# HYDROGEOLOGY OF THE BORKENA RIVER BASIN WOLLO - ETHIOPIA

A Thesis
Presented to
The School of Graduate Studies
Addis Ababa University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Geology

by
Ketema Tadesse
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## ACKNOWLEDGEMENT

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## ABSTRACT

The Borkena River Basin is located in Wollo governorate general. It is part of a major graben related to the Ethiopian Rift System, which extends north to Korbeta graben around Maichew and south upto Debre Berhan, and approximately stretches in a north-south direction. There are significant contrasts of topography in the basin where the structural control is very strong.

The hydrology of the area varies in different parts of the basin. Consequently, the hydrogeology of the basin also differs, such that there is a great potential of groundwater in the flat low lying alluvial sediments while a less significant amount exists within the volcanic rocks forming the uplifted borders of the graben. Several springs with discharges of less than 5 lit/sec. occur in the area issued from the volcanic rocks. There are eleven water supplying drilled wells in the area, seven located in the alluvium aquifers and the remaining four on basaltic aquifers. Pump tests have been carried out in some of the wells which gave transmissibility coefficient of 94 to 28.1 $m^3$ per day per meter. However, it was impossible to calculate the coefficient of storage, a significant parameter which measures the volume of water, the aquifer releases or takes into storage.

Proper chemical analysis of both the ground and surface waters carried out in the area show low total dissolved solids. All of

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the samples in the area have less than 1000 mg/l (1 mg/l = 1 ppm) dissolved solids, except for the hot spring waters. Few of the bacteriological tests of the waters in the area show low pathogenic organism though most of the water samples, (particularly the groundwaters) contain high nitrate content.

The water balance for the area has been determined. The total annual rainfall calculated on the basis of the mean annual precipitation for the basin is 1846.41 x $10^6$ $m^3$. The groundwater recharge for the area has been calculated based on the evapotranspiration data at Cheffa, where the water loss is maximum to approximate the minimum infiltration, and amounts to 185.11 x $10^6$ $m^3$. This is 10.02% of the precipitation. The actual evapotranspiration in the area amounts to 872, 834.8 and 836.1 mm. for Cheffa, Dese and Kombolcha respectively. 218.55 x $10^6$ $m^3$ of water leaves the basin at the Borkena River outlet as runoff and is equivalent to 11.83% of the precipitation.

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# 1. INTRODUCTION

## 1.1 Scope and Nature of Work

It is well known that there had been a famine in Ethiopia, particularly in Tigrai and Wollo Governorate Generals fifteen years back. The main cause for the famine was drought supplemented by other causes such as overfarming, soil erosion in the plateau and overgrazing together with the land tenure system. Since 1974, due to the drought and famine, the rural population in the mentioned regions started moving to the towns nearby with an assumption of finding jobs and to get into the rehabilitation centres located around Dese and Kombolcha, the biggest administrative centres in Wollo Governorate Generals. The Borkena River Basin amid the center of the famine striken areas, has a very thick, rich, alluvial deposit and is a potential area for farming except for lack of sufficient amount of water. In effect with the government's plan to rehabilitate and settle the migrant rural population in the basin, it become imperative to study groundwater potential as surface water was inadequate. Water for irrigation was not the only problem in the area as water for domestic use is also very insufficient for the fast growing urban population. With this in mind, it was the suggestion of some of the staff of Hydrogeology Division in the Ministry of Mines, Energy and Water Resources and full assistance of the Ministry which

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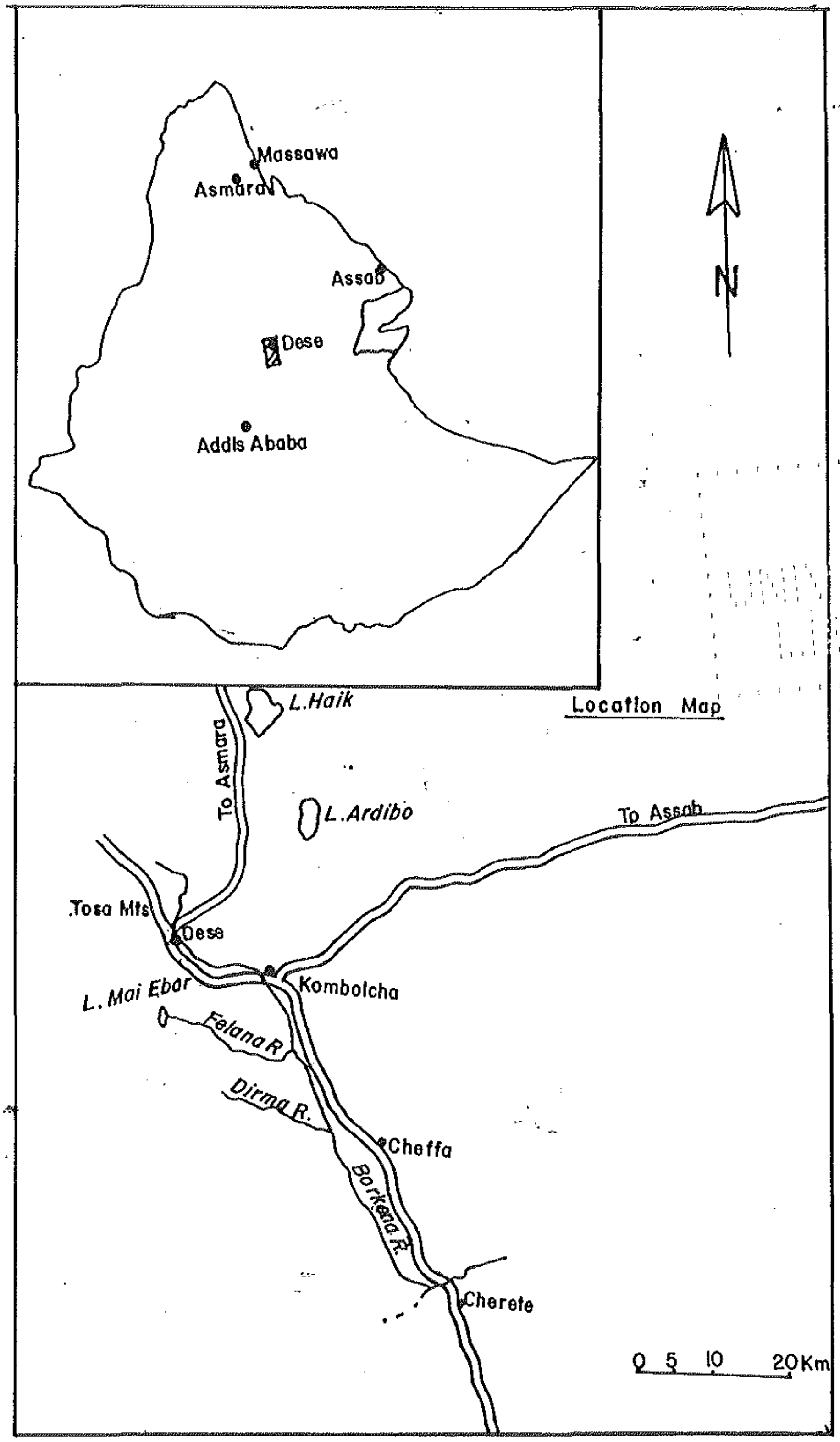
Massawa
Asmara
Assab
Dese
Addis Ababa
N
Location Map
L.Haik
To Asmara
L.Ardibo
To Assab
Tosa Mts
Dese
Kombolcha
L. Mai Ebar
Felana R
Dirma R.
Cheffa
Borkena R.
Cherete
0 5 10 20Km

MAP 1

made this hydrogeological study successful to evaluate the groundwater potential in the basin. This paper at the same time has been presented for a partial fulfilment of the requirements for degree of Master of Science in the Department of Geology at Addis Ababa University.

## 1.2 Location and Extent of the Area

The Borkena River Basin lies between 10° 35' and 11° 18' North latitudes and between 39° 30' and 39° 56' East longitudes. It is crossed by the main road from Addis Ababa to Asmara via Dese (MAP 1). The southern boundary of the basin is around Cherete village about 5 kms. from the river outlet, which is also the boundary between Shoa and Wollow Governorate Generals. The northern boundary is 28 kms. north of Dese where the river emanates from a seepage area. The East-west boundary is dictated by the surface water divide (MAP 2). The total area of the basin is 1735 $km^2$; about 30% of this area is suitable for mechanized farming. So far, one large scale government farm is in operation in Cheffa, located on the alluvial deposits. The remaining area of the basin is too rough to be suitable for mechanized farming. Hence a subsistence farming is only possible adjacent to the gullies in the uplifted areas, and where erosion is intense.

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1.3 Physiography and Drainage

A distinct elevation contrast exists between the floor of the graben lying at an average elevation of 1400 - 1500 m., and the water divide in the west, east and north of the graben where elevations reach 3000 metres (Map 4).

Eventhough, Borkena River Basin is itself part of the main structural system extending north-south and forming several minor grabens and horsts, three sub-basins have been established within the area under study based on physiography, and sediment type. These are the Dese, Kombolcha and Cheffa Sub-Basins. The Dese Sub-Basin has a maximum of 2900 m. elevation in the Tesa Mountain area.and the lowest part of the sub-basin lies at an elevation of 2450 meters south of Dese town. The Kombolcha Sub-Basin has a maximum of 3000 m. in the western uplifted blocks and minimum elevation of 1500 meters in the graben floor. Cheffa Sub-Basin on the other hand, has a maximum elevation of 2999 metres on the western uplifted blocks. The minimum elevation in this sub-basin is (1300 - 1400 m.) occupied by a marshy area located south of Cheffa town. The marsh covers an area of 55 $km^2$.

Borkena River emanates north of Dese and in its first course flows along the middle of the graben in a north south direction. Then it deviates to the east approaching the

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eastern margin of the graben and follows the NS running fault. It finally leaves the basin in an eastward direction after the marshy area.

## 1.4 Previous Work

Quite a number of articles have been published concerning the Afar Depression which is the immediate eastern boundary of the Borkena River Basin. On these publications about the Afar Rift, few aspects of the geology of the Borkena Basin is discussed in connection with the whole structure. Most of the published literature obtained on the area are works of a general nature and specific publications have not been available concerning neither the geology nor the hydro-geology except by Zanettin et al. (1974) who discusses the petrochemistry of the volcanics. Other popular scientists who worked in the immediate vicinity include McConnel (1974) on the evolution of the taphrogenic lineaments in continental platforms; Gibson et al. (1970), on the structures of Afar and the northern part of the Ethiopian Rift; Gouin (1976) on the seismicity of the general area in the Rift including the area under study, where he classified it to be one of the most seismically risky area in Ethiopia. Emilia et al. (1976) have worked on the groundwater exploration in the region applying geophysical methods while Gregnanin (1973) has sub-divided

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the volcanics in the region. Tectonism and volcanism of the particular area has been discussed by Zanettin (1974), plate tectonics of the Red Sea and East Africa with some connotations on the area under study has been dealt by McKenzie et al. (1970). Due to the similarity of tectonism and magmatism which resulted the area under discussion and the Afar and Danakil Depressions, it is worth considering works of Barberi et al. (1972, 1977) and Merla et al. (1979) who delt on the magmatology, volcanology and tectonism in the northern Danakil Depression and Afar in detail.

Unpublished report on the area has been carried out by Mezmure (1977) concerning the groundwater in the lowlands immediate to the western escarpment, northern Wollo and Tigrai regions. A geophysical survey has been carried out and is still on the process in Tendaho area by the Ministry of Mines, Energy and Water Resources in collaboration with the Italian Government to evaluate the geothermal resources - an area some 200 kms. east from the basin. Ketema (1978) has worked in the assessment of groundwater for Dese town water supply.

## 1.5 Present Work

The hydrogeological work in the basin was carried out in May, and September 1979. The field work concentrated more in mapping the area to differentiate the rock units of groundwater significance and in collecting hydrogeological information, i.e. locating of water points, collection of water samples, measurement of flow of s springs and streams etc. Hydrogeological data was obtained from different institutions in Addis Ababa. Pump testing and recovery data for the wells in the area has been supplied by different institutions, from which essential aquifer coefficients were determined.

