	8	0.3
5. Debre Zeit Maize Mill	9	1.2
6. WSSA(shimbra meda)	22	0.7
7. WSSA(shimbra meda)	23	0.7
8. WSSA(shimbra meda)	24	0.9
9. WSSA(shimbra meda)	25	0.9
10. Air force	28	1.2
11. Tedecha Farmers	31	0.9
12. Godino spring	-	1.0
13. Lake Hora	-	0.2
14. Lake Bishoftu	-	9.7
15. Lake Bishoftu Guda	-	0.6
16. Lake Kurfitu	-	0.7
17. Ato Gizaw (dug well)	15	0.8
18. Wodecha River	-	0.1

Table 6, SAR of waters found in the area

The SAR values of all waters in the basin ranges from 0.1 to 9.7. The values indicates that the ground, surface and spring waters have very small amount of sodium so that the waters have very good quality for irrigation.The chemical constituents of each water arealso below the standard limit.Therefore, no objection will rise to use the waters found in the area for irrigation purpose.

Another classification of water for irrigation is with respect to electrical conductivity and percent sodium as recommended by Wilcox (1955).

The sodium content is usually expressed in terms of percent as:

$$\%Na = \frac{(Na+K)100}{Ca+Mg+Na+K} \qquad (1)$$

where ionic concentrations are given in meq/l. The electrical conductivity (EC) caused by cations have been calculated using the following formula, equation 2, at a standard temperature.

$$1meq/l \text{ of cations} = 100EC \times 10^{6} \qquad (2)$$

The EC denotes electrical conductivity of most waters with EC ranging between 100 and 5000 micromhos/cm at 25°C (Kashef 1986).

Representative samples of waters were taken to calculate per cent sodium and EC appling equation 1 and 2 the values are listed in table 7.

Well Owner or Location	WELL CODE	%Na	$ECx10^{6}$ at 25°C
1. Debre Zeit Swine farm	1	23	458.04
2. Poultry Devp't and F.P.E.	4	16.7	636.17
3. Adea Flour Mill	7	15	734.1
4. Adea Flour Mill	8	8.6	678.44
5. Debre Zeit Maize Mill	9	34	697.07

6. WSSA(shimbra meda)	22	22.4	657.4
7. WSSA(shimbra meda)	23	22.5	594.4
8 WSSA(shimbra meda)	24	28.9	633.4
9. WSSA(shimbra meda)	25	28.9	633.4
10.Air force	28	34.1	743.44
11.Tedecha	31	25.6	451.9
12 Godino spring	-	28.5	713.4
13.Lake Hora	-	6.5	704.0
14.Lake Bishoftu	-	83.9	2109.04
15.Lake Bishoftu Guda	-	30.4	747.04
16 Lake Kurfitu	-	51.0	418.5
17.Ato GIZAW (dug well)	-	21.7	1223.04
18.Wedecha river	-	8.1	446.4

Table 7, %Na and EC of waters in the area.

Based on the electrical conductivity and percent sodium, the quality classification of water for irrigation. is given in fig 16.

From the graph it can be concluded that most waters have good quality except some lake waters which have unsuitable and permissible quality for irrigation.

According to the quality criteria of waters for irrigation which was set by California Water Pollution Control Board, the maximum acceptable and the maximum allowable concentration of sodium ion in the water is 50 mg/l and 300 mg/l respectvely.

The sodium content of almost all water found in the area is below the range given above. Which indicates, except lake Bishoftu water, the suitability of groundand surfacewaters for agricultural purpose.

Besides sodium hazard, salinity hazard of the waters isassessed by plotting conductivity (micromhos) vs sodium adsorption ratio(SAR), (see fig 17).

From the plot it is observed that all ground and surfacewaters have medium to very high salinity hazard and low sodium hazard.But still one lake (Bishoftu) indicates high sodium hazard and very high salinity hazard. The presence of high salinity indicates poor drainage and less opportunity for leaching excess salts.

7.5 WATER QUALITY CRITERIA FOR INDUSTRY

Water quality standards for industrial use depend on the function of the industry. Recommended water quality criteria for selected industries are given in table 8(source American Water Works Association 1971). The water quality criteria for food processing industries is more or less similar to those of drinking waters (Kashef 1986). These industries are the most abundant industries found in the area. Based on the standard water quality criteria, the waters found in the area fits the water quality need of food processing and other simillar industries found in the area.

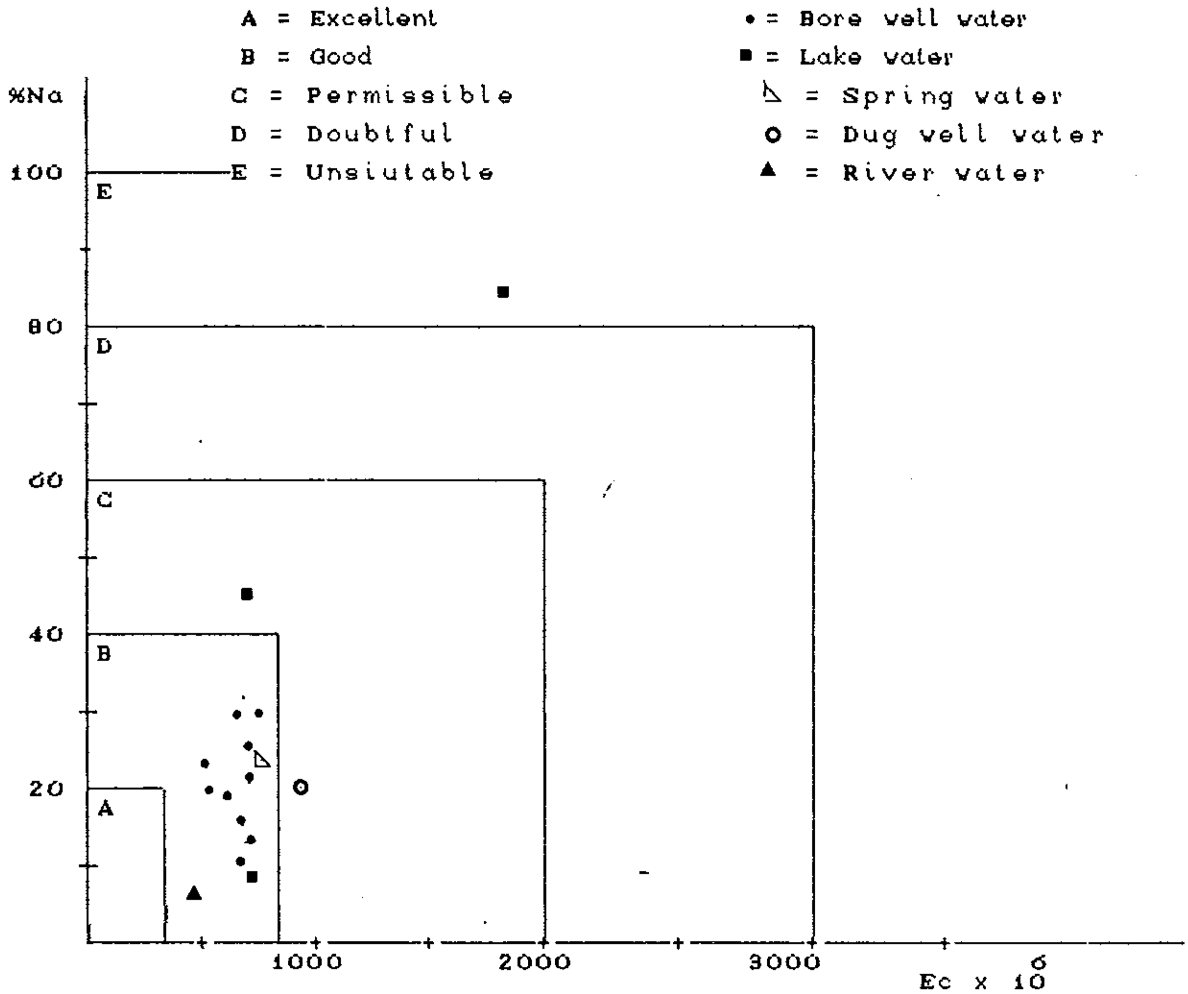


Fig.16 ,Classification of water for irrigation (after Wilcox, 1955)

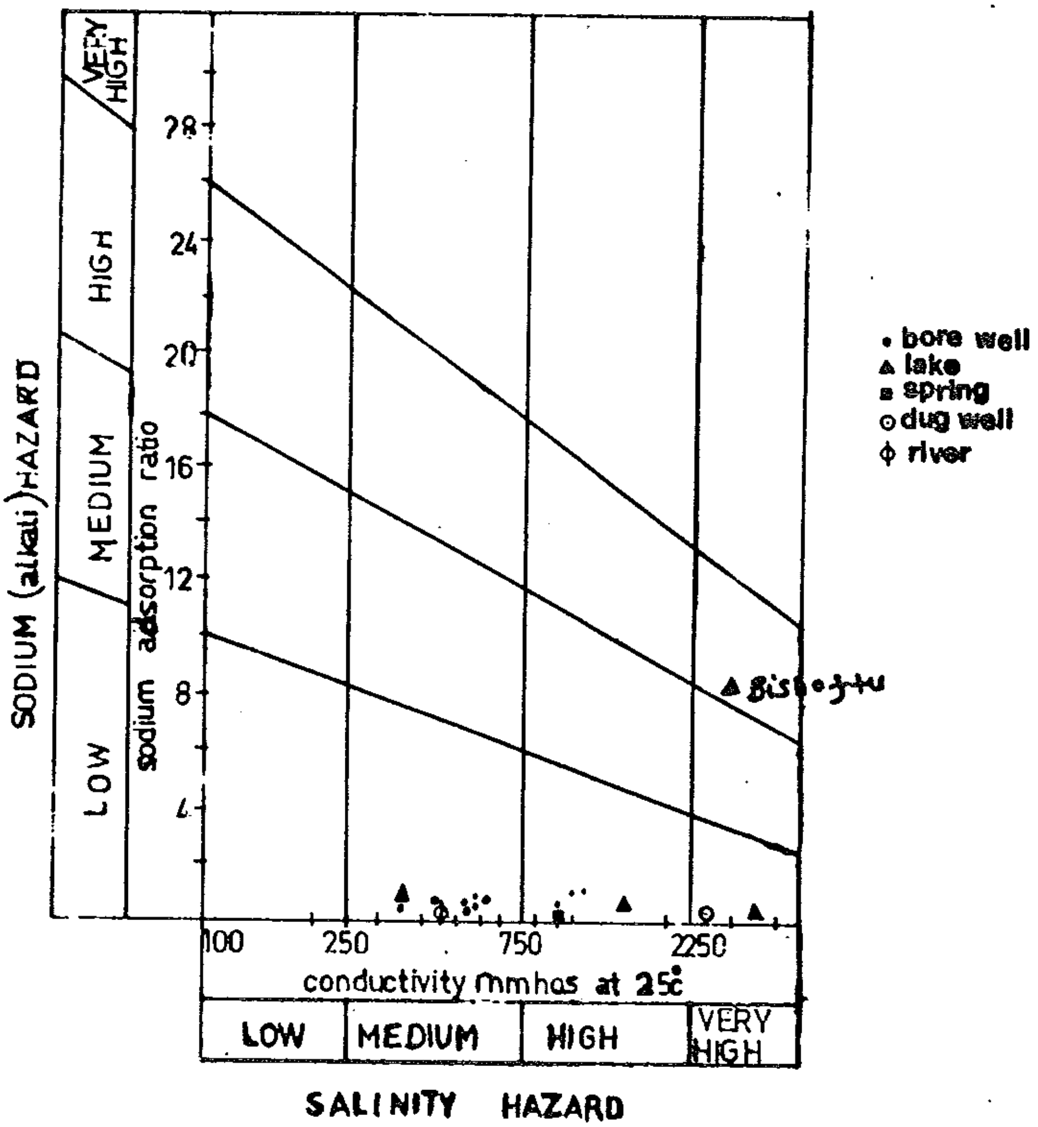


Fig-17 – CLASSIFICATION OF WATER FOR IRRIGATION BASED ON SALINITY HAZARD (after wilcox, 1955)

Parameters		Acceptable value
Turbidity		1-10
Color		5-10
Taste and Odour		Inoffensive
Dissolved solids		850mg/l
Total hardness as $CaCo_3$		10-250mg/l
Total alkalinity as $CaCo_3$		30-250mg/l
Total solids		1000mg/l
pH		>7.5
Sodium	(Na^+)	300mg/l
Potassium	(K^+)	-
Magnesium	(Mg^+)	40mg/l
Calcium	(Ca^{2+})	80mg/l
Iron	(Fe^{2+})	0.2mg/l
Manganese	(Mn^{2+})	0.2mg/l
Chloride	(cl^-)	300mg/l
Flouride	(F^-)	1mg/l
Nitrite	(No_2^-)	-
Nitrate	(No_3^-)	20mg/l
Bicarbonate	(Hco_3^-)	300mg/l
Carbonate	(Co_3^{2-})	-
Sulphate	(So_4^{2-})	-
Silica	(Sio_2)	50mg/l

Table 8 ,Water quality criteria for food processing food canning and freezing industries.

source-American Water Works Association
Water quality and Treatment, McGrav-Hill
NevYork, 1971

8. CONCLUSION AND RECOMMENDATION

CONCLUSION

Due to the similarity in hydraulic properties of the rocks exposed in the area, one hydrogeological basin has been recognized which has the same boundaries of the two catchment areas: Yerer-Sokoru and Wodecha 2. The main hydrogeological basin is divided in three sub-basins: Yerer, Sokoru and Wodecha 2.

The main hydrological elements such as rainfall, evapotranspiration and runoff have strong seasonal variations in the area. The smallest possible average rainfall depth in the area is 859.9 mm. The average yearly temperature is 19.1^{o}Cwhile the mean yearly maximum temperature is 25.4^{o}C and the mean yearly minimum temperature is 11.3^{o}C.

Due to the high daily temperature, the Potential evapotranspiration (857.1mm) is higher than the Actual evapotranspiration (606.2mm).

Because of the large value of evapotranspiration, hardly any precipitation infiltrate in to the ground. The amount of rainfall, which is able to escape the evapotranspiration processes recharges the aquifer of the area.

Since the runoff of the Yerer-Sokoru basin infiltrate directly into the alluvial deposits, the only runoff that leaves the studied area comes through Wodecha river and is

25.568 million cubic meter of water. The amount of water which is actually available to recharge the groundwater circulation within the hydrogeological basin is 54.391 million cubic meter.

The most important aquifer found in the area, which is recognized by means of several field checks and periodical phreatimetric measurement is located in the lower part of the area and is made of various basaltic flow units. The groundwater occur within the unconfined, semiconfined or confined conditions, where the thin clayey layers play an important role as leaky aquitards.

The hydraulic conductivity and transmissivity of the aquifers found in the north western part of the area is 1.5 x 10^{-4}cm/s and 8.8 x 10^{-5} m^2/s while in the central part of the area the former is 4.05 x 10^{-3}cm/s and the later is 0.9x 10^{-3} m^2/s. These results represent the smallest values in the area.

All the three sub-basins play the most important recharging function, while Wodecha basin is known to have the highest groundwater potential.

From the shape of the groundwater level contour line it is confirmed that the three sub-basins converge towards the main aquifer occuring in the lower part of the area which is considered as a medium through which the discharge of the whole hydrogeological basin takes place. The general trend of the groundwater flow direction is East - West.

The complex multilayer aquifer seems tobe hydraulically connected with the lakes particularly with those occuring along the main groundwater flow direction (i,e Kurfitu, Bishoftu Guda and Hora).

From the geochemical point of view, Bishoftu Guda and Kuriftu lake fall in the groundwater group while Hora lake shows large amount of chloride concentration. But Bishoftu lake represents the most mature water in the area as it contains large amount of bicarbonate.

From lake level fluctuation data it is known that in September and October the level was increased indicating that the groundwater has infulence on the lakes.

Most of the waters show generally a low degree of water-rock interaction with TDS (total dissolved solids) values ranging between 300 and 700 mg/l.The most concentrated water in the study area is from Bishoftu lake which has a salinity of about 1600 mg/l.High saline waters are located within the discharging zone and less saline waters in the recharging zone.

The sampled groundwater has constant percentage of bicarbonate and carbonate ions and variable cation content that ranges between 60 and 90%,(eq %),in calcium and magnesium.Generally they are calcium magnesium bicarbonate type waters.But Bishoftu lake is sodium bicarbonate type.

RECOMMENDATION

High sodium hazard can be prevented by cation exchange processes. Organic manures can help in ckecking the increase in the exchangeable sodium in soils.

The waters with high salinity hazard can be used under proper soil drainage condition and for medium to high salt tolerant crops such as barley, cotton, beets etc. If the fertility condition of the soil is improved, other crops can also be irrigated with the water.

Assuming the necessary daily water consumption of the population in the basin is 100 l/day/person, since in the coming 30 years the total population will be about 1000 000, the amount of water required will be 36.5 million cubic meter.

Since towns are highly populated, their water consumption is large as compared to rural villages. Because of the location of Debre Zeit town on the main aquifer, good productive wells can be constructed.

Due to poor productivity of the aquifer found in the farmer's village and the lack of electricity, deep bore wells can be constructed with proper installation of hand pumps.

Out of $54.391 \times 10^6 m^3$ of total available water, the remaining 17.891 million cubic meter can be used for industrial and agricultural purpose. Most part of the remaining water (about 10 million cubic meter)has to be given to the industries and the rest 7.891 million cubic meter has to be alloted to the agricultural purpose. Additional water for the agricultural work can be taken from Wodecha river by construction an earth dam south of Godino village.

The only way to increase the groundwater recharge of the whole area is by using the runoff from Wodecha river for artificial recharge and by connecting the Yerer-Sokoru catchment area with Wodecha catchment area by means of an underground tunnel and several hydraulic installations.

The proper place for future establishment of industries in the area is in the vicinity of swampy area.

The most important water management which has to be practiced in the area is planning and protection of the water from contaminants.

The following are recommendations for planned groundwater utility in the area:

1. cotrolled withdrawals of the water in order to preserve aquifer collapse and to prevent the overdaft of the aquifer to maintain the water level shallow which encourage plant growth.

2. proper artificial recharge of the multilayer aquifer which are found north,west and south of the area by collecting seasonal surface runoff.

3. protecting the aquifers from contamination.

4. conjuctive use of groundwater and surface water for irrigation.

Abandoned wells which are found in the area have to be back-filled forever. If they remain open, the aquifers can be easily contaminated by solid and liquid waste disposal.