As the emphasis of the work was more on groundwater evalution surface water investigation has also been done to support the previous. Chemical analysis of the waters in the basin has been done in the Ministry of Mines, Energy and Water Resources to see the suitability of the waters from domestic, agricultural and industrial use point of view. Mapping of the area has facilitated in establishing the boundary conditions of groundwater aquifers.

Finally, from the hydrogeological and hydrological informations the water balance of the basin has been calculated.

## 2. GEOLOGY

The geology of the Borkena River Basin comprises two main, distinct rock units of the Tertiary age observed very well along an east-west section across the graben. They are classified by Zanettin et al. (1974) as:

i. "Termaber" Basalts (28 - 13 million years)

ii. "Alaji" Rhyolites (32 - 15 " " )

The reamining of the investigated area is covered by recent alluvial deposits (MAP 2).

The rock units outcropping in the area, chronologically classified by Zanettin et al (1974) and Justin - Visentin et al (1974) can be compared in the following table.

Table 1

| Zanettin et al. (1974) | | | Justin - Visentin et al (1974) | | |
|---|---|---|---|---|---|
| Chrono-stratigraphy | | Lithostratigraphy | Chrono-stratigraphy | | Lithostratigraphy |
| TERTIARY | Upper Miocene | Termaber Basalts 28 - 13 m. years | TERTIARY | Middle Upper Miocene | Termaber Basalts 28 - 18 m. years |
| | Oligocene | Alaji Rhyolites 32 - 15 m. years | | Lower Miocene | Alaji Rhyolites 32 - 28 m. years |

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2.1. General Geological History of the Studied and Surrounding Areas

Two major tectonic phenomenon have taken place in Ethiopia and each has left a particular impression on the present morphology, physiography and geological setting. The first phase of tectonism took place in the late Mesozoic-Early Tertiary to produce the uplift of the Afro-Arabian swell while the second period of tectonism resulted in rift faulting and related phenomenon during the Tertiary-Quaternary periods.

The tectonics which resulted the Ethiopian uplift has a major role in the geology of the country as the Trap Basalt eruptions were supposed to be immediate consequences, Mohr (1967). The cause and mechanism of the great uplift in Ethiopia, however, is not completely understood. The Trap Series were later out by the rift system faulting in the Miocene.

The rift system which produced the Rift Valley in Ethiopia is well known to be one of the latest structural features of the earth's crust and is related to the Rift Valley pattern of East Africa. According to McConnel (1974), it is related to the world wide mid-ocean ridge system which penetrated the Afro-Arabian swell.

The Afar Rift System and the Ethiopian Rift System have distinct characters both from the time of their formation and from the geological outcrops comprised in the rifts. So are

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the rifts of the Gulf of Aden and the Red Sea. However, Gibson et al. (1970) conclude that the origin of these rifts is related, and is mainly due to the north easterly drift of the Arabian block away from a more slowly moving African block. McKenzie (1970) further postulates, that the Red Sea and the East African Rift Valley were the first major features in a continental area to be recognized as having been produced by extension of the earth's crust. The position of the plate boundaries has been established from the seismicity of the Middle East, the Ethiopian Rift, the Middle part of the Gulf of Aden and the Red Sea.

The rift is controlled by NE - SW running faults in the Ethiopian Rift proper and tend to divert their direction towards E - W further north from Miesso to Lake Abbe which follows the Gulf of Aden Rift trend. On the other hand, the faulting system in the northern Afar is N - S and NNW-SSE.

In the Ethiopian Rift Valley and in the Afar, basalts and rhyolites are the predominant rock types with some intercalations of tuffs and some marine episodes of evaporite facies. More acid volcanic eruptions and tuffs dominate in the southern Ethiopian Rift.

The Borkena River Basin - the area of interest is located on the western margin of the Afar Rift. The basin is related to

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a graben bounded by a north-south running faults in the eastern and western boundaries. Volcanics and recent sediments cover the area. Age determinations on the volcanics from the basin by Justin-Visentin et al. (1974) revealed 32 - 28 million years for the rhyolites and 28 - 13 million years for the basalts.

These volcanics form the uplifted blocks of the graben. It is therefore, obvious that the graben has been in existence for a maximum of 13 million years.

## 2.2 Geology of the Investigated Area

In the Borkena River Basin at least seven basaltic flows have been observed. The acid volcanic rocks are predominantly rhyolites with some minor outcrops of trachytes. These basalts and acid volcanics have been classified as the "Termaber" basalts and "Alaji" rhyolites respectively according to the classification of Zanettin et al. (1974). This classiica-tion has been adopted by the author, and all the volcanics will be treated together in most instances except in this chapter due to their occurrence in unfavourable topographic conditions for the purposes of groundwater exploitation to fulfil the purpose of this paper. The sediments will be discussed separately.

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### 2.2.1 The "Alaji" Rhyolites

The "Alaji" Rhyolite is the oldest outcropping rock unit in the Borkena River Basin. Generally, it consists in an alternation of alkaline and peralakaline rhyolites and flood basalts. The acidic terms are represented mainly by large ignimbrites and tuffaceous levels. The basalts are tholeiitic of transitional types, Merla et al, (1979).

In the studied area they are represented by very compact acidic rocks of rhyolitic composition overlying pitchstones. The rhyolitic rocks are highly glassy and contain phenocrysts of feldspar. Probably they correspond to an ignimbritic cover. They outcrop east of Kombolcha. Slightly decomposed rocks of this unit, outcrop east of Kemise. Along the Kombolcha-Dese road these rocks are not exposed. It is probably due to a smaller uplift during the tectonic event. According to Gregnanin et al. (1973) all the volcanics - the basalts, agglomerates and some of the trachytic rocks have been grouped under Shield Volcanics in the area under discussion.

This unit has not been observed on the western part of the escarpment. The exposure of the rhyolites which is limited to the eastern part of the graben has been hypothesized by Zanettin et al. (1974) to be due to the set of prevalent, distinct faults uplifting the blooks. On the western

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escarpment, however, the author thinks that the uplift was insufficient to expose the rhyolites. In the southern part of the basin some small outcrops of the acid volcanics have been observed in the graben floor which may be due to intense erosion.

The mineralogical composition of rhyolites and obsidian is dominantly glassy with some feldspar microlites, rare quartz and pyroxenes while the trachyte is mainly composed of orthoclase and few ferro-magnesian minerals.

In the geological map of the area under discussion, the trachytes and obsidian have not been represented on the map with a scale of 1:250,000 due to their small aerial extent. Rather they have been grouped under rhyolites.



## 2.2.2 "Termaber" Basalts

This rock unit outcrops in most parts of the basin particularly in the higher elevated areas adjacent to the graben floor overlying the "Alaji" rhyolites. The different basaltic flows as a whole have an average thickness of 200 m. in most parts of the basin. Merla et al. (1979) refers to this unit to be made up of basalts with a large amount of tuffs, scoraceous lava flows and red palaeosoils. This succession particularly outcrops along the Kombolcha-Dese road. The basaltic flows are related to the fracturing and faulting which took place since 65 million years, Kazmin (1975).

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Age determination on the basalts within the basin has not been available. However, the "Termaber" Basalts in other localities have been dated by Zanettin et al. (1974) and ages ranging 28 - 13 million years have been obtained.

In the graben floor, however, it has been observed underlying the sediments. These basalts have big phonocrysts of plagioclase and pyroxene, and few grains of olivines.

The palaeosoils in the area are found in between the basaltic flows and have generally less than 5 metres thickness as observed in road cuttings and stream sections particularly in the succession exposed along the Kombolcha-Dese road. More than one layer of palaeosoils has been observed along the mentioned road where as these exposures lack in the uplifted blocks of Cheffa Sub-Basin for correlation.

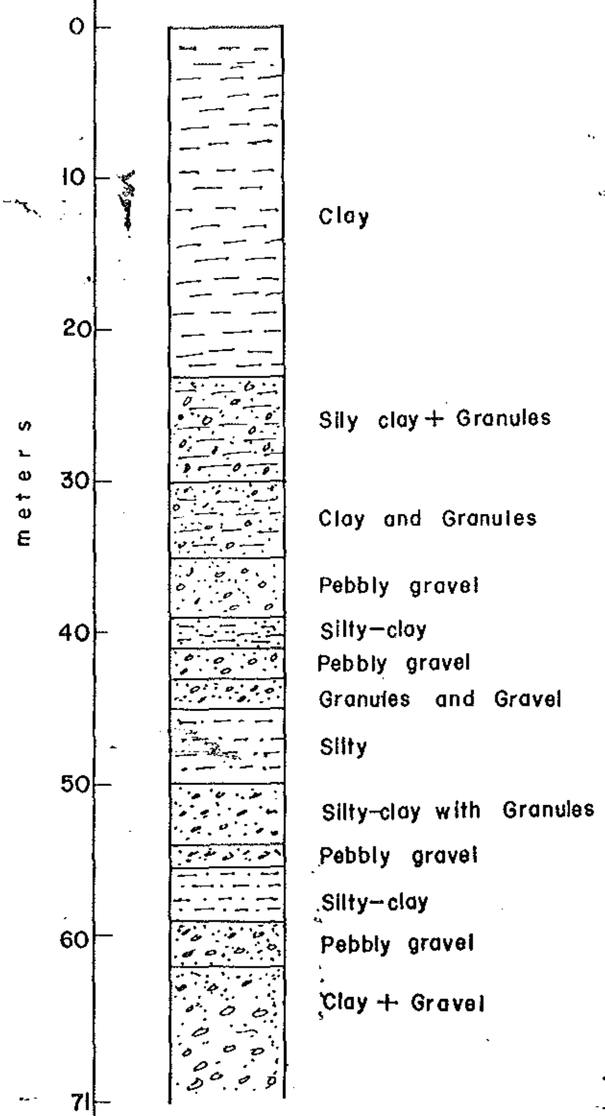
### 2.2.3 Recent Alluvial Sediments

Almost all the floor of the Borkena graben at an elevation below 1600 m. is covered by recent alluvial sediments. The sediment grains and the thickness of the deposit in different parts of the graben is not similar.

From a section of the alluvial sediments exposed by Borkena River in the Dese area predominant sand and pebbles have been observed. The bore hole at Hote Meda drilled to 71 m. depth has not encountered a bed rock. The clasts in the

Fig. 1

Lithological Log for Ethiopian Textiles Corporation
Well # 1 Kombolcha




* Data from National Boring Co.
Modified by Ketema Tadesse

area are predominantly basaltic and might have been derived from outcrops in the surroundings.

In the Kombolcha area, grains from gravel to clay size were seen from the Textile wells which are not yet in operation, (Figures 1 and 2). The alluvial sediments have here a thickness exceeding 100 m. Where as it does not in the Dese area.

From the logs of the Textile wells sediments containing some orgainc ash have been encountered at depths of 22 - 23 m. and 52 - 56 m. depth respectively (Figures 1 and 2). There is a speculation by the author that some time in the past the whole of the basin might have been covered by a lake extending to Kobo graben, 200 kms. north of this area. There is, however, insufficient data and exposures of lacustrine deposits, to support the hypothesis.

In the southern part of the basin, in the Cheffa area more fine grained materials, mainly silt and clay cover the area (Fig. 3). This is particularly true in Cheffa marsh. All of the wells in this area are located on the eastern side of the graben where the alluvial sediment has less than 30 m. thickness. Though there are not wells in the middle of the graben floor greater thickness is expected. The fine sediments covering the marsh are transported by

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the stream to be deposited where the topography is flat. The coarser sediments on the other hand are left behind in the upper course of the Borkena River. Generally, different periods of depositions has taken place in the whole basin. This is evidenced from alternating sediment grain size deposition in the whole thickness of the alluvium in the area.

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## 3. HYDROLOGY

The occurrence of ground and surface waters is controlled by many factors such as lithology, geological structure, physiography, climatology, soil and vegetation. Of the total amount of rainfall precipitated in a basin some of the water is evaporated directly or transpires from vegetation, some leaves the basin as runoff and some infiltrates and joins the groundwater system. A reasonable amount of imported water from another basin which joins the groundwater system should also be taken into account for a proper estimation of water balance.

In the following paragraphs the hydrology of the Borkena River Basin will be discussed with particular emphasis on rainfall, runoff, temperature, and evapotranspiration.

### 3.1 Rainfall

In the Borkena River Basin, three climatological recording stations exist covering an area of 1735 sq. km. For a better understanding of the hydrology of the basin, a greater number of stations would have been necessary. The rainfall recording stations are located in Dese, Kombolcha and Cheffa. These stations are considered to be the best sites and are well distributed to approximate the rainfall of the region. The elevation of the stations at Dese, Kombolcha and Cheffa is 2365, 1870 and 1490 metres respectively, where the

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elevation of the basin ranges from 1400 to 3000 metres.

The mean annual rainfall recorded for the respective stations is 1156.0, 1052 and 1052 and 1062.8 mm. for a thirteen year period from 1966 to 1978 (Appendix 1, 2 and 3). Most of the rains occur in July, and August with some additional rains occurring in March, April and May.

The basin has been classified into two rainfall groups based on the rainfall coefficient which is the ratio between the mean monthly rainfall and the "rainfall module", that is one-twelfth of the annual mean. Type I rainfall group represents a contagously distributed rainy months and Type II represents two rainy seasons. This applies for tropical climates Daniel (1974).

In a region with a high potential evapotranspiration, heavy rains occurring within a short time constitute an advantageous factor in providing a greater amount of water disposable for infiltration than low intensity rains. In addition, the depth of rainwater cover positively affects infiltration, Ven Te Chow (1964).

The following is the monthly rainfall coefficient for the town of Dese, Kombolcha and Cheffa respectively.

Rainfall Coefficient

| Jan | Feb | Mar | Apr. | May | Jn. | Jly | Aug. | Sept. | Oct | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.2 | 0.3 | 0.7 | 1.0 | 0.7 | 0.4 | 3.1 | 3.2 | 1.6 | 0.5 | 0.2 | 0.2 |
| 0.3 | 0.5 | 1.0 | 0.9 | 0.8 | 0.7 | 2.8 | 3.0 | 1.3 | 0.3 | 0.3 | 0.2 |
| 0.3 | 0.6 | 0.7 | 1.1 | 0.8 | 0.4 | 2.6 | 3.1 | 1.3 | 0.4 | 0.3 | 0.1 |

Where a rainfall coefficient of:

| | | |
|---|---|---|
| $<0.6$ represents | | dry months |
| 0.6 and over represents | | rainy months |
| 0.6-0.9 | " | small rains |
| 1.0 and over | " | big rains |
| 1.0-1.9 | " | moderate concentration |
| 2.0-2.9 | " | high concentration |
| 3.0 and over | " | very high concentration |

3.2 Evapotranspiration

Evapotranspiration (Et) is defined as the total amount of water returned to the atmosphere by direct evaporation from ground surface and by transpiration from plants. The value of evaporation can be calculated from air temperature applying the formula $E = 0.1\, T^2 + 5.5\, T$, where temperature is expressed in centigrade degrees. Aquater (1979). Direct evaporation measurement can also be obtained applying the Colorado evaporation pan. Estimation of evaporation

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measurement by the above two methods usually gives very high values in tropical climates and cannot be used.

A more reliable estimates of evapotranspiration can be made using Thornthwaites empirical formula which is based on the theory of water loss corresponding to available energy. The formula is expressed as:

$$E = 1.6 \left( \frac{10T}{I} \right)^{a}$$

where E = monthly gross evapotranspiration (in cm)

T = Mean monthly air temperature (in C°)

I = Average annual heat index

I is obtained by averaging the twelve values of the monthly index (i) where $i = \left( \frac{T}{5} \right)^{1.514}$ and (a) is obtained by the formula:

$$a = (6.75 \times 10^{-7} I^3) - (7.71 \times 10^{-4} I^2) + (1.729 \times 10^{-2} I) + 0.492$$

The above formula gives the gross potential evapotranspiration assuming there is sufficient available water to meet the demand of vegetation as opposed to actual evapotranspiration which takes into account the actual water that evaporates and transpires.

Evaporation data using the Colorado pan has been available for Cheffa farm, which shows a gross evaporation of 2618.5 mm. for the same period, showing a heavy loss of surface waters,

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and implies all the water that precipitates and even transported is evaporated. The above value also suggests that there is no groundwater recharge through infiltration and therefore, the data cannot be taken into consideration.

But from the calculation of the gross evapotranspiration using Thornthwaites formula, the actual evapotranspiration can be obtained taking into account soil moisture accretion, and a correction factor for the latitude (Tables 1, 2,3). This method enables the evaluation of plant intake deficiet by subtracting the actual evapotranspiration from the potential. The surplus is obtained by subtracting the actual evapotranspiration from the precipitation. The actual evapotranspiration is calculated on the following basis. A soil moisture accretion of 100 mm. has been taken for the Cheffa area. Thornthwaite assumes a maximum useful moisture accretion of 100 mm. This accretion varies from one soil to another. It may be as low as 50 mm. in rocky soils and as high as 300 mm. in other soils. The procedure to calculate the actual evapotranspiration is based on some assumptions corresponding to boundary conditions. Thus:

1. When the rainfall each month is greater than the potential evapotranspiration, then the actual evapotranspiration is equal to the potential evapotranspiration (cf months of July, August and September in Table 1).

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TABLE 1

Station: Cheffa

## COMPUTATION OF ACTUAL EVAPOTRANSPIRATION

| | Jan | Feb | March | April | May | June | July | August | Sept | Oct. | Nov. | Dec. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1) Monthly θ (Air T°) | 18.9 | 20.2 | 21.9 | 22.9 | 23.6 | 24.9 | 23.3 | 22.7 | 21.6 | 20.2 | 19.2 | 18.1 | |
| 2) Monthly indices (i) | 7.49 | 8.28 | 9.36 | 10.01 | 10.49 | 11.37 | 10.28 | 9.88 | 9.17 | 8.28 | 7.67 | 7.01 | I 109.29 |
| 3) Thermal Indix I = Σ i | | | | | | | | | | | | | |
| 4) Gross Potential Evapotranspiration | 95 | 98 | 103 | 106 | 108 | 111 | 107 | 105 | 102 | 98 | 95 | 92 | |
| 5) Correction Coef. Lat 10° N | 1.0 | 0.91 | 1.03 | 1.03 | 1.08 | 1.06 | 1.08 | 1.07 | 1.02 | 1.02 | 0.98 | 0.99 | |
| 6) Corrected potential Evapotranspiration | 95 | 89 | 106 | 109 | 117 | 118 | 116 | 112 | 104 | 100 | 93 | 91 | |
| 7) Precipitation P | 30.7 | 55.2 | 66.2 | 95.6 | 72.2 | 39.3 | 2305 | 259.9 | 132.4 | 37.8 | 28.4 | 14.6 | 1052.8 |
| 8) Variation in soil Moisture ACCRETION | | | | | | | | | | 62.2 | 37.8 | | |
| 9) Moisture accretion for Vegetation | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 100 | 37.8 | 0 | 0 | |
| 10) Actual Evapotransiration | 30.7 | 55.2 | 66.2 | 95.6 | 72.2 | 39.3 | 116 | 112 | 104 | 100 | 66.2 | 14.6 | 874.0 |
| 11) Plant intake deficit pot Evapotr. ACT. ET | 64.3 | 33.8 | 39.8 | 13.4 | 44.8 | 87.7 | - | - | - | - | - | 76.4 | 360.2 |
| 12) Surplus (PPT-Act.Et | | | | | | | 4.5 | 147.9 | 28.4 | | | | 190.8 |

Station: Dese

TABLE 2

COMPUTATION OF ACTUAL EVAPOTRANSPIRATION

| | Jan | Feb | March | April | May | June | July | Aug. | Sept | Oct. | Nov. | Dec. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1) Monthly $\theta$ (air T) | 18.9 | 20.2 | 21.9 | 22.9 | 23.6 | 24.9 | 23.3 | 22.7 | 21.6 | 20.2 | 19.2 | 18.1 | |
| 2) Monthly indicer (i) | 7.47 | 2.28 | 9.36 | 10.61 | 10.49 | 11.37 | 10.28 | 9.88 | 9.17 | 8.28 | 7.67 | 7.01 | |
| 3) Thermal Indix I $=\Sigma i$ | | | | | | | | | | | | | I=109.29 |
| 4) Gross Potential Et | 95 | 98 | 103 | 106 | 108 | 111 | 107 | 105 | 102 | 98 | 95 | 92 | |
| 5) Correction Coef. (Lat 10°N) | 1.0 | 0.91 | 1.03 | 1.03 | 1.08 | 1.06 | 1.08 | 1.08 | 1.02 | 1.02 | 0.98 | 0.99 | |
| 6) Corrected Potential Et | 95 | 89 | 106 | 109 | 117 | 118 | 116 | 112 | 104 | 100 | 93 | 91 | |
| 7) Precipitation | 19.3 | 30.2 | 64.4 | 99.9 | 67.0 | 36.0 | 284.6 | 311.9 | 156.7 | 46.3 | 21.4 | 18.3 | 1156.0 |
| 8) Variation in soil moisture accretion | | | | | | | | | | -53.7 | -46.3 | | |
| 9) Moisture accretion available for vegetation | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 100 | 46.3 | 0 | 0 | |
| 10) Actual Et | 19.3 | 30.2 | 64.4 | 99.9 | 67.0 | 36.0 | 116 | 112 | 104 | 100 | 67.7 | 18.3 | 834.8 |
| 11) Plant Intake deficit (pot Et-Actual Et) | 75.7 | 58.8 | 41.6 | 9.1 | 50.0 | 82 | | | | 0 | 25.3 | 72.7 | 415.2 |
| 12) Surplus | | | | | | | 68.6 | 199.9 | 52.7 | | | | 321.8 |

Table 3

Station: Kombolcha

COMPUTATION OF ACTUAL EVAPOTRANSPIRATION

| | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1) Monthly θ (air T°) | 18.9 | 20.2 | 21.9 | 22.9 | 23.6 | 24.9 | 23.3 | 22.7 | 21.6 | 20.2 | 19.2 | 18.1 | |
| 2) Monthly indices (i) | 7.49 | 8.28 | 9.36 | 10.01 | 10.49 | 11.37 | 10.28 | 9.88 | 9.17 | 8.28 | 7.67 | 7.01 | |
| 3) Thermal Indix (I) $=\sum i$ | | | | | | | | | | | | | I=109.29 |
| 4) Gross Pot Et | 95 | 98 | 103 | 106 | 108 | 111 | 107 | 105 | 102 | 98 | 95 | 92 | |
| 5) Correction Coeff-icent (Lat 10°N) | 1.0 | 0.91 | 1.03 | 1.03 | 1.08 | 1.06 | 1.08 | 1.07 | 1.02 | 1.02 | 0.98 | 0.99 | |
| 6) Corrected Pot Et | 95 | 89 | 106 | 109 | 117 | 118 | 116 | 112 | 104 | 100 | 93 | 91 | |
| 7) Precipitation | 24.5 | 42.9 | 91.9 | 80.6 | 67.4 | 59.5 | 242.6 | 261.1 | 114.3 | 29.9 | 23.3 | 14.0 | 1052 |
| 8) Variation in soil moisture accretion | | | | | | | | | | -70.1 | -29.9 | | |
| 9) Moisture Accretion available for vegetation | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 100 | 29.9 | 53.2 | 0 | |
| 10) Actual Et | 24.5 | 42.9 | 91.9 | 80.6 | 67.4 | 59.5 | 116 | 112 | 104 | 100 | 23.3 | 14.0 | 836.1 |
| 11) Plant intake Deficit (pOt Et-Act.Et) | 70.5 | 46.1 | 14.1 | 28.4 | 49.6 | 58.5 | | | | | 69.7 | 77.0 | 413.9 |
| 12) Surplus | | | | | | | 26.6 | 149.1 | 10.3 | | | | 186.0 |

2. When the potential Et is greater than the rainfall, the actual Et is equal to the depth of rain plus a certain depth of water taken from the accretion. If the soil moisture accretion is sufficient so that when added to to the rainfall the resulting total is equal to the potential Et, then the actual Et is again equal to the potential Et (cf. months of October and November).