Before costruction of cesspools, septic tanks, gasoline storages etc, approprate determination of depth of the well and thickness of the wall has to be done because of the location of Debre Zeit town on the main dischanging zone. Infact, immediate contamination of groundwater may result from leakages. Generally, in the studied area, planning is necessary to develop the best policies for the regulation of contaminants that are discharged into the groundwater and surface waters.

Annex 1 Pumping test of Tedecha well

Pumping test

Owner	-WSSA
Location	-Tedecha
Pumping date	-10,05,1987
Total depth	-140m
Pump type	-Electrical submersible
Type of test	-Constant rate
Pumping rate	-2.9l/s

Elapsed time t(min)	Water level B.G (m)	Drawdown S(m)
0	45.42	0
0.5	48.70	3.18
1	52.80	7.28
1.5	53.90	8.38
2	55.28	9.76
2.5	56.57	11.05
3	57.60	12.08
3.5	58.35	12.83
4	59.00	13.48
4.5	59.60	14.08
5	60.12	14.60
6	60.98	15.46
7	61.70	16.18
8	62.31	16.79
9	62.91	17.39
10	63.40	17.88
12	64.07	18.55
14	64.68	19.16
16	65.23	19.71
18	65.70	20.18
20	66.12	20.60
25	66.93	21.41
30	67.55	22.03
35	68.05	22.53
40	68.52	23.00
45	68.93	23.41
50	69.27	23.75
55	69.57	24.05
60	69.85	24.33
70	70.33	24.81
80	70.73	25.21
90	71.11	25.59
100	71.45	25.93
150	72.70	27.18
200	73.49	27.97
250	74.13	28.61
300	74.50	28.98
350	74.85	29.33
400	74.98	29.46

pumping hours=7:06

Annex 5
Subject - Precipitation in mm
Station - Air force
Latitude - 08°44'N

Longitude - 38° 58°E
Altitude - 1850 m
Element - Monthly total rainfall

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
1951	0.0	0.0	49.0	36.5	x	15.2	118.5	80.4	40.0	25.6	2.0	2.2	369.4
1952	0.0	0.0	0.0	42.6	17.2	59.5	134.2	187.8	127.4	9.2	0.0	0.0	577.9
1953	0.0	24.4	11.0	88.0	18.0	77.8	96.6	165.2	53.2	0.0	0.0	24.7	557.9
1954	0.0	0.0	57.0	30.5	6.6	70.5	160.0	130.7	174.2	28.9	0.0	0.0	683.4
1955	11.1	0.0	23.0	36.4	0.0	30.1	353.9	208.4	142.9	0.0	0.0	0.0	855.8
1956	1.5	1.4	8.9	48.0	7.1	84.3	134.9	7[illegible].0	[illegible]	50.4	[illegible].5	0.4	4[illegible].4
1957	0.0	25.6	65.0	91.5	48.1	123.1	209.5	305.4	24.8	5.0	1.0	1.0	900.0
1958	65.5	52.3	23.8	49.7	7.0	175.9	243.8	24[illegible]	172.2	16.3	0.8	0.0	1050.5
1959	18.0	34.0	33.4	43.9	42.1	108.3	244.3	197.4	154.2	14.5	0.0	16.0	911.1
1960	0.8	5.0	48.1	16.6	99.5	56.3	167.9	269.5	161.0	0.0	5.2	0.0	829.9
1961	0.0	5.2	111.2	41.9	28.2	107.2	153.8	[illegible]	89.9	59.5	16.7	0.0	818.6
1962	0.0	1.0	62.0	24.7	2.7	0.0	202.5	237.3	181.8	46.5	0.9	21.0	780.4
1963	3.0	1.6	0.0	61.9	103.5	76.0	281.2	457.0	105.2	0.0	2.7	27.5	1119.6
1964	0.0	0.0	0.0	184.0	46.9	56.0	434.5	365.7	187.1	[illegible].6	0.0	11.0	1507.4
1965	37.8	0.0	58.5	29.5	0.0	38.2	408.5	246.5	1[illegible].6	76.9	6.7	0.0	1028.2
1966	0.0	160.8	15.1	149.8	9.9	120.1	264.8	581.4	147.6	37.5	0.0	0.0	1286.8
1967	0.0	0.0	100.0	73.9	164.2	62.1	314.2	259.6	1[illegible]6.0	16.0	79.1	0.0	1205.1

Annex 5

Subject-precipitation in mm
Station-Air force
Latitude-08°44 N

Longitude-38°58 E
Altitude-1850m
Element-Monthly total rainfall

YEAR	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1968	0.0	190.1	12.6	102.0	5.0	60.1	272.3	140.2	203.0	0.0	17.8	0.0	1083.1
1969	11.0	0.0	56.7	104.0	24.9	137.1	125.1	278.6	64.6	7.5	3.2	0.0	812.7
1970	44.1	31.1	7.5	21.4	45.3	56.0	250.7	290.1	112.0	5.9	0.0	0.0	854.1
1971	0.7	0.0	16.5	63.0	107.6	121.3	215.8	281.0	123.1	2.9	3.0	14.4	949.3
1972	0.0	95.2	53.7	136.0	47.7	102.1	214.4	224.6	66.0	2.6	0.0	0.0	942.3
1973	0.0	0.0	0.0	2.7	28.0	x	138.5	251.9	133.7	42.1	0.0	2.0	598.9
1974	0.0	12.5	104.2	7.6	98.1	114.4	307.3	199.0	x	3.0	0.0	0.0	846.1
1975	0.0	x	19.5	72.1	54.5	149.7	375.1	223.4	154.0	7.0	0.0	0.0	1055.7
1976	0.0	0.0	71.1	x	81.7	102.9	x	232.2	42.2	3.8	35.2	0.8	569.9
1977	43.1	1.0	87.7	90.2	57.6	101.3	272.8	202.7	82.2	x	3.4	0.0	942.0
1978	1.4	69.0	34.5	47.4	28.5	133.7	132.3	191.1	122.3	24.6	x	0.1	784.9
1979	77.7	0.0	54.7	13.4	76.0	110.9	224.9	187.6	83.8	12.6	0.0	0.1	841.8
1980	20.0	10.1	32.3	24.2	69.4	76.1	242.4	215.5	58.1	40.7	0.0	0.0	788.8
1981	0.0	20.5	164.2	62.1	7.1	35.8	294.6	151.8	162.8	4.2	0.0	1.2	904.3
1982	20.8	75.4	34.5	47.3	57.7	91.0	123.9	238.8	46.1	25.5	9.4	0.0	765.4
1983	0.0	10.2	46.8	105.2	209.2	149.4	128.8	344.8	88.6	23.4	0.0	0.0	1106.7
1984	0.0	0.0	19.3	0.0	108.7	80.7	220.5	x	85.0	0.0	0.0	3.6	517.6
1985	3.5	0.0	14.5	51.9	111.5	74.0	307.3	272.7	1.1	1.1	0.0	0.6	838.2
1986	0.0	23.6	51.7	141.6	72.4	166.8	178.8	162.5	90.2	3.2	0.0	0.0	890.8
1987	0.0	61.4	138.2	90.1	164.0	65.5	83.3	155.9	80.9	4.6	0.0	0.0	843.9
1988	8.0	14.9	6.0	44.6	36.8	100.6	145.9	236.8	121.4	16.6	0.0	0.0	731.6
1989	0.9	12.2	35.1	47.0	0.4	59.0	138.7	171.7	135.2	21.2	0.0	0.0	624.7
Ave	9.5	24.6	44.4	60.0	55.0	89.2	215.2	229.4	107.3	16.9	5.1	3.3	859.9

Annex 6

Subject: Mean Monthly Temperature(°C)
Latitude: 08°44,N

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Aver.
1951	16.4	18.1	19.3	16.6	x	19.1	x	16.9	18.2	x	22.7	17.6	18.3
1952	x	x	20.7	20.4	20.1	20	18.1	17.1	18	17.6	16.7	17.3	18.6
1953	17.8	19.2	20.4	20.4	20.8	20.1	17.9	17.4	17.6	18.4	15.3	16.9	18.5
1954	16.9	19.6	20.5	21	21	19.4	16.5	17.4	17.8	16.9	17.3	16.9	18.4
1955	18.2	19.2	20	20.6	20.1	19.1	18.2	17.8	18.1	17.9	18	18.1	18.8
1956	17.8	18.3	20.7	21	20.7	19.7	17.9	19.9	18.1	17.6	15.8	16.7	18.6
1957	17.2	18.3	19.2	19.8	20.2	18.8	18.6	18.1	18.7	18.9	19.4	17.5	18.7
1958	18.4	18.6	18.3	20.9	21.7	19.7	18.3	18.1	18.8	18	17.1	18.2	18.8
1959	19.4	19.3	20.8	21.6	21.5	20.4	18.4	18.1	18.5	18.8	17.1	17	19.2
1960	17	19.3	20.3	20.8	20.6	20	19.3	19	18.7	18.4	17.4	17.9	19
1961	18	19.1	20	20.3	21.1	19.3	18.1	16	18.9	18	17.8	16.7	18.6
1962	16.6	17.9	19.7	21	21	19.9	14	18.6	19.2	17.3	17.8	18.1	18.4
1963	17.6	19.8	21	19.8	20.2	20	18.8	18.5	18.7	18.5	18.4	17.7	19.1
1964	18.6	20.5	21.8	20.5	19.9	18.8	18.1	18	18	17.9	17.2	16.3	18.8
1965	18.1	18.5	19.9	20.8	21.2	20.9	18.7	18.4	19	18.2	18	17.6	19.1
1966	18.8	19.5	20.1	20.5	21.2	19.6	18.7	18.5	18.2	18.5	18	17.6	19.1
1967	16.8	19.6	20.4	20.3	20.1	19.7	17.9	18.3	18.5	17.7	17.6	14.9	18.5
1968	16.6	18.1	18.6	19.9	20.4	19.8	18.1	18.4	19.1	18.4	17.7	17.4	18.5
1969	19	18.3	19.5	20.6	20.5	18.9	18.6	18.5	19	18.8	18.4	17	18.9
1970	18.7	19.8	20.3	21.1	21.4	20.5	19.2	18.2	18.8	18.7	16.3	16.1	19.1
1971	17.7	~~18.6~~	20	20.3	19.8	19	18.3	17.7	18	17.9	16.6	15.8	18.3