3. When the accretion is not sufficient, the actual Et is equal to the depth of rain (cf. month of November) plus the accretion left over from the previous month.

4. When the accretion is zero, the actual Et is equal to the depth of rain. (cf. January to June and December).

Based on the above calculations the annual actual evapotranspiration is equal to 872.0 mm. From the total annual precipitation of 1062.8 mm. in Cheffa area, the surplus is only 190.8 mm., available for infiltration and runoff.

## 3.3 Runoff

There are several intermittent streams in the Borkena River Basin. Borkena River is, however, the major perennial stream. Felang River is a perennial stream which emanates from the very small fault bounded, L. Mai Ebar, located on the highlands. The lake has an area of 1.5 sq. km. (approximately) and gets its supply of water from springs and rainfall. The Felana River is a result of an overflow from L. Mai Ebar, and the volume of the stream flow increases as it drains from the uplifted blocks into the graben floor of the basin.

On the major river in the basin - Borkena, two gaging stations have been established, one, opposite Fontanina village (Upper Borkena), and by the outlet of the marsh (Lower Borkena), from where records of flow has been collected by the Ethiopian Valley Agricultural Development Authority and the Ethiopian Water Resources Authority (Appendix 5 and 6). Data on the Upper Borkena has been recorded for two years and ten months since 1976, while for the Lower Borkena records are available since 1963 with records of 1969, 1970, and 1971 missing.

The data for Upper Borkena River indicates that a high mean discharge occurs in March during the small rains and in July - August corresponding to the big rains. The mean minimum discharge occurs in June and December.

In the Lower Borkena River, however, the mean maximum discharge for the fourteen years period occur in August - September and the mean minimum is in June and March. The final runoff leaving the basin is $218.55 \times 10^6$ $m^3$ (Appendix 5).

The discharge of this river is variable at different parts of its course and at different seasons. The variation is explained by the amount, intensity and distribution of rainfall;

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the seasonal variation of evapotranspiration, soil types, vegetation and land use. Rate of the stream flow is also the other factor as evidenced from the immediate correlation of rainfall and discharge in the steep physiographic region in the Upper Borkena. On the other hand maximum discharge of this same river was recorded a month after the maximum rainy season in the flat, low lying region in the Lower Borkena River .

Another interpretation for the maximum discharge to lag behind the maximum rainy season in the Lower Borkena is due to a high evapotranspiration loss by plants in the marsh and high specific retention capacity of the fine sediments which are predominant in the Cheffa Sub-Basin.

The mean annual runoff of the stream has been calculated with respect to the drainage area. The data from the gaging station opposite Fontanina village takes into account drainage areas of the Dese and Kombolcha Sub-Basins and the other records would take the whole basin into consideration.

The following table shows the rainfall runoff relation in the basin, (Table 4).

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Table 4

| Sub-basin | Area ($km^2$) | Approx. mean annual rainfall in (mm.) | Mean volume in the catchment (in million $m^3$) | Mean volume of runoff leaving the basin at (in million $m^3$) | |
|---|---|---|---|---|---|
| Dese | 87.5 | 1156.0 | 101.15 | Fontanina | 67.68 |
| Kombolcha | 343.0 | 1052.0 | 360.84 | by the outlet | 218.55 |
| Cheffa | 1304.5 | 1062.8 | 1386.42 | | |
| TOTAL | 1735.0 | | 1848.41 | | |

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It is possible to see from table 4 that of the total amount of $1810.1 \times 10^6$ $m^3$ of precipitation, $218.55 \times 10^6$ $m^3$ leaves the basin as runoff. The percentage of surface water that is transported out of the basin is therefore:

$$\frac{218.55 \times 10^6 \; m^3 \times 100}{1848.41 \times 10^6 \; m^3} = 11.82 \%$$

The remaining 88.18% of the precipitation is either lost by evapotranspiration or joins the groundwater system as infiltration.

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# 4. HYDROGEOLOGY

As previously mentioned, the Borkena River Basin has been divided into three main hydrogeological regions on the basis of geological characteristics and groundwater occurrence. Before the problem of groundwater occurrence and potentiality is treated the hydrogeological characters of the outcropping lithotypes will be discussed with particular reference to infiltration and to water bearing capacity of the rocks. Therefore all volcanics, showing homogeneity in hydrological characters have been grouped together.

## 4.1. Volcanic Rocks

As previously described these rocks consist in acid volcanics of rhyolitic and trachytic composition, mainly represented by obsidians and ignimbrites, and basaltic lava flows locally separated by palaeosoils.

From field observations the acid volcanic rocks lack primary permeability generally and are considered poor aquifers. Most acid volcanic rocks and rhyolites in particular have very low porosities to decrease the specific yield of these rocks. De Wiest et al (1966) gives a porosity of 14% for welded tuffs which could be very near to the value of rhyolites as opposed to the porosity of pumice which could reach a value of 85%.

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Cracks, joints and fractures which are significant features to be noted in volcanic rocks for groundwater exploration are scanty and widely spaced. Another factor which discourages the occurrence of water in these rocks is the morphology of the outcrops. The steep topography highly facilitates the runoff and consequently the infiltration is lowered. Groundwater exploitation is also discouraged due to unfavourable morphology, (Map 3).

As already pointed out the acid volcanic rocks are the lower most outcropping units exposed to the surface by faulting. Consequently, the faults act as conduits for the groundwater to be channelled in the direction of the fault plane thus limiting storage.

Four hot springs have been encountered; issued from the rhyolitic rocks in the Borkena River basin indicating a high thermal gradient at depth. The springs are located along a fault line and temperatures of 60°C was recorded in one of the springs (Appendix 8). Eventhough, the area under discussion is over 200 kms. away from the thermally active area - (Afar Rift System), these springs indicate a shallow heat source. The lower temperatures for these springs could be attributed to mixing by shallow, cold groundwater.

On the other hand the basaltic rocks in the area outcrop on the uplifted blocks in the graben and they are

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exposed in the east and west of the graben at an elevation of over 2000 m. in most of the localities. Some patches of these basalts however outcrop within the graben proper eventhough their extent is limited.

Along the Kombolcha-Dese road seven basaltic flows have been observed with development of palaeosoils in between the flows, acting as impervious strata. These rocks cover an area of 1030 $km^2$ in the basin, but their significance from the hydrogeological point of view is very limited due to two main factors.

First, the rocks cover the higher elevated regions of the basin where the topography is rugged and the erosion is intense. In effect the soil moisture retention is minimized and most of the precipitation as rainwater is rapidly chanelled to limit the infiltration into the groundwater system.

Second, of the limited amount of water that percolates into the rocks most of it is lost immidiately as seepage or in the form of small springs as the vertically moving infiltrated water encounters the palaeosoils which act as an aquiclude limiting the volume of the aquifers. Consequently, these wells located on the basaltic rocks have small yields in general.

Otherwise, the basalts in the area would have been favourable as they possess secondary permeability and transmissivity which play a great role in the occurrence and movement of groundwater.

Due to the above mentioned facts only three wells have been drilled on the volcanic rock aquifers in the basin, and these wells have very low yields compared to wells from the alluvial aquifers (Appendix 9).

Geophysical survey carried out in the Corbetta graben (a graben system of similar structural control to the Borken Graben) indicated that the basalts are saturated for a few meters on the weathered zone and give ample water where as the massive rocks below the weathered layer do not. In the Corbetta graben the thick gravel overlying the basalts showing a resistivity of 40 ohm/m has been recommended as a water bearing layer, Emilia et al (1976). It is possible to infer the same case for the Borkena River Basin where similar conditions occur.

## 4.2. Alluvial Sediments

In the Borkena River Basin the alluvial sediments do not constitute a continuous cover but they are scattered at 3 localities - in Dese, Combolcha and Cheffa areas. They cover a total area of 493 sq. kms. All the alluvial sediments are located within the graben floor and are never observed at higher elevations where the volcanics outcrop. Their thickness ranges from 30 to

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over 100 meters and contain the most important aquifers in the basin.

The alluvial sediments in Dese area have been observed and coarse grained sediments are predominant. This was primarily because of the Borkena River leaving the heavy, coarser sediments in its upper course. The very fine sediments - silt and clay however are predominant in the lower course of Borkena in Cheffa area where they had been easily transported by suspension, and deposited by a great decrease in hydraulic gradient. In the Kombolcha area however grains of all sizes have been observed from the logs of the wells (Figs. 1 and 2).

With the assumption that the sediments in Kombolcha area would represent the whole alluvial sediments in the basin, grain size analysis have been carried out from a pit sample of 10 m. depth. By mixing the samples, weight of the grains retained in percentages was plotted against diameter (Fig. 4). From the figure 51 per cent of the sediments are silt and clay while 49 per cent is either sand or gravel. The occurrence of the grain sizes above sand suggest positive infiltration of rainwater. However, the lateral and vertical extent of these grains plays an important role. Other factors of significance for groundwater evaluation - roundness and sphericity of the coarse sediments were not possible to be

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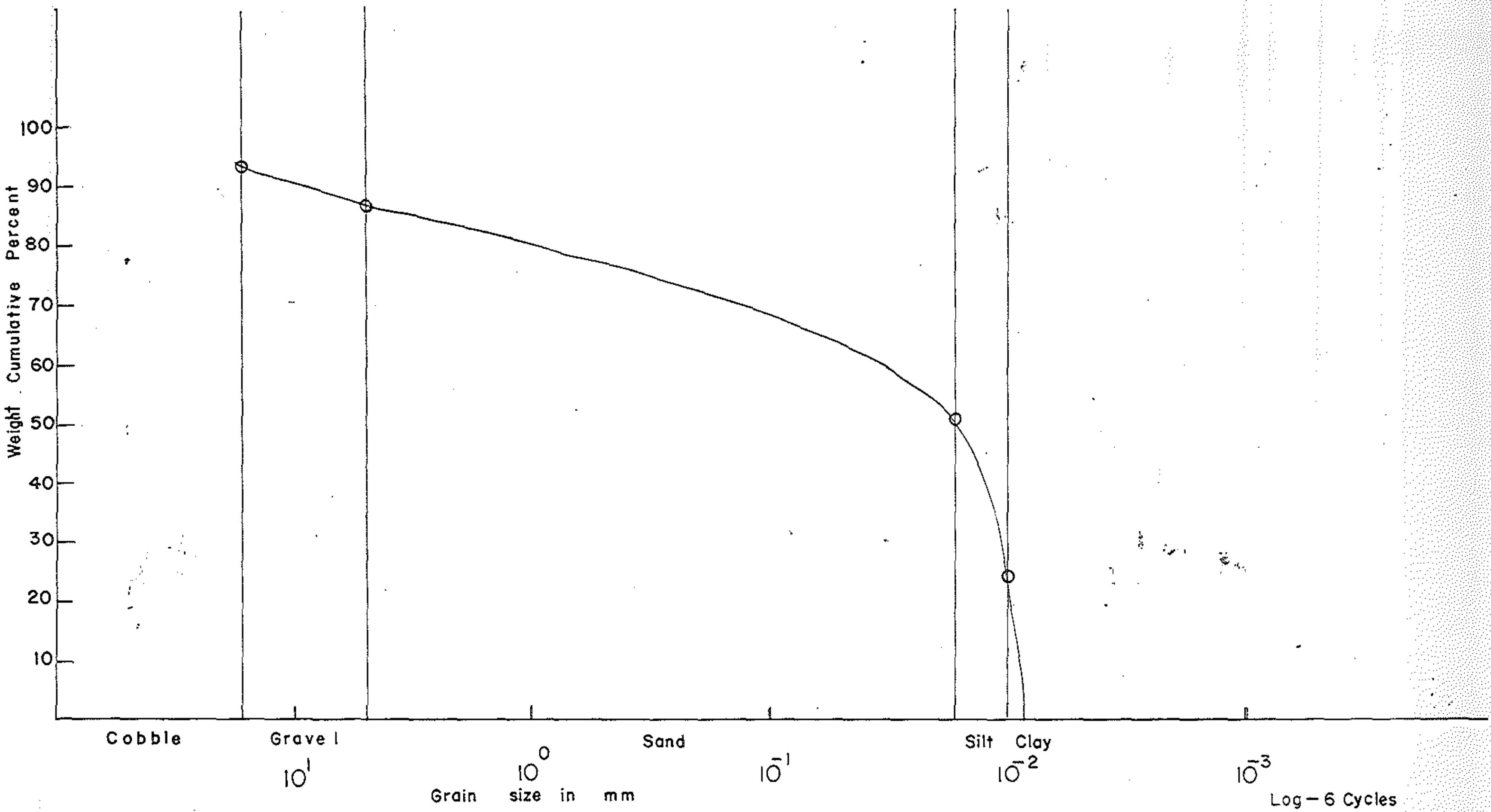
Fig. 4

Grain Size Distribution of the Sediments in Kombolcha



determined. But from visiual estimates all the clasts in the basin have moderate roundness and sphericity. The value of these parameters increases as one goes to the south of the basin.