Annex 6
Subject - Mean monthly temp.(°c)
Latitute - 08° 44' N
Longitute - 38° 58'E

Altitude - 1850 m
Station - Airforce

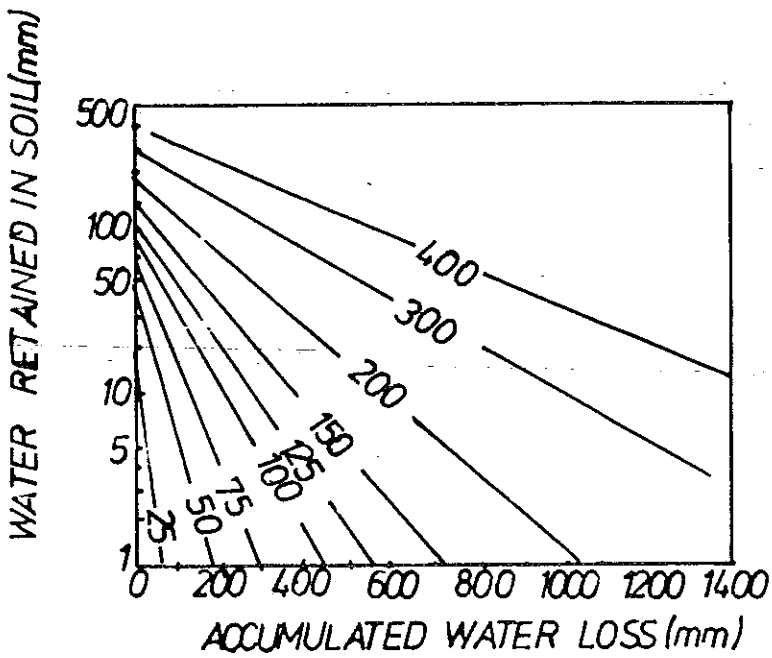
YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	AVE
1973	18.2	19.4	21.2	22.5	20.6	18	18.5	17.6	18.1	17.2	16.8	15.2	18.7
1974	17.8	18.6	19.6	20.2	20.0	19.1	17.9	17.8	x	18.4	15.9	16.5	18.3
1975	17.1	x	20.8	20.3	20.6	18.9	17.6	17.6	17.9	17.4	16.0	16.3	18.3
1976	16.9	19.7	20.3	x	12.7	19.4	x	18.0	18.6	19.2	17.6	17.3	18.7
1977	17.2	18.0	20.0	20.1	20.0	19.3	18.3	18.0	17.9	x	16.9	16.7	18.4
1978	16.9	18.8	20.0	21.2	20.3	19.3	18.3	18.7	18.4	18.1	x	17.3	18.8
1979	18.0	18.9	19.7	20.6	20.5	19.7	18.1	18.5	18.7	18.4	17.2	17.2	18.8
1980	17.6	19.3	21.0	20.8	20.7	19.8	18.7	18.1	18.5	18.3	17.9	16.8	19.0
1981	18.5	19.3	19.8	19.5	20.7	20.4	18.7	18.3	18.2	17.5	17.0	15.8	18.6
1982	17.8	18.7	19.4	19.2	20.4	19.7	18.5	18.1	18.7	17.7	18.1	18.0	18.7
1983	17.9	19.9	21.0	20.3	21.0	19.6	19.4	18.7	18.7	18.2	17.8	17.1	19.1
1984	17.1	17.6	20.6	22.0	20.7	19.5	18.5	x	18.5	18.1	18.0	16.8	17.6
1985	17.5	18.3	20.5	19.8	19.7	19.5	17.5	17.4	17.9	17.6	17.7	17.3	18.4
1986	x	x	x	x	x	x	18.6	19.0	18.7	18.7	18.3	18.0	-
1987	17.8	19.2	20.2	20.1	20.8	19.6	20.1	19.5	19.8	19.9	18.4	18.4	19.5
1988	19.1	20.6	22.0	22.1	21.5	20.4	18.9	18.7	18.7	18.2	16.6	17.1	19.5
1989	18.2	22	21.4	23.4	21.7	22.0	19.9	19.3	19.9	18.8	18.8	19.9	20.4
Ave.	17.1	19.3	20.2	20.5	20.6	19.7	18.3	18.2	22.8	18.2	17.5	17.2	19.1

ANNEX 7

Subject - Monthly total evaporation in mm- Altitude - 1850 m
Latitude - 03° 44' Station - Airforce
Longitude - 38°05'E

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	TOTAL
1975	x	97.7	299.0	x	278.5	79.5	35.1	48.9	x	109.0	209.1	x	1156.8
1976	199	244.0	209.4	180.0	118.1	177.9	89.5	105.6	174	277.1	191.1	217.9	2183.6
1977	173.6	x	274.5	258.1	x	81.0	x	x	x	x	x	x	767.0
1978	x	x	x	204.5	x	86.0	x	x	x	x	x	x	290.5
1979	123.8	176.7	220.9	227.3	231.3	215.1	x	x	149.8	255.0	258.5	255.9	2110.1
1980	256.9	251.4	298.3	307.9	338.0	179.1	19.4	41.4	134.5	204.6	247.3	269.9	2538.5
1981	298.6	251.7	112.9	162.4	297.0	265.0	114.2	124.9	130.3	255.9	271.8	249.1	2533.8
1982	165.8	172.5	268.3	208.6	280.3	182.9	131.8	49.9	122.8	213.0	165.3	207.8	2160.0
1983	206.0	186.1	211.1	190.4	181.5	172.6	122.6	88.3	128.4	189.0	214.5	198.7	2089.2
1984	235.8	279.9	322.6	352.1	289.0	174.2	181.8	146.1	245.0	209.4	121.1	x	2557.0
1985	124.8	129.9	233.3	118.5	106.1	139.3	91.3	98.8	135.5	184.1	186.7	32.3	1580.6
1986	229.4	145.8	250.1	158.1	189.4	111.0	125.3	117.3	129.4	211.6	233.7	212.5	2113.6
1987	238.0	154.5	149.5	195.8	185.3	142.3	158.8	121.7	157.9	205.9	237.0	213.5	2160.0
1988	211.9	225.6	344.8	221.2	270.9	154.9	113.5	128.3	171.1	163.6	199.7	164.2	2369.7
Ave.	204.5	193.0	245.7	212.7	230.5	155.4	107.6	97.4	151.7	206.4	211.3	202.1	2218.3

Annex 8 : SOIL MOISTURE



(After Leopold, B)

ANNEX 9 LAKE LEVEL FLUCTUATION

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG.	SEPT	OCT.	NOV.	DEC.
LAKE HORA												
1986	-	-	-	-	-	-	-	-	0.65	0.63	0.53	0.44
1987	0.37	0.30	0.38	.29	0.46	0.54	0.54	0.57	0.62	0.62	0.44	0.59
1988	0.26	0.19	0.12	.06	0.04	0.05	0.15	0.27	0.46	0.47	0.42	0.40
1989	0.37	-	-	-	0.29	0.24	0.34	0.51	0.61	0.59	0.51	0.45
AVE.	0.33	0.26	0.25	.28	0.26	0.28	0.34	0.45	0.59	0.58	0.48	0.47
LAKE BISHOFTU GUDA												
1987	0.80	0.73	0.79	0.87	0.83	0.91	0.90	0.89	0.88	0.79	0.67	0.61
1988	0.54	0.50	0.46	0.40	0.42	0.42	0.52	0.69	0.81	0.81	0.71	0.62
1989	0.56	0.53	0.50	0.56	0.54	0.50	0.60	0.75	0.81	0.76	0.66	0.60
AVE	0.63	0.59	0.58	0.61	0.60	0.61	0.67	0.78	0.83	0.79	0.69	0.61
LAKE BISHOFTU												
1982	0.55	0.59	0.58	0.58	0.58	0.57	0.62	0.71	0.77	0.75	0.74	0.76
1983	0.76	0.76	0.76	0.80	0.85	0.91	0.94	1.10	1.25	1.37	1.49	1.57
1984	1.63	1.64	1.63	1.59	1.59	1.64	1.71	1.76	1.77	1.68	1.63	1.61
1985	1.60	1.58	1.53	1.52	1.56	1.61	1.60	1.77	-	-	-	-
1986	1.78	1.80	1.83	1.82	1.86	1.88	1.88	1.95	1.92	1.91	1.84	1.82
1987	1.77	1.73	1.78	1.83	1.78	1.81	1.79	1.80	1.79	1.71	1.62	1.56
1988	1.53	1.50	1.43	1.38	1.36	1.38	1.45	1.52	1.63	1.64	1.60	1.60
1989	1.62	1.66	1.73	1.84	1.84	1.77	1.85	1.96	2.01	1.98	1.92	1.91
AVE	1.41	1.41	1.41	1.42	1.43	1.43	1.48	1.57	1.59	1.58	1.55	1.55

Annex 10 *Ground and Surface waters chemical analysis*

Water point / Parameters		swine farm #1	poultry devp't& feed pro #4	Adea Flour Mill #7	Adea Flour Mill #8	Debre Zeit Maize Mill #9
Appearance		Colorless	colorless	colorless	colorless	colorless
Odour		Odurless	Odourless	Odourless	Odourless	Odourless
Taste		Tastless	Tastless	Tastless	Tastless	Tastless
Color(true		Colorless	Colorless	Colorless	Colrless	Colorless
Turbidity		Clear	Clear	Clear	Clear	Clear
pH		7.76	7.93	7.40	7.84	8.06
Ele.con μs/cm		600	900	547.9	900	950
TDS(mg/l)		405.84	497.87	633.18	513.97	594.57
CATIONS	Na^+ mg/l	27.14	17.48	25.4	11.04	40.71
	Na^+ meq/l	1.18	0.76	1.10	0.48	1.77
	Na^+ %	25.8	11.9	15	7.1	25.4
	K^+ mg/l	15.6	11.7	Nil	3.9	23.4
	K^+ meq/l	0.4	0.3		0.1	0.6
	K^+ %	8.6	4.7		1.5	8.6
	Ca^{2+} mg/l	42	55.6	56.1	63.2	50
	Ca^{2+} Meq/l	2.1	3.0	2.8	3.2	2.5
	Ca^{2+} %	45.8	47.2	38.14	47.2	35.9
	Mg^{2+} mg/l	10.8	27.12	41.8	34.56	25.6
	Mg^{2+} meq/l	0.9	2.3	3.44	3.0	2.1
	Mg^{2+} %	20	36.2	46.9	44.2	30.1
	Fe^{2+} mg/l	0.01	0.03	0.03	0.01	0.02
	Fe^{2+} meq/l	0.0004	0.001	0.001	0.004	0.0007
	Fe^{2+} %	0.004	0.02	0.01	0.005	0.01
	Mn^{2+} mg/l	Nil	0.02	Nil	0.1	Nil
	Mn^{2+} meq/l		0.0007		0.004	
	Mn^{2+} %		0.01		0.06	
Total	meq/l	4.5804	6.3617	7.341	6.7844	6.9707
	%	100.009	100.03	100.05	100.065	100.01
ANIONS	Cl^- mg/l	11.55	16.5	11.3	13.2	9.9
	Cl^- meq/l	0.3	0.5	0.2	0.4	0.3
	Cl^- %	6.5	7.9	4.3	5.9	4.2
	No_2^- mg/l	0.002	0.007	0.01	0.0066	0.018
	No_2^- meq/l	0.00004	0.00001	0.0006	0.0001	0.004
	No_2^- %	0.009	0.0002	0.008	0.002	0.06

...continued Annex 10

ANIONS	NO_3^-	mg/l	2.6	0.9	0.6	9.68	3.28
		meq/l	0.04	0.01	0.008	0.16	0.06
		%	0.9	0.2	0.1	2.3	0.7
	F^-	mg/l	0.66	0.97	0.3	0.45	0.48
		meq/l	0.49	0.05	0.02	0.02	0.02
		%	0.9	0.08	0.3	0.3	0.3
	HCO_3^-	mg/l	254.94	357.46	439.2	378.2	405.04
		meq/l	4.2	5.8	7.2	6.2	6.6
		%	91.7	91.1	95.6	91.0	92.0
	CO_3^{2-}	mg/l	Nil	Nil	Nil	Nil	Nil
		meq/l					
		%					
	SO_4^{2-}	mg/l	Nil	Nil	Nil	1.0	9.0
		meq/l				0.02	0.2
		%				0.3	2.8
	PO_4^{3-}	mg/l	0.03	0.16	0.3	0.72	0.45
		meq/l	0.0006	0.0003	0.009	0.01	0.009
		%	0.01	0.005	0.12	0.2	0.1
Total		meq/l	4.58064	6.36031	7.5576	6.8101	7.183
		%	100.01	100.0	100.428	100.002	100.16
OTHERS	Al^{3+}	mg/l / meq/l	ND	ND	ND	ND	ND
	NH_4^+	mg/l	0.0516	0.076	0.08	0.0774	0.1935
		meq/l	0.003	0.004	0.04	0.004	0.o1
	Silica as SiO_2	mg/l	43.225	10.926	59.0	8.55	30.26
	Car. alka. as $CaCO_3$	mg/l	Nil	Nil	Nil	Nil	Nil
	Bica alka. as $CaCO_3$	mg/l	127.0	293.0	360.0	310.0	332.0
	Tot. hard. as $CaCO_3$	mg/l	150.0	252.0	312.0	302.0	232.0

Date of analysis=May 29,1991

Nd= Not detectable, ND=Not Determined

...continued Annex 10

Para. \ Water po.		WSSA #22	WSSA #23	WSSA #24	WSSA #25	WSSA #26
Appearance		Colorless	Colorless	Colorless	Colorless	Colorless
Odour		Odourless	Odourless	Odourless	Odourless	Odourless
Taste		Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
Color(true)		Colorless	Colorless	Colorless	Colorless	Colorless
Turbidity		Clear	Clear	Clear	Clear	Clear
pH		8.10	6.90	6.90	7.01	8.00
Ele.Conduc. μs/cm		540	530	530	530	540
TDS(mg/l)		531.74	536.40	568.33	568.33	418.73
CATIONS Na^{+}	mg/l	24.81	23.92	30.59	30.59	32.89
	meq/l	1.07	1.04	1.33	1.33	1.43
	%	16.3	17.51	21.0	21.0	22.6
K^{+}	mg/l	15.6	11.7	19.5	19.5	19.5
	meq/l	0.4	0.3	0.5	0.5	0.5
	%	6.1	5.0	8.0	8.0	8.0
Ca^{2+}	mg/l	62.0	69.2	83.2	83.2	60.0
	meq/l	3.1	3.5	4.20	4.20	3.0
	%	47.2	58.9	66.1	66.1	47.5
Mg^{2+}	mg/l	19.2	12.9	3.36	3.36	17.28
	meq/l	2.0	1.1	0.3	0.3	1.4
	%	30.4	18.52	5.0	5.0	22.1
Fe^{2+}	mg/l	0.01	0.01	Nd	Nd	Nd
	meq/l	0.0007	0.0007			
	%	0.01	0.02			
Mn^{2+}	mg/l	0.1	0.1	0.1	0.1	Nil
	meq/l	0.004	0.004	0.004	0.004	
	%	0.06	0.07	0.03	0.03	
Total	meq/l	6.574	5.944	6.334	6.334	6.330
	%	100.06	100.00	100.13	100.13	100.00
ANIONS Cl^{-}	mg/l	29.70	9.80	24.75	24.75	24.75
	meq/l	0.84	0.3	0.7	0.7	0.7
	%	12.70	5.0	11.0	11.0	11.0
No_2^{-}	mg/l	0.0115	0.0165	0.033	0.033	0.0165
	meq/l	0.0002	0.0004	0.0007	0.0007	0.0004
	%	0.005	0.07	0.01	0.01	0.006
No_3^{-}	mg/l	13.20	2.33	10.252	10.252	12.34
	meq/l	0.2	0.04	0.2	0.2	0.2
	%	3.03	0.7	3.2	3.2	3.2
F^{-}	mg/l	0.5	1.75	0.65	0.65	0.3
	meq/l	0.03	0.1	0.03	0.03	0.01
	%	0.5	1.7	0.5	0.5	0.2

...continued Annex 10

ANIONS	HCO_3^- mg/l	335.1	333.1	331.8	392.8	244.0
	meq/l	5.5	5.5	5.44	6.4	4.0
	%	83.6	91.2	86.6	83.4	91.05
	CO_3^{2-} mg/l meq/l %	Nil	Nil	Nil	Nil	Nil
	SO_4^- mg/l	Nil	4.0	Nil	Nil	Nil
	meq/l		0.08			
	%		1.3			
	PO_4^{3-} mg/l	0.375	0.3	0.15	0.15	0.25
	meq/l	0.01	0.009	0.005	0.005	0.008
	%	0.2	0.1	0.08	0.08	0.1
Total	mg/l	6.5803	6.0294	6.3357	6.3357	6.3584
	%	100.035	100.07	100.0	100.0	100.006
OTHERS	Al^{3+} mg/l meq/l	ND	ND	ND	ND	ND
	NH_4^+ mg/l	0.032	0.032	0.0675	0.0645	Nil
	meq/l	0.002	0.002	0.004	0.004	
	sil- mg/l as SiO_2	45.0	70.0	75.0	75.0	20.0
	crb. alk. mg/l as $CaCO_3$	Nil	Nil	Nil	Nil	Nil
	Bic. alk. mg/l as $CaCO_3$	275.0	273.0	269.0	269.0	272.0
	Tot. har. mg/l as $CaCO_3$	229.0	225.0	232.0	232.0	222.0