From the well logs in Kombolcha (Figs. 1 and 2), well stratified sand and gravel sediments have been seen, though the vertical position of these sediments in different wells does not very well correlate. It is from these sand and gravel layers of the alluvial sediments that most of the groundwater is tapped from the wells in the basin. In light of this, the aquifer characteristics in each of the sub-basins (Dese, Kombolcha and Cheffa) will be discussed in detail with particular emphasis on the aquifers from the alluvial sediments.

### 4.2.1. Hydrogeology of the Dese Sub-basin

This sub-basin is located in the northern part of the Borkena River Basin and is different from the others in some respects. Two major faults define the sub-basin. The block corresponding to the present Tosa Mts. is produced by the N-S fault in the west and a NW running fault defines the eastern boundary of the sub-basin.

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The basalts in this area comprise 55.5 sq. kms while the sediments cover 30 sq. kms. There is a small marshy area on a relatively flat topography having an area of 2 sq. kms. in the vicinity where Borkena R. emanates. Recharge to the marsh comes out as seepage and from the contaots of different basaltic flows along the fault scarp.

The basaltic rocks outcropping in this particular sub-basin show a moderate significance from the hydrogeological point of view. This may be due to the secondary permeabilities developed in the rock, as several small springs with small discharges have been observed from these aquifers.

Two kilometers from the center of Dese Town around the neighbourhood of Kurkur, a borehole has been drilled. Data from the Municipality of Dese shows the static water level to be at 20 m. below ground level. During pumping at a constant discharge of 6.6 lit/sec, the water level stabilized at 38 m. depth showing a relatively good performance. Other data were not available to calculate the transmissivity, permeability and storage coefficient.

There are several springs with small discharge

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located at the foot of the Tosa Mts. along the fault scarp. The biggest of the springs is named Kurkur and is located, uphill some 300 m. north of the mentioned well. It has a yield of 2-3 lit/sec, Ketema, (1978). Another spring, Shola though not within the basin, is also issued from the basaltic rock aquifer south of Dese. It has a discharge of 6-8 Lit/sec. but it is outside the Borkena River Basin on the west side of the water divide. It can be inferred that there is an underground divide corresponding to the surfacial. This may be one of the factors to explain the moderate discharge of the springs. Another factor is the limited recharge area and/or the total volume of the aquifer.

A bore hole drilled on the basaltic rock, at the foot of Tosa Mts. along the fault zone has been abandoned due to a low yield. The low yield is attributed by groundwater channeling, along the fault line.

Proper pump testing have not been carried out on the wells located on the basalts and quantitative determination of coefficient of transmissivity (T), coefficient of storage (S) has not been calculated. Theis(1935) defines transmissivity as quantity of

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water in gallons per day per foot in an aquifer 1 foot wide and the full saturated thickness under a hydraulic gradient of 100 per cent. From Ferris et.al. (1962) storage coefficient is the volume of water the aquifer releases or takes into storage per unit surface area of the aquifer per unit change in hydraulic head normal to the surface. The determination of these parameters which are important in groundwater hydraulics would have been essential except for lack of pump test data.

The clay and silts extend for a few distance laterally. Wells penetrating these impervious layers give rise to the groundwater level which in time drops as the pressure is released and these aquifers will be discussed as semi-confined, and will be shown in the sketch below. A similar phenomenon quite common in the alluvials, exists in the other sub-basins.

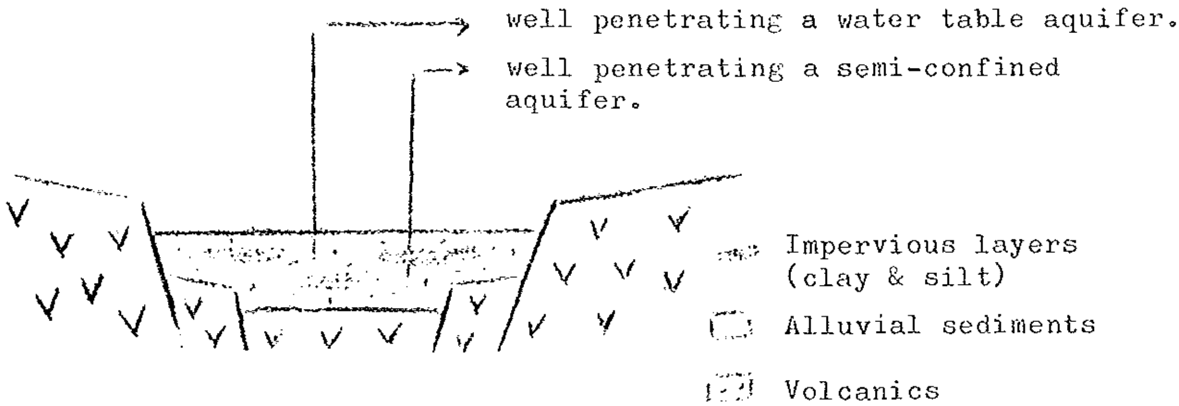


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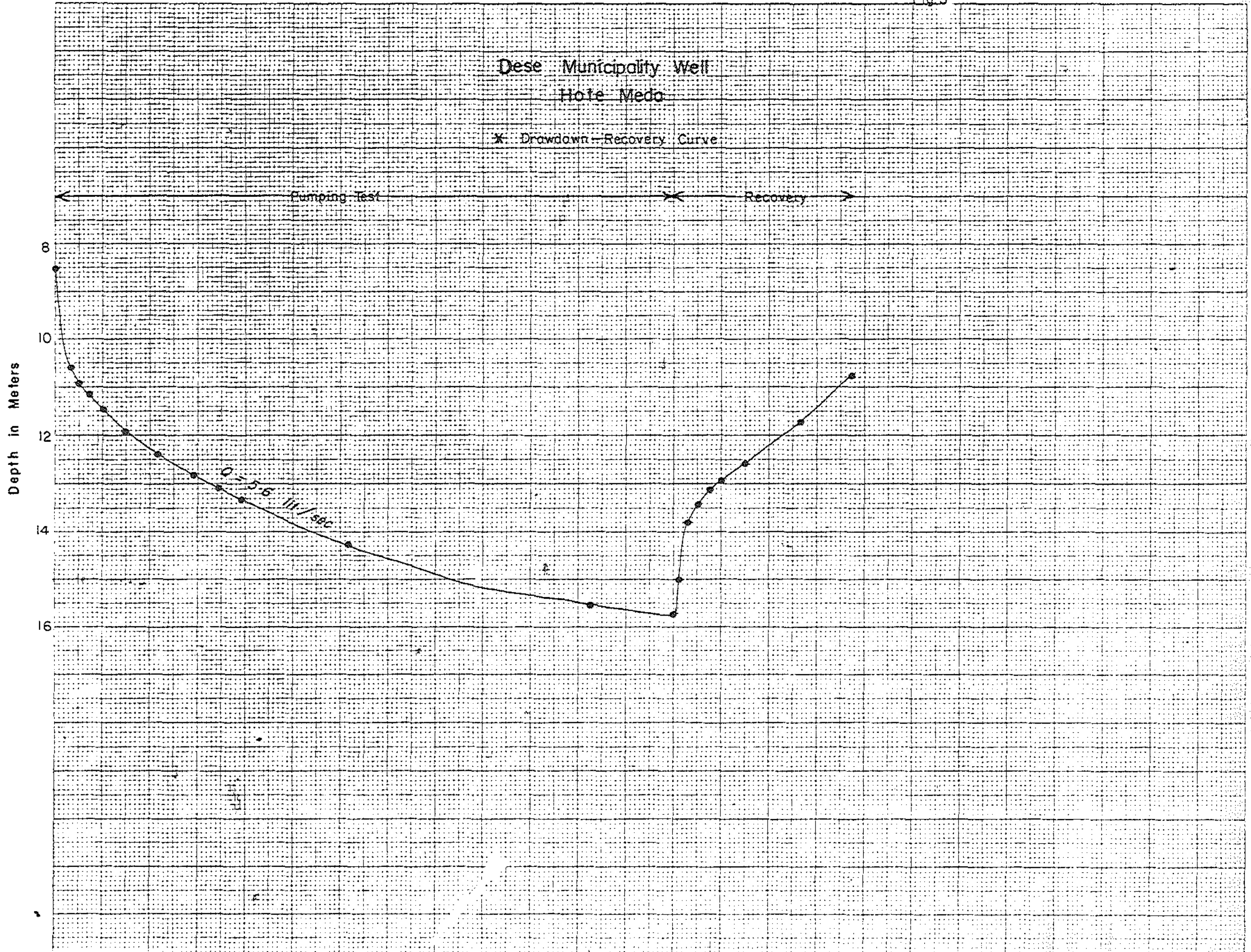
Fig.5


Dese Municipality Well
Hote Meda
* Drawdown - Recovery Curve
Pumping Test
Recovery
Q = 5.6 lit/sec
Depth in Meters
8
10
12
14
16

In general the alluvial sediments in Dese Sub-Basin are semi-confined aquifers and have proved to be hydrogeologically very significant to give quite an amount of water as evidenced from the well yield at Hote Meda. This well tapping water from an alluvial aquifer has been pump tested. Drawdown recovery data from the discharging well has been plotted on a graph. It indicates that neither the drawdown is that fast, nor the recovery so slow to indicate the potentiality of the aquifer, (Fig. 5 ).

Since no observation well or piezometer was available to measure the drawdown further away from the discharging well, Theis Non-Equilibrium formula has not been applied to calculate the storage coefficient. However, applying Jacob's Non-Equilibrium formula the parameters, transmissivity and permeability have been calculated. Jacob's formula approximated from Theis in the final analysis is expressed by Walton, (1970) as:

$$T = \frac{264\ Q}{\Delta s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where $\Delta s$ = change in drawdown over 1 log cycle.

Q = Discharge

T = Transmissivity

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The above formula is valid for English units where transmissivity is expressed in U.S.A gallons per minute per day. A formula which is valid for metric units has been applied to treat the data, for the test carried out in the Hote Meda well and transmissivity is expressed as

$$T = \frac{2.3\,Q}{4\pi\,\Delta s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Based on the above formula and applying drawdown-recovery data (Table 5 and 6) the transmissivity value by graphical solution has been calculated (Fig. 8) where

$Q = 5.6$ lit/sec

$\Delta S = 0.95$ m

Thus $T = \frac{2.3 \times 483.8\ m^3/day}{4\pi(0.95\ m)} = 94\ m^3/d/m.$

The permeability can be calculated dividing the obtained transmissivity by the thickness of the saturated aquifer. Hence

$$K = T/M \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where K = permeability

M = saturated aquifer thickness

Thus $K = \frac{94\ m^3/d/m}{30\ m} = 3.1$ m/day which is equivalent to $3.58 \times 10^{-3}$ cm/sec.