Date of analysis=may 29,1991

...continued Annex 10

Param. \ water P.			Air force #28	Tedecha #31	Godino spring	Dug well	Wedecha river
Appearance			colorless	colorless	colorless	colorless	not clear
Odour			odourless	odourless	odourless	odourless	odourless
Taste			Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
Color(true)			colorless	colorless	colorless	colorless	muddy
Turbidity			clear	clear	clear	clear	Turbid
pH			7.20	7.20	7.40	8.7	7.5
Ele.cond. µs/cm			1000	460	580	2600	650
TDS(mg/l)			615.22	376.19	615.19	1017.30	367.06
CATIONS	Na^+	mg/l	44.39	26.4	36.19	38.4	3.7
		meq/l	1.93	1.18	1.53	1.67	0.16
		%	26.0	25.45	21.5	13.6	3.6
	K^+	mg/l	23.4	0.4	19.5	38.7	8.0
		meq/l	0.6	0.009	0.5	0.99	0.2
		%	8.1	0.002	7.1	8.1	4.5
	Ca^{2+}	mg/l	51.6	41.7	74.0	97.2	57.2
		meq/l	2.6	2.08	4.00	4.85	2.9
		%	35.0	46.03	56.1	39.7	65
	Mg^{2+}	mg/l	28.56	15.6	13.2	57.4	14.6
		meq/l	2.3	1.28	1.1	4.72	1.2
		%	30.9	28.32	15.4	38.6	26.9
	Fe^{2+}	mg/l	0.01	Nil	Nil	0.01	Nil
		meq/l	0.0004			0.0004	
		%	0.005			0.003	
	Mn^{2+}	mg/l	0.1	Nil	0.1	Nil	0.1
		meq/l	0.004		0.004		0.004
		%	0.05		0.08		0.09
Total		meq/l	7.4344	4.519	7.134	12.2304	4.464
		%	100.055	99.802	100.00	100.003	100
ANIONS	Cl^-	mg/l	24.75	9.9	13.2	42.9	29
		Meq/l	0.7	0.3	0.4	1.21	0.82
		%	9.1	6.8	5.6	9.0	18.4
	NO_2^-	mg/l	0.033	0.12	0.019	0.019	0.095
		meq/l	0.0007	0.003	0.0004	0.0004	0.0021
		%	0.009	0.07	0.006	0.003	0.05
	NO_3^-	mg/l	16.28	2.1	61.6	62.0	0.88
		meq/l	0.3	0.04	1.0	1.1	0.01
		%	3.9	0.9	14.0	8.0	0.22
	F^-	mg/l	0.56	0.89	0.59	0.7	0.48
		meq/l	0.03	0.05	0.03	0.04	0.03
		%	0.4	1.2	0.4	3.0	0.67

...continued Annex 10

	HCO_3^- mg/l	392.5	244	348.9	430.1	219
	meq/l	6.4	4.0	5.7	7.0	3.6
	%	83.4	91.05	80.0	44.3	80.6
	CO_3^{2-} mg/l	Nil	Nil	Nil	242.4	Nil
	meq/l				8.07	
	%				38.1	
	SO_4^{2-} mg/l	12.0	Nil	1.0	Nil	Nil
	meq/l	0.25		0.02		
	%	3.2		0.3		
	PO_4^{3-} mg/l	0.15	Nil	0.19	0.61	0.1
	meq/l	0.003		0.006	0.01	0.0032
	%	0.04		0.08	0.07	0.06
Total	meq/l	7.6807	4.393	7.1584	13.3804	4.4653
	%	100.049	100.02	100.036	100.673	100.00
OTHERS	Al^{3+} mg/l meq/l	ND	ND	ND	ND	NIL
	NH_4^+ mg/l	0.2967	Nil	0.1086	ND	0.0854
	meq/l	0.02		0.006		0.005
	sil-mg/l as SiO_2	37.725	36.3	108.5	69.6	25.0
	car. alk. mg/l as $CaCO_3$	Nil	Nil	Nil	198.4	Nil
	Bic. alk. mg/l as $CaCO_3$	322.0	200.0	286.0	369.1	158
	Tot. had. mg/l as $CaCO_3$	248.0	130.0	240.0	482.0	203

Water point / Paramete.		Lake Hora	Lake Bishoftu	Lake Bishoftu Guda	Lake Kuriftu
Appearance		Not clear	Not clear	Not clear	Not clear
Odour		Odourless	Odourless	Odourless	Odourlesss
Taste		Tasteless	Tasteless	Tasteless	Tasteless
Color(True)		Colorless	Colrless	Colorless	Colorless
Turbidity		Sl.turbid	Sl.turbid	Sl.turbid	Sl.tubid
pH		7.30	7.37	7.25	6.36
Ele.Cond. μs/cm		3600	2400	1500	380
TDS (mg/l)		534.55	1575.89	644.67	313.35
CATIOOS	Na^+ mg/l	6.0	289.7	23.0	23.7
	meq/l	0.26	12.6	1.00	1.03
	%	3.7	59.7	13.4	24.6
	K^+ mg/l	7.8	199.5	49.7	43.0
	meq/l	0.20	5.1	1.27	1.10
	%	2.8	24.2	17.0	26.3

...continued Annex 10

	Ion	Unit				
	Ca^{2+}	mg/l	36.8	45.4	48.8	27.2
		meq/l	1.78	2.26	2.44	1.36
		%	25.3	10.7	32.7	32.5
	Mg^{2+}	mg/l	58.32	13.7	33.6	8.4
		meq/l	4.80	1.13	2.76	0.69
		%	68.2	5.4	36.9	16.5
	Fe^{2+}	mg/l	Nil	0.01	0.02	0.13
		meq/l		0.0004	0.0004	0.06
		%		0.001	0.005	0.1
	Mn^{2+}	mg/l	Nil	Nil	Nil	Nil
		meq/l				
		%				
Total		mg/l	7.04	21.0904	7.4704	4.185
		%	100.0	100.001	100.005	100.0
ANIONS	Cl^{-}	mg/l	118.8	76.9	19.8	21.45
		meq/l	3.35	2.14	0.56	0.61
		%	47.6	10.1	7.5	14.6
	NO_2^{-}	mg/l	0.0198	0.0492	0.0231	0.0165
		meq/l	0.0004	0.001	0.0005	0.0003
		%	0.006	0.005	0.007	0.007
	NO_3^{-}	mg/l	6.16	3.52	4.8	5.72
		meq/l	0.1	0.06	0.08	0.09
		%	1.4	0.28	1.1	2.2
	F^{-}	mg/l	1.33	0.39	0.27	1.4
		meq/l	0.07	0.02	0.01	0.7
		%	1.0	0.09	0.1	16.7
	HCO_3^{-}	mg/l	235.53	659.9	415.4	169.9
		meq/l	3.52	10.8	6.80	2.78
		%	50.0	51.2	91.0	66.5
	CO_3^{2-}	mg/l	Nil	242.4	Nil	Nil
		meq/l		8.07		
		%		38.2		
	SO_4^{2-}	mg/l	Nil	1.0	1.0	Nil
		meq/l		0.02	0.02	
		%		0.09	0.3	
	PO_4^{3-}	mg/l	0.14	0.27	0.16	0.06
		meq/l	0.003	0.006	0.003	0.001
		%	0.04	0.04	0.04	0.02
Total		meq/l	7.0434	21.117	7.4736	13.3804
		%	100.046	100.005	100.047	188.873

...continued Annex 10

O T H E R S	Al^{3+} mg/l meq/l	ND	ND	ND	ND
	NH_4^+ mg/l meq/l	ND	ND	ND	ND
	sil. mg/l as sio_2	71.7	48.0	53.5	18.3
	Car. mg/l alk. as $Caco_3$	Nil	202.0	216.0	Nil
	Bic. mg/l alk. as $Caco_3$	109.3	532.0	119.0	137.0
	Tot. mg/l har. as $Caco_3$	332.0	246.0	282.0	103.0

Date of analysis= august 15,1991

Annex 11 Monthly runoff for Mojo river

Area 1206 sq.km

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1962	-	-	-	-	-	-	-	24.81	37.48	6.93	0.57	0.66
1963	0.91	0.62	0.59	1.66	1.78	2.7	56.33	82.28	6.1	0.92	0.38	0.48
1964	0.5	0.42	0.30	1.24	3.19	6.87	60.6	65.93	32.93	3.19	-	-
1965	-	-	-	-	-	1.82	16.59	27.99	16.38	0.1	-	0.07
1966	0.07	1.02	0.19	0.79	0.07	1.61	20.48	115.2	20.26	0.76	-	-
1967	-	-	-	-	-	-	30.2	89.55	34.17	2.16	6.63	1.4
1968	1.23	2.41	1.46	3.14	2.16	3.49	26.6	46.26	12.1	1.59	0.89	3.4
1969	5.67	7.38	10.13	9.9	8.4	12.29	37.92	148.8	19.71	6.63	4.26	-
1970	0.24	0.79	0.65	2.04	1.65	1.26	26.64	59.64	33	12.33	9.87	11.33
1971	12.5	9.44	10.84	12.12	16.81	24.4	42.21	128.8	22.14	-	0.06	0.44
1972	1.95	1.57	1.66	0.99	1.26	2.11	17.46	26.07	8.11	1.3	0.92	1.09
1973	1.41	8.06	10.16	10.56	9.34	12.26	34.96	64.4	31.24	11.34	10.4	11.32
1974	11.06	10.04	13.36	9.11	12.77	14.77	76.15	60.83	32.6	6.46	5.36	5.21
1975	8.83	5.26	5.32	8.94	9.67	17.69	83.71	35.84	25.43	4.87	5.86	5.81
1976	8.05	7.35	8.3	9.38	11.13	14.73	16.6	81.22	12.2	22.5	32.06	24.5
1977	-	-	-	-	-	23.85	33.07	68.15	16.33	16.02	1.19	0.13
1978	0.13	2.35	0.42	0.43	0.96	8.44	9.03	59.1	18.55	1.55	0.68	0.7
1979	5.8	8.09	9.22	12.3	6.51	1.26	12.18	25.34	2.78	0.85	0.87	0.79
1980	0.77	0.65	0.75	0.74	2.76	11.53	25.25	40.01	6.09	0.99	0.72	0.77
1981	-	-	-	-	-	-	-	-	-	-	-	-
1982	-	-	-	-	-	-	-	-	-	-	-	-
1983	0.52	0.69	4.03	0.91	3.54	5.51	15.25	82.84	25.2	0.73	0.6	0.52
1984	0.44	0.38	0.5	0.31	1.05	5.62	26.17	69.38	9.51	0.86	0.76	0.67
1985	0.6	0.39	0.37	0.77	2.52	0.90	19.8	77.44	11.87	0.92	0.90	1.03
1986	0.93	0.8	1.15	2.59	1.50	14.91	13.36	40.03	12.83	0.9	0.58	0.76
1987	0.72	0.75	2.76	2.07	8.59	3.69	3.14	10.2	2.44	0.68	0.53	0.59
1988	0.79	0.88	0.49	0.92	1.2	3.28	21.17	59.31	29.99	2.68	0.24	0.67
1989	0.83	0.63	0.73	1.40	0.33	0.38	17.83	27.31	23.48	1.27	0.70	0.83
AVE.	2.91	3.18	3.79	4.19	4.87	8.11	29.63	62.19	19.34	4.34	3.69	3.18

Monthly runoff in million cubic meter.

YEARLY AVERAGE= $149.42 \times 10^{6} M^{3}$

Annex12 STUDIED AREA & MOJO RIVER CATCHMENT BASIN

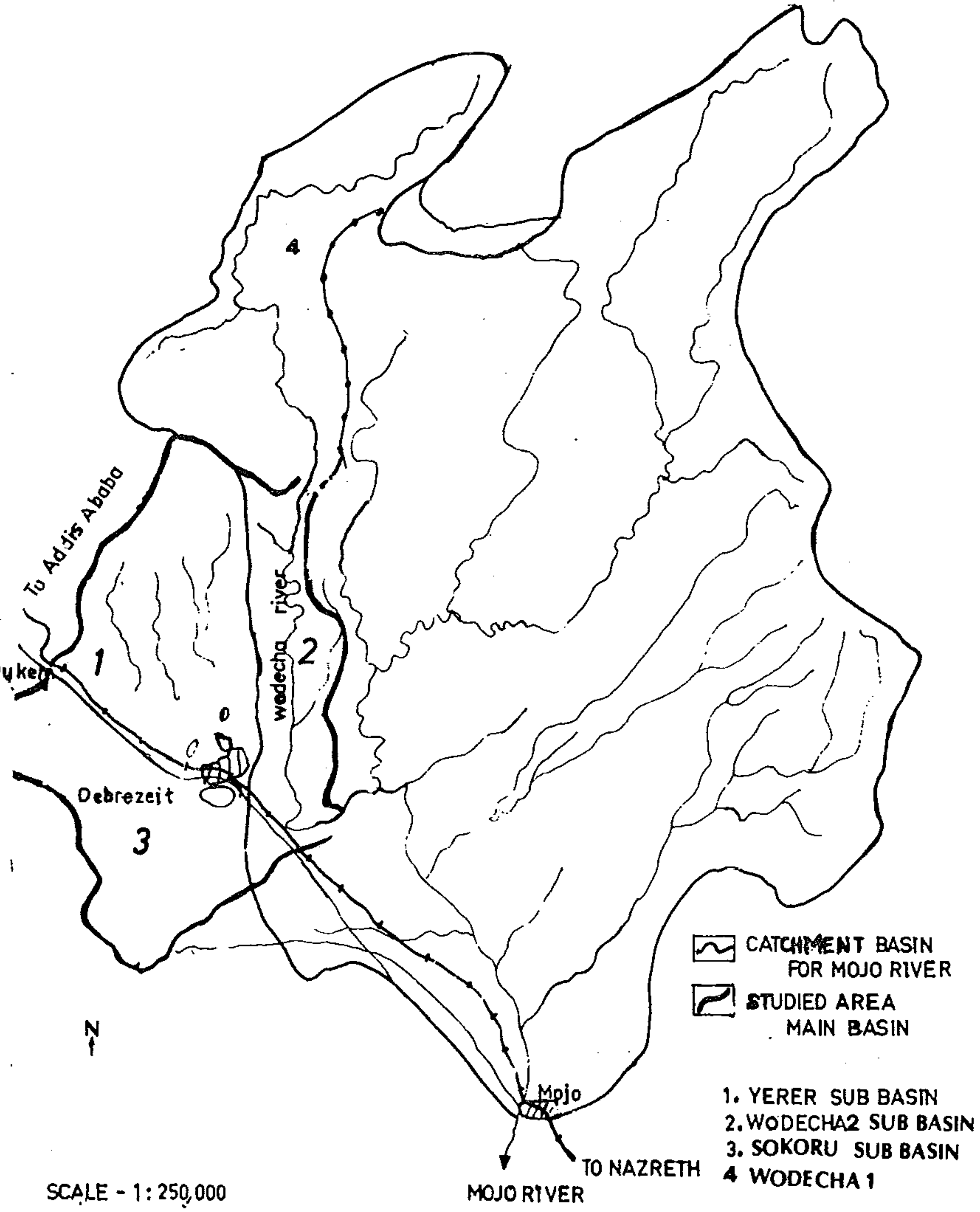
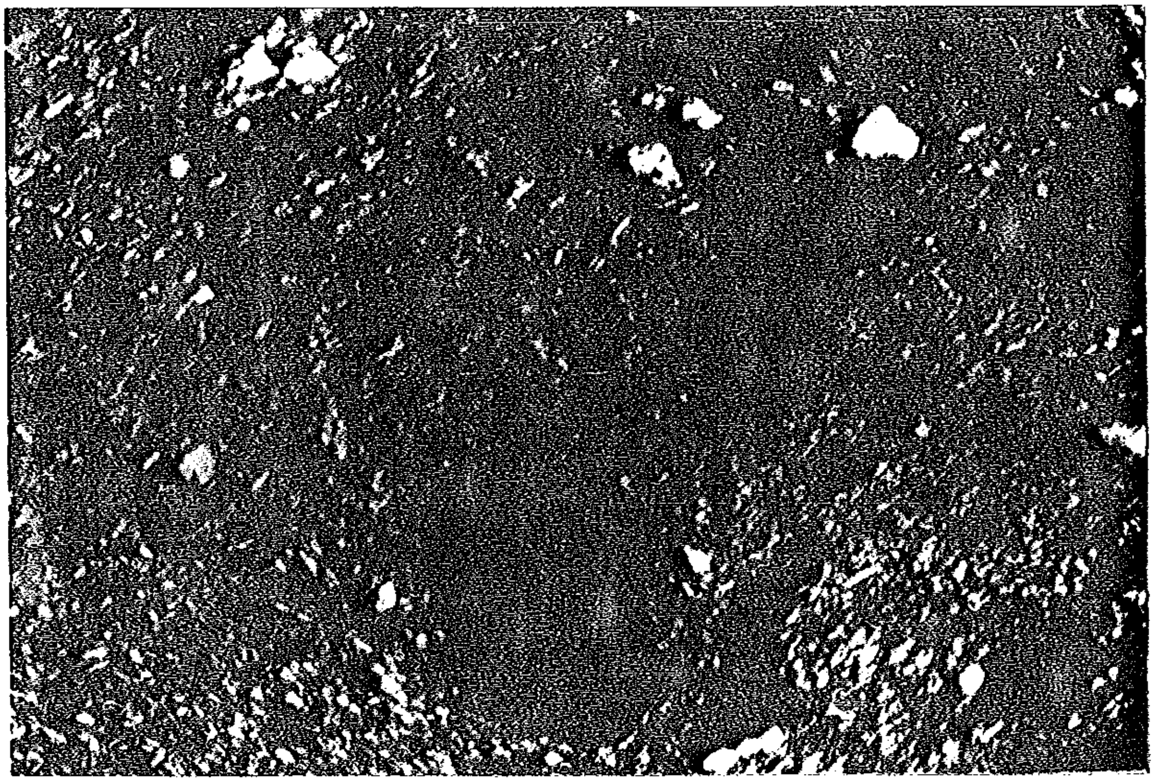