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TABLE 5

PUMPING TEST

Pumping date : August 25, 1977

Location : Dese - (Hote Meda)

Owner : Dese Municipality

Well size : $6^5/8$ Total depth = 60m. (BGL)

Perforated depth : 6 - 12 m., 30 - 54 m.

Pump setting depth: 54 m. Discharge (Q) = 5.6 lit/sec
= 485 $m^3$/day

Pump Type : Electro-submersible

Static Water Level: 8.65 m.

Elevation of Well : 2465 m. a.s.l.

| Progressing Time (t) in min. | Water Level BGL in meters | Drawdown (s) in m |
|---|---|---|
| 0 | 8.65 | 0 |
| 1 | 9.98 | 1.33 |
| 1.5 | | |
| 2.0 | 10.06 | 1.41 |
| 3 | 10.10 | 1.45 |
| 4 | 10.14 | 1.49 |
| 5 | 10.16 | 1.51 |
| 6 | 10.19 | 1.54 |

TABLE 5 (Contd.)

| Progressing Time (t) in min. | Water Level BGL in meters | Drawdown (s) in m |
|---|---|---|
| 7 | 10.22 | 1.57 |
| 8 | 10.24 | 1.59 |
| 9 | 10.26 | 1.61 |
| 10 | 10.28 | 1.63 |
| 12 | 10.32 | 1.67 |
| 14 | 10.36 | 1.71 |
| 16 | 10.40 | 1.75 |
| 18 | 10.44 | 1.79 |
| 20 | 10.46 | 1.81 |
| 22 | 10.49 | 1.84 |
| 24 | 10.52 | 1.87 |
| 26 | 10.55 | 1.90 |
| 28 | 10.58 | 1.93 |
| 30 | 10.60 | 1.95 |
| 35 | 10.68 | 2.03 |
| 40 | 10.74 | 2.09 |
| 45 | 10.80 | 2.15 |
| 50 | 10.87 | 2.22 |
| 55 | 10.91 | 2.26 |

TABLE 5 (Contd.)

| Progressing Time (t) in min. | Water Level BGL in meters | Drawdown (s) in m |
|---|---|---|
| 60 | 10.96 | 2.31 |
| 70 | 11.01 | 2.36 |
| 80 | 11.18 | 2.53 |
| 90 | 11.25 | 2.60 |
| 100 | 11.34 | 2.69 |
| 120 | 11.50 | 2.85 |
| 140 | 11.66 | 3.01 |
| 160 | 11.80 | 3.15 |
| 180 | 11.93 | 3.28 |
| 200 | 12.07 | 3.42 |
| 230 | 12.26 | 3.61 |
| 290 | 12.60 | 3.95 |
| 350 | 12.87 | 4.22 |
| 410 | 13.15 | 4.50 |
| 470 | 13.39 | 4.74 |
| 735 | 14.34 | 5.69 |
| 1290 | 15.52 | 6.87 |
| 1440 | 15.72 | 7.07 |

*Data: Underground Water Resources Project

TABLE 6

## TIME RECOVERY TEST

Date : 26 - 8 - 77

Location : Dese - (Hote Meda)

Owner : Dese Municipality

well depth : 60 m. (BGL)

Type of Pump : Electrosubmersible 70 m. head

Perforated length : 6 - 12 m., 30 - 54 m.

Pump setting depth : 54 m.

Elevation : 2465 m. (a.s.l.)

Discharge Quantity : (before Pump Stoped) 337.2 L/m/d

Discharging time (t) : (until Pump Stoped) 1440 min.

| Time | Water Level m | Recovery (s') m | Residual Drawdown (Sr) 8.65 m SWL | PROGRESSING (t)+(t') min | (t')after pump stoped min | TIME RATIO (t/t') — |
|---|---|---|---|---|---|---|
| 3.45a.m. | 15.33 | 0 | 7.07 | 1440 | 0 | |
| 3.46 | 14.33 | 1.39 | 5.68 | 1441 | 1 | 1441 |
| 3.47 | 14.30 | 1.42 | 5.65 | 1442 | 2 | 721 |
| 3.48 | 14.27 | 1.45 | 5.62 | 1443 | 3 | 481 |

TABLE ξ (Contd.)

| Time | Water Level m | Recovery (s') m | Residual Drawdown (Sr) m | PROGRESSING (t)+(t') min | (t')after pump stoped min | TIME RATIO (t/t') — |
|---|---|---|---|---|---|---|
| 3.49 | 14.24 | 1.48 | 5.59 | 1444 | 4 | 361 |
| 3.50 | 14.21 | 1.51 | 5.56 | 1445 | 5 | 289 |
| .51 | 14.18 | 1.54 | 5.53 | 1446 | 6 | 241 |
| .52 | 14.16 | 1.56 | 5.51 | 1447 | 7 | 206.7 |
| .53 | 14.14 | 1.58 | 5.49 | 1448 | 8 | 181.0 |
| .54 | 14.12 | 1.60 | 5.47 | 1449 | 9 | 161.0 |
| .55 | 14.10 | 1.62 | 5.45 | 1450 | 10 | 145.0 |
| .57 | 14.06 | 1.66 | 5.41 | 1452 | 12 | 121.0 |
| .59 | 14.03 | 1.69 | 5.38 | 1454 | 14 | 103.9 |
| 4.01 | 14.00 | 1.72 | 5.35 | 1456 | 16 | 91.0 |
| .03 | 13.96 | 1.76 | 5.31 | 1458 | 18 | 81.0 |
| .05 | 13.93 | 1.79 | 5.28 | 1460 | 20 | 73.0 |
| .07 | 13.90 | 1.82 | 5.25 | 1462 | 22 | 66.5 |
| .09 | 13.87 | 1.85 | 5.22 | 1464 | 24 | 61.0 |
| .11 | 13.85 | 1.87 | 5.20 | 1466 | 26 | 56.4 |

TABLE 6 (Contd.)

| Time | Water Level m | Recovery (s') m | Residual Drawdown (Sr) m | PROGRESSING (t)+(t') min | (t')after pump stoped min | TIME RATIO (t/t') — |
|---|---|---|---|---|---|---|
| 4.13 | 13.83 | 1.89 | 5.18 | 1468 | 28 | 52.4 |
| .15 | 13.80 | 1.92 | 1.15 | 1470 | 30 | 49.0 |
| .20 | 13.77 | 1.95 | 5.12 | 1475 | 35 | 42.1 |
| .25 | 13.76 | 1.96 | 5.11 | 1480 | 40 | 37.0 |
| .30 | | | | 1485 | 45 | 33.0 |
| .35 | 13.52 | 2.20 | 4.87 | 1490 | 50 | 29.8 |
| .40 | 13.50 | 2.22 | 4.85 | 1495 | 55 | 27.2 |
| .45 | 13.43 | 2.29 | 4.78 | 1500 | 60 | 25.0 |
| .55 | 13.41 | 2.31 | 4.76 | 1510 | 70 | 21.6 |
| 5.05 | 13.20 | 2.52 | 4.55 | 1520 | 80 | 19.0 |
| .15 | 13.13 | 2.59 | 4.48 | 1530 | 90 | 17.0 |
| .25 | 13.06 | 2.66 | 4.41 | 1540 | 100 | 15.4 |
| .45 | 12.94 | 2.78 | 4.29 | 1560 | 120 | 13.0 |

TABLE 6 (Contd.)

| Time | Water Level m | Recovery (s') m | Residual Drawdown (Sr) m | PROGRESSING (t)+(t') min | (t')after pump stoped min | TIME RATIO (t/t') — |
|---|---|---|---|---|---|---|
| 6.05p.m. | 12.73 | 2.99 | 4.08 | 1580 | 140 | 11.3 |
| 6.25 | 12.62 | 3.10 | 3.97 | 1600 | 160 | 10.0 |
| 6.45 | 12.59 | 3.13 | 3.94 | 1620 | 180 | 9.0 |
| 7.05 | 12.35 | 3.37 | 3.70 | 1640 | 200 | 8.2 |
| 9.05 | 11.70 | 4.02 | 3.05 | 1760 | 320 | 5.5 |
| 1.05a.m. | 10.80 | 4.92 | 2.15 | 2000 | 560 | 3.6 |

*Data: Underground Water Resources Project

Based on the above results the alluvial sediment in Dese Sub-Basin has transmissivity of 94 $m^3/d/m$ and a permeability value of $3.58x10^{-3}$ cm/sec.

According to Johnson, (1966) transmissivity values of an aquifer with 1000 gall/day/ft is sufficient to meet domestic needs while values greater than 10,000 can be used for industrial, municipal and irrigation purposes. In metric units, the above values are 14.9 $m^3$/day/m and 149.2 $m^3$/day/m respectively. The transmissivity value obtained in the aquifer at Dese, can therefore be recommended for municipal uses where water consumption is not high and other alternative source of water is not at hand.

4.2.2. Hydrogeology of the Kombolcah Sub-Basin

The Kombolcha Sub-Basin is located south of Dese Sub-Basin. There is an average difference in elevation of 600 m. between the two sub-basins. They are connected by the Borkena River which has developed a gully . By cutting the volcanics over 100 m. a "V" shaped valley has been developed at the outlet leaving the Dese Sub-Basin before the stream finally reaches the Kombolcha plains

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There are outcrops of volcanics (basalts and rhyolites) in this sub-basin and wells have been drilled on these rocks in Muti Kola village (Fig. 10) and within Kombolcha (Ghion Hotel and Agip filling station wells). The maximum continuous pumping time of these wells does not exceed 3 hours with discharges of less than 2 lit/sec, as the dynamic water level drops below the pump setting depth. Due to the insignificance of the volcanic aquifers in this basin they have not been taken into consideration from the water resources potentiality point of view.

The alluvial sediments, however have proved to be very rich in groundwater resources and will be dealt with in detail. Samples of sediments have been collected from this sub-basin from a pit for grain size analysis which could give a clue to the porosity of the sediments. The measurement of porosity is an important parameter in understanding groundwater storage in clastic sedimentary rocks and sediments as opposed to massive and fine grained rocks where transmission capacity is the measure for groundwater potential which is strictly dependant on joints, cracks and bedding planes. But as the samples from the

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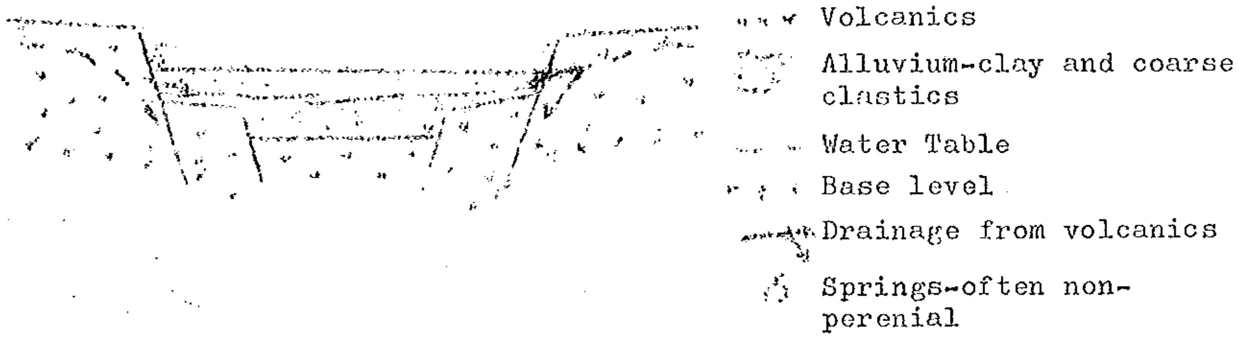
drilled wells were not in their natural state to conduct a porosity test, grain size analysis was conducted on the contrary.

From analysis of the grains (Section 4.2), the distribution of the fine sediments - silt and clay to sand and gravel is 1:1. The mixing of the fine grained and coarse grained sediments may discourage infiltration.

However, some infiltration takes place vertically in areas where the rain water encounters the coarse grained sediments. A horizontal supply of water to the alluvial sediments can also be inferred from water moving out of the volcanics, particularly the basalts. (Fig. 6).

Fig. 6




If there had not been a horizontal flow of water from the volcanics into the sediments, the high yield from the alluvial aquifers cannot be justified otherwise.

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During drilling in the Kombolcha Sub-Basin flowing wells "artesians" have been encountered, when the water bearing aquifer was struck at 61 m. depth below ground level (BGL) at the Textile's Co. well, where water gushed out from the gravel aquifer. The "artesian" effect has been observed on the other 4 wells, 2 owned by the Municipality, one each owned by the Textile's Co. and the Oil and Food Corporation. The piezometric surfaces of the Municipality wells No. 1 and No. 2 decreased to 0.7 and 4.4 m. BGL, five months later. The other wells for Textiles Co. and Oil and Food Corporation, however maintain the same piezometric surface as before. All the wells are located at least 200 m. apart and the textile well is over 1 km. away from the other wells. Most of the wells penetrate to a reasonable depth into the main saturated aquifers and there is no interference between the wells (wells not yet in operation). The lowering of the piezometric surface of some of the wells could be the result of lowering of the hydrostatic head in the recharge area.

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In the Kombolcha Sub-Basin there are 12 boreholes and of these 6 are operating - 3 each located on the basaltic and allucial aquifers. Two wells located on the basalts are sited on the fault-scrap and one on the water divide: The poor siting is the main cause for the low yield of the wells. The Municipality, Meat Factory and the Water Resources wells are the presently functioning wells tapping water from the alluvial aquifers. (Fig. 7) The yield of these wells is reasonable, though more can be expected if drilling of the wells has been conducted to the full depth of the alluvial aquifers. Pump test data for these wells was not obtained. However, for the four wells drilled in the same area, and where depths of 94 m. has been obtained pump test data has been available. Drawdown-recovery data was conducted on the discharging wells (Fig. 11) and no observation wells were available during the test and thus the coefficient of storage has not been calculated. Based on the drawdown-recovery data (Table 7 and 8) a graphical solution by Jacob's method (Fig. 9) for transmissivity (T) has been carried out using formula (2).

Fig. 7 Piezometric Surfaces of Wells in Kombolcha

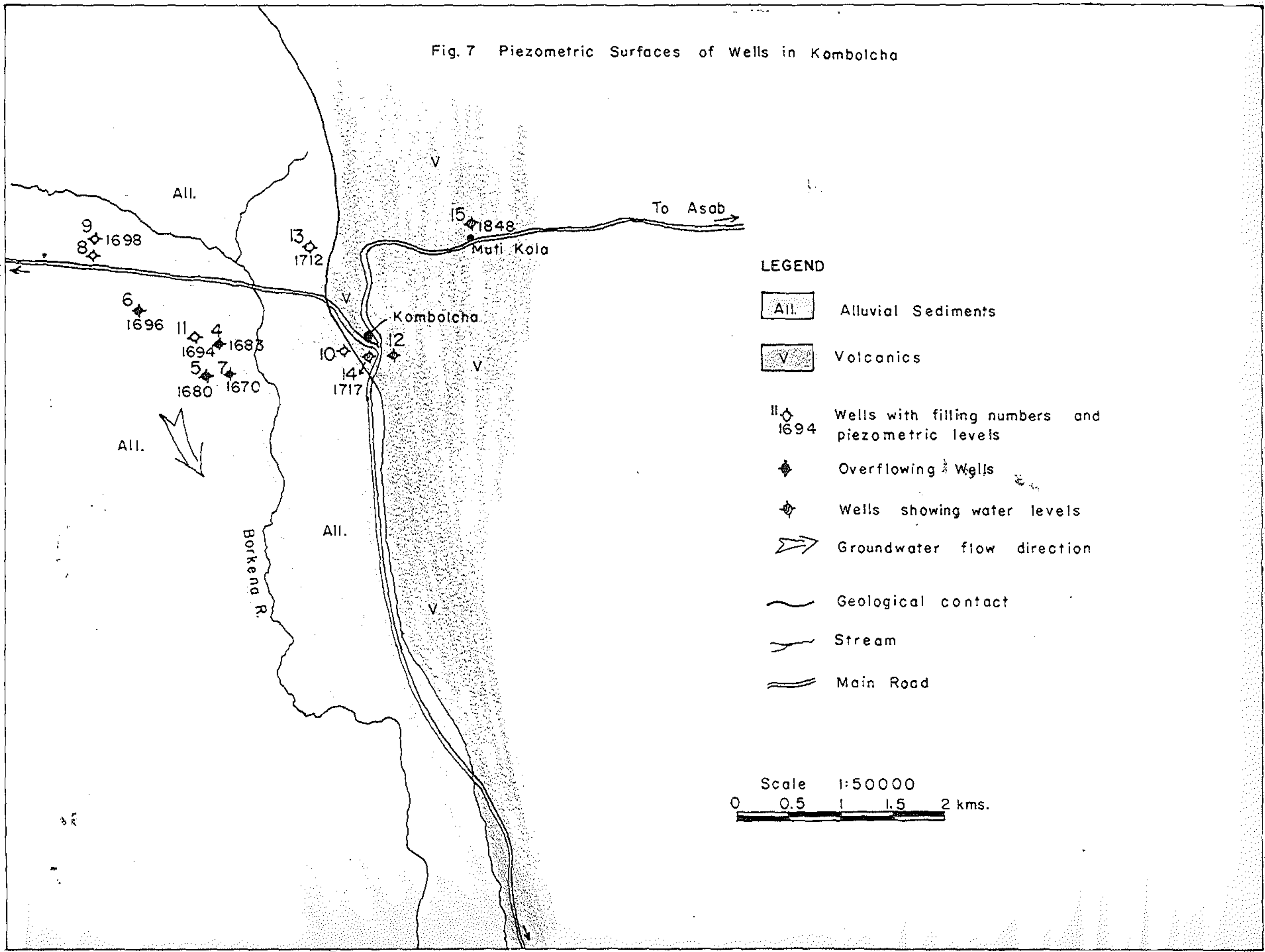


TABLE 7

Pumping Test

Pumping date : 17 - 4 - 79 to 19 - 4 - 79

Location : Kombolcha

Owner : Ethiopian Textiles Corporation Well #1

Pump setting depth : 64 m Total depth = 71 m

Elevation : 1695 m

Discharge : 8 lit/sec ≡ 691.2 $m^3$/day WL = 0.00(over flow)

| Time Since Pumping started (t) in min. | Water Level BGL in meters | Drawdown (s) in m. |
|---|---|---|
| 0.00 | overflow | overflow |
| 1.00 | 2.6 | 2.6 |
| 1.5 | 3.75 | 3.75 |
| 2 | 4.50 | 4.50 |
| 3 | 5.87 | 5.87 |
| 4 | 6.98 | 6.98 |
| 5 | 7.49 | 7.49 |
| 6 | 7.94 | 7.94 |
| 7 | 8.45 | 8.45 |
| 8 | 8.83 | 8.83 |
| 9 | 9.16 | 9.16 |
| 10 | 9.43 | 9.43 |

TABLE 7 (Contd.)

| Time Since Pumping started (t) in min. | Water Level BGL in meters | Drawdown (s) in m. |
|---|---|---|
| 12 | 9.97 | 9.97 |
| 14 | 10.43 | 10.43 |
| 16 | 10.85 | 10.85 |
| 18 | 11.14 | 11.14 |
| 20 | 11.38 | 11.38 |
| 22 | 11.54 | 11.54 |
| 24 | 11.69 | 11.69 |
| 26 | 11.84 | 11.84 |
| 28 | 11.97 | 11.97 |
| 30 | 12.09 | 12.09 |
| 35 | 12.31 | 12.31 |
| 40 | 12.53 | 12.53 |
| 50 | 12.88 | 12.88 |
| 60 | 13.16 | 13.16 |
| 70 | 13.24 | 13.24 |
| 80 | 13.61 | 13.61 |
| 90 | 13.62 | 13.62 |
| 100 | 14.00 | 14.00 |
| 120 | 14.30 | 14.30 |
| 150 | 14.65 | 14.65 |

TABLE 7 (Contd.)

| Time Since Pumping started (t) in min. | Water Level BGL in meters | Drawdown (s) in m. |
|---|---|---|
| 180 | 14.97 | 14.97 |
| 210 | 15.55 | 15.55 |
| 240 | 15.90 | 15.90 |
| 280 | 16.24 | 16.24 |
| 300 | 16.36 | 16.36 |
| 330 | 16.56 | 16.56 |
| 420 | 17.11 | 17.11 |
| 480 | 17.39 | 17.39 |
| 540 | 17.64 | 17.64 |
| 600 | 17.85 | 17.85 |
| 660 | 18.05 | 18.05 |
| 720 | 18.23 | 18.23 |
| 780 | 18.39 | 18.39 |
| 840 | 18.54 | 18.54 |
| 900 | 18.68 | 18.68 |
| 960 | 18.81 | 18.81 |
| 1020 | 18.94 | 18.94 |
| 1080 | 19.02 | 19.02 |
| 1140 | 19.10 | 19.10 |
| 1200 | 19.19 | 19.19 |

TABLE 7 (Contd.)

| Time Since Pumping started (t) in min. | Water Level BGL in meters | Drawdown (s) in m. |
|---|---|---|
| 1260 | 19.28 | 19.28 |
| 1320 | 19.35 | 19.35 |
| 1380 | 19.44 | 19.44 |
| 1440 | 19.49 | 19.49 |
| 1560 | 19.62 | 19.62 |
| 1680 | 19.78 | 19.78 |
| 1800 | 19.93 | 19.93 |
| 1920 | 20.06 | 20.06 |
| 2040 | 20.20 | 20.20 |
| 2160 | 20.33 | 20.33 |
| 2220 | 20.37 | 20.37 |

Total Pumping Hours = 37

*Data: National Boring Co.

TABLE 8

## Time Recovery Test

Date : 19 - 4 - 79

Location : Kombolcha

Owner : Eth. Textiles Corporation Well 4

Pump setting : 64 m. Total depth = 71 m.

Elevation : 1695 m. SWL = Overflow = GROUND LEVEL.

| Water Level (m) | Recovery (s') (m) | Residual draw down (SR) overflow | PROGRESSING TIME (t)+(t') (min) | (t') after pumping stopped (min.) | TIME RATIO (t/t') |
|---|---|---|---|---|---|
| 20.37 | 0 | 20.37 | 2220 | 0 | |
| 16.00 | 4.37 | 16.00 | 2221 | 1 | 2221 |
| 15.25 | 5.12 | 15.25 | 2221.5 | 1.5 | 1481 |
| 14.60 | 5.77 | 14.60 | 2222 | 2 | 1111 |
| 13.10 | 7.27 | 13.10 | 2223 | 3 | 741 |
| 13.00 | 7.37 | 13.00 | 2224 | 4 | 556 |

TABLE 8(Contd.)

| Water Level (m) | Recovery (s') (m) | Residual draw down (SR) overflow | PROGRESSING TIME | | TIME RATIO |
|---|---|---|---|---|---|
| | | | (t)+(t') (min) | (t')after pumping stopped (min.) | (t/t') |
| 12.70 | 7.67 | 12.70 | 2225 | 5 | 445 |
| 12.50 | 7.87 | 12.50 | 2226 | 6 | 371 |
| 12.35 | 8.02 | 12.35 | 2227 | 7 | 318 |
| 12.09 | 8.28 | 12.09 | 2228 | 8 | 279 |
| 11.84 | 8.53 | 11.84 | 2229 | 9 | 248 |
| 11.51 | 8.86 | 11.51 | 2230 | 10 | 223 |
| 11.18 | 9.19 | 11.18 | 2232 | 12 | 186 |
| 10.88 | 9.49 | 10.88 | 2234 | 14 | 160 |
| 10.65 | 9.72 | 10.65 | 2236 | 16 | 140 |
| 10.43 | 9.94 | 10.43 | 2238 | 18 | 124 |
| 10.28 | 10.09 | 10.28 | 2240 | 20 | 112 |
| 10.12 | 10.25 | 10.12 | 2242 | 22 | 102 |
| 9.98 | 10.39 | 9.98 | 2244 | 24 | 94 |

TABLE 8 (Contd.)