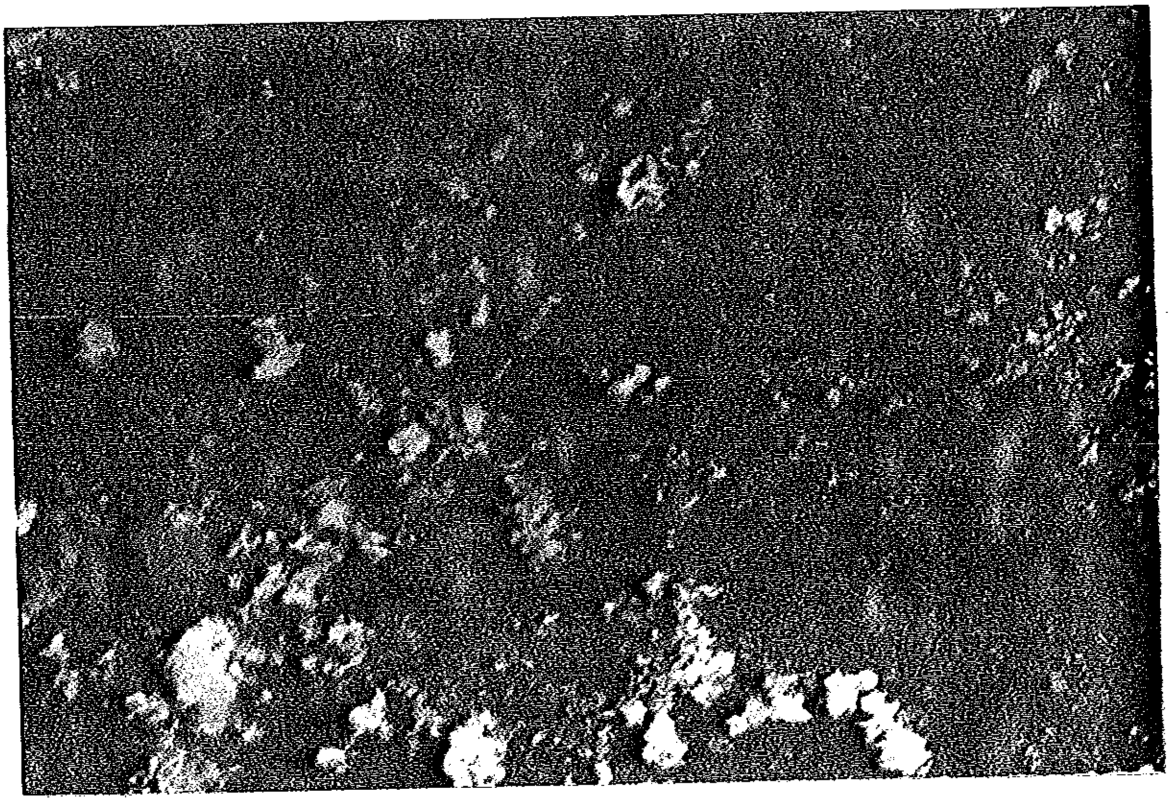
PHOTO 1, SAMPLE FROM TRACHYTE DOME



a) pink trachyte 5x
plagioclase feldspar phenocryst

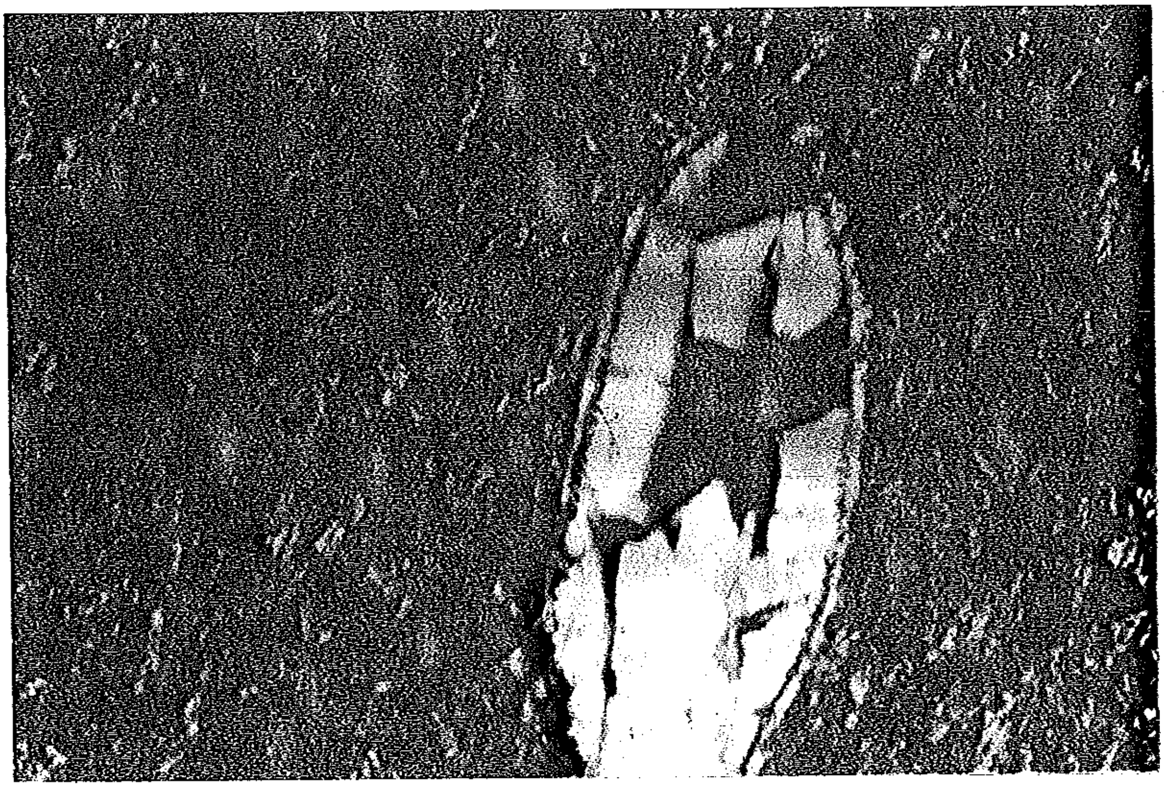
b) pale grey trachyte 5x
plagioclase feldspar phenocryst
feldspar lath

PHOTO 2 SAMPLE FROM RHYOLITIC FLOW



a) 10x
plagioclase feldspar
biotite, quartz

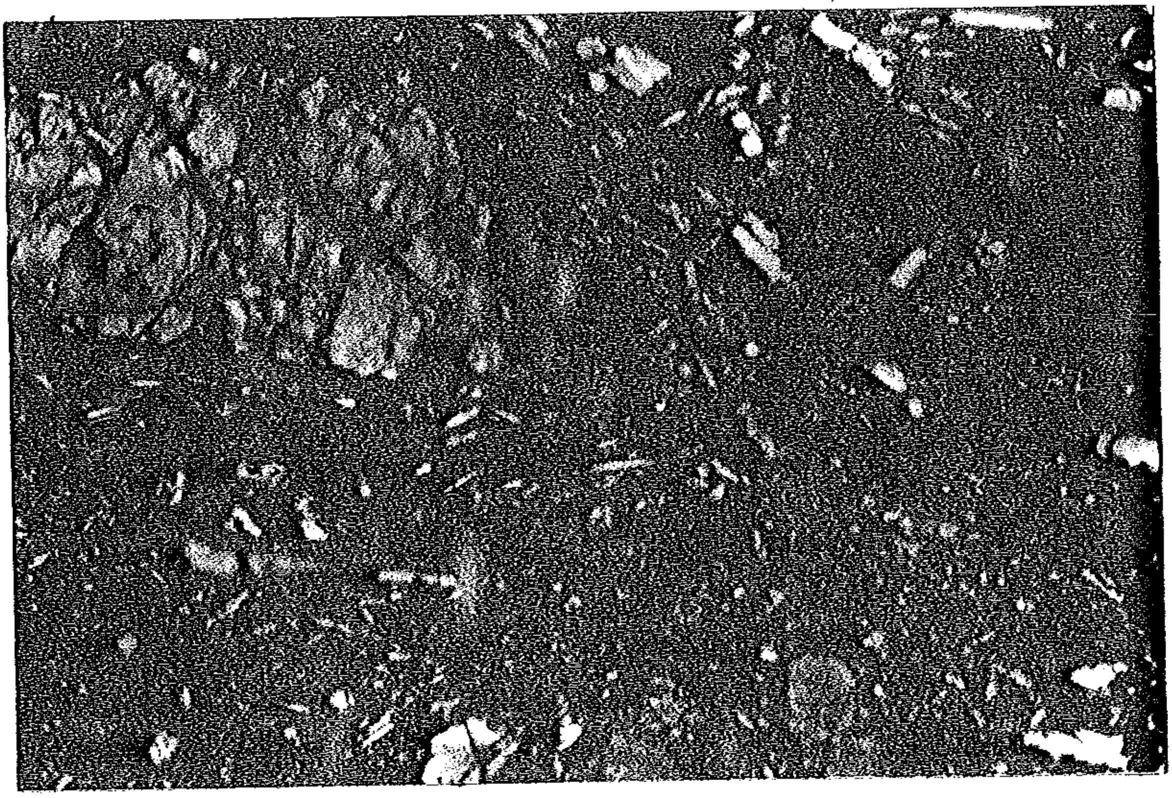
PHOTO 3 SAMPLE FROM RHYOLITIC IGNIMBRITE



a) 5X

collapsed pumice with plagioclase crystal
biotite, opaque minerals , iron oxide

PHOTO 4 SAMPLE FROM OLIVINE BASALTIC LAVA FLOW



a) 5x
olivine phenocryst
plagioclase feldspar, pyroxene
feldspar lath

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