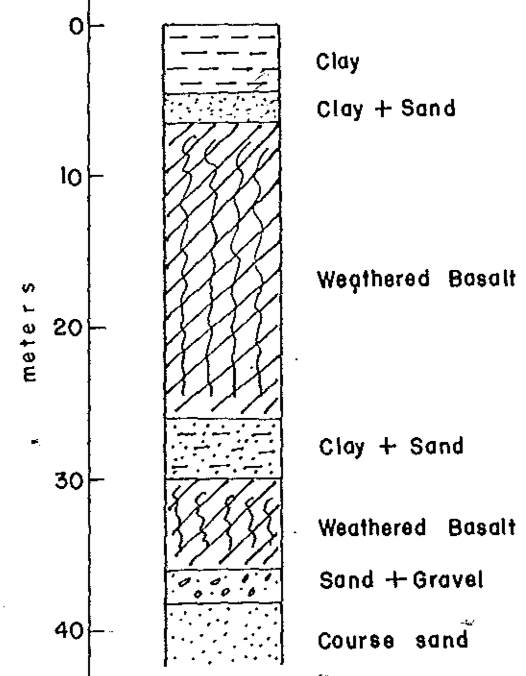
| Water Level (m) | Recovery (s') (m) | Residual draw down (SR) overflow | PROGRESSING TIME | | TIME RATIO |
|---|---|---|---|---|---|
| | | | (t)+(t') (min) | (t')after pumping stopped (min.) | (t/t') |
| 9.85 | 10.52 | 9.85 | 2246 | 26 | 86 |
| 9.72 | 10.65 | 9.72 | 2248 | 28 | 80 |
| 9.57 | 10.8 | 9.57 | 2250 | 30 | 75 |
| 9.32 | 11.05 | 9.32 | 2245 | 35 | 64 |
| 9.06 | 11.31 | 9.06 | 2260 | 40 | 57 |
| 8.67 | 11.7 | 8.67 | 2270 | 50 | 45 |
| 8.34 | 12.03 | 8.34 | 2280 | 60 | 38 |
| 8.05 | 12.32 | 8.05 | 2290 | 70 | 33 |
| 7.81 | 12.56 | 7.81 | 2300 | 80 | 29 |
| 7.58 | 12.79 | 7.58 | 1310 | 90 | 26 |
| 7.40 | 12.97 | 7.40 | 2320 | 100 | 23 |
| 7.05 | 13.32 | 7.05 | 2340 | 120 | 20 |
| 6.64 | 13.73 | 6.65 | 2370 | 150 | 16 |

TABLE 8 (Contd.)

| Water Level (m) | Recovery (s') (m) | Residual draw down (SR) overflow | PROGRESSING TIME | | TIME RATIO |
|---|---|---|---|---|---|
| | | | (t)+(t') (min) | (t') after pumping stopped (min.) | (t/t') |
| 6.28 | 14.09 | 6.28 | 2400 | 180 | 13 |
| 5.91 | 14.46 | 5.91 | 2430 | 210 | 12 |
| 5.71 | 14.66 | 5.71 | 2460 | 240 | 10 |
| 5.40 | 14.97 | 5.40 | 2500 | 280 | 9 |
| 5.20 | 15.17 | 5.20 | 2520 | 300 | 8 |

*Data: National Boring Co.

Lithological Log for Well in Muti Kola Village – Wollo




* Data from UNICEF — Technical Report — Eth.(1977)

Modified by Ketema Tadesse

Thus

$$T = \frac{2.3 \times 691.2\ m^3/d}{4\pi \times 4.5\ m} = 28.1\ m^3/d/m$$

where $Q = 8$ lit/sec $= 691.2\ m^3/day$

$s = 4.5$ m

and the permeability (K) from formula (3) gives:

$$K = \frac{28.1\ m^3/d/m}{26\ m} = 1.08\ m/day$$

$$= 1.25 \times 10^{-3}\ cm/sec$$

where m= 26 m.

The alluvial aquifer in the Kombolcha Sub-Basin has thus a transmissivity of 28.1 $m^3/d/m$ and a permeability of 1.08 m/d, i.e. $1.25 \times 10^{-3}$ cm/sec. The transmissivity value of the aquifers could supply wells with enough water to substantiate for the town's water need, where the population is less than 10,000.

4.2.3. Hydrogeology of the Cheffa Sub-Basin

The Cheffa Sub-Basin is the southern most part of the Borkena R. Basin. The geology of the area is similar to the volcanics outcropping in Dese and Kombolcha sub-basins. In effect, from hydrogeological point of view the basalts, rhyolites and trachytes in this sub-basin are also insignificant as in the other sub-basins, (Section 4.2.1 and 4.2.2) The alluvial sediments cover an area of

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395 sq. kms corresponding to 80 per cent of the sediments in the sub-basin. It is partially separated from the Kombolcha Sub-Basin by a basalt and rhyolite rock outcrops exposed due to faulting and erosion south of Fontanina village.

The average elevation of the basin is 1550 m. above sea level which is about 250 m. below the Kombolcha Sub-Basin.

In the Cheffa Sub-Basin there are 4 drilled wells located in Harbu, Kemise, Cherete and Cheffa villages. All of the wells are located on alluvial sediments which is predominantly clay, silt and sand. These wells are located on a thin alluvial sediments, overlying the volcanics. The center of the graben has thicker sediments. Log information from the wells at Harbu and Cherete indicates that there is some gravel overlying the volcanics. Water is tapped from this gravel and from the wea weathered top most of the volcanics.

The groundwater potential in the sub-basin is estimated to be relatively low both from the alluvial sediments and the volcanic rocks. Quantitative estimates of well performance has not been made due to lack of pump testing data in the region. From the mixing of different grain sizes

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and dominance of the fine sediments in the top layer of the alluvial depositions in the basin much infiltration can not be expected.

4.2.3.1. The Cheffa Marsh

The Cheffa marsh comprises an area of 55 sq. kms. When floods occur immediate to the heavy rains in September and October the area of the marsh increases. The flood levels at times cover the Addis Ababa - Dese road making the road temporarily unavailable to the traffic. The sediment type in this marsh as the whole of the Cheffa Sub-Basin is predominantly silt and clay. These fine sediments are transported under suspension by the river from the higher elevated Kombolcha and Dese Sub-Basins to be deposited in the flat, low lying marshy area. The water from the marsh, is finally drained through the "V" shaped highly incissed valley where a very small outcrop of trachytic rock is exposed. The age and development of the Borkena River is not certainly known. The author thinks the river

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pre-existed or was contemporaneous to the faulting which resulted the graben. The river through time has eroded the adjoining elevated areas, in the mean time depositing all the sediments in the flat, low lying Dese, Kombolcha and Cheffa area on the floor of the graben.

The large area occupied by the marsh was thought to be reclamated. The problem of draining the marsh and other factors have retarded the process. Three methods can be suggested by the author.

1. Dewatering the marsh by deepening the river bank, at the outlet of the marsh.
2. Pumping of the marsh water and discharging the water downstream.
3. Construction of a dam upstream to restrict the Borkena River from flowing into the marsh.

The groundwater level in the marshy area rises to the surface and joins the stagnated water. It would thus be very espensive to discharge the water by pumping. Therefore suggestion two cannot be applied.

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As the marsh is perennial it means the drainage towards the stream is poor. Therefore deepening the river bed would not be sufficient unless proper channels are constructed within the marsh. If this method is applied the whole water in the marsh is drained in a short time to create environmental imbalance.

The third method would be the most advantageous method to be implemented. This way, flooding of the Cheffa sub-basin can be controlled; the water can be used for irrigation to reclamate the marshy area and a hydro-electric power station can be constructed.

It is therefore the opinion of the author to dam the river opposite Fontanina village so that the water may be used for irrigation in the whole of the Cheffa Sub-Basin downstream. In fact the rhyolitic outcrops exposed by faults opposite Fonatanina village on both sides of the river bank would be the best site. This site chosen, the cost of constructing the dam would be low and

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the infiltration loss through the volcanics would be minimized as opposed to sites chosen on the alluvial sediments.

# 5. WATER QUALITY

In the Borkena R.Basin complete water quality assessment for both groundwaters and surface waters has been conducted (Appendix 10-A,B,C) with more emphasis on hydro-geochemistry. Data on Bacteriological tests was obtained for only one bore well drilled in Dese by the Aid Bank Underground Water Resources Development Project. The means to conduct bacteriological test was not at hand by the author.

## 5.1 Hydrogeochemistry

Chemical analysis of waters for the basin was conducted at three different times by the author. Analysis for the groundwaters in Dese town was first conducted in January, 1978 Ketema (1978) when a study was carried out to evaluate the water supply of the town. Under the present ground-water evaluation of the basin however, samples for analysis were taken twice in May, and September, from the same water points. This was done primarily to check the ground-water quality before the rains and immediate to the rains. The analysis was conducted at the Ministry of Mines, Energy and Water Resources laboratory. (Appendix 10-A,B,C)

For the samples taken from the same water points, but sampled and analyzed at different seasons the following results were obtained. Generally the waters from the cold springs and bore wells, showed higher cations and anions for the samples collected after the heavy rains. Samples from rivers, the Cheffa swamp and the Mai Ebar lake however showed a decrease in the concentration of anions and cations for the analysis of waters sampled after the rainy season. The dug wells in the basin are mostly concentrated in Cheffa farm area, and most of the analysis of the water samples sampled after the rains showed a decrease in dissolved solids and in $P^H$ values.

The results being so, it is speculated by the author that lower total dissolved solids for the wells in Cheffa is attributed to lower use of fertilizers during the rainy seasons while the decrease in the river and swamp water is due to dilution by the relatively pure rain water runoff in the rainy seasons. The higher dissolved constituent for the cold spring and bore well waters however is thought to be due to easy leaching and dissolvation of minerals as water infiltrates into groundwater system by recharge from the rains. In this case the water has been in contact with minerals for longer periods facilitating the dissolvation. Lower than expected dissolved solids in the hot springs sampled and analyzed after the rainy seasons should be treated strictly as these waters which come from greater depths should have been constant in chemical constituents throughout the year. Unless there could have been an error in sampling or in analysis; it is possible to hypothesize that there is the possibility for the hot waters which come from depth to have been diluted by surface runoff with lower dissolved solids.

The chemistry of the waters in the basin has been treated based on the respective aquifers the samples come from, temperature of the waters during sampling and mode of occurrence of the surface waters.

The groundwater in the basin comes from alluvium, basalts and rhyolites. All the cold spring waters, a borehole in Dese and three wells in Kombolcha come from basalts while all the hot springs come from rhyolites. The remaining groundwater in the basin comes from alluvial sediments (all waters from shallow dug wells and the remaining boreholes). The surface waters comprise; stream waters, a lake and swamp water; and have been treated separately.

Based on the above classification, the mean for the cation and anion concentration has been plotted on a Piper Diagram (Fig. 12). The standard deviation from the mean at 95% confidence interval has been represented by a circle. The results indicate the hot spring waters from the rhyolites are strictly alkaline bicarbonate-sulfate type. The rest of the water (both ground and surface) are magnesium-calcium bicarbonate type. The bicarbonate concentration in igneous rocks could be accounted for the dissociation of water under the presence of carbon-dioxide, but sulfur is not a major constituent of igneous rocks. Its occurrence in the hot spring waters upto 40% in the investigated area is unusual. The presence of certain igneous minerals of the feldspathoid group, Hem, (1959) or presence of gypsum or anhydrite could explain the sulfate waters due to groundwater contact with underlying unhydrites or igneous rocks containing feldspathods though these outcrops are missing in the area.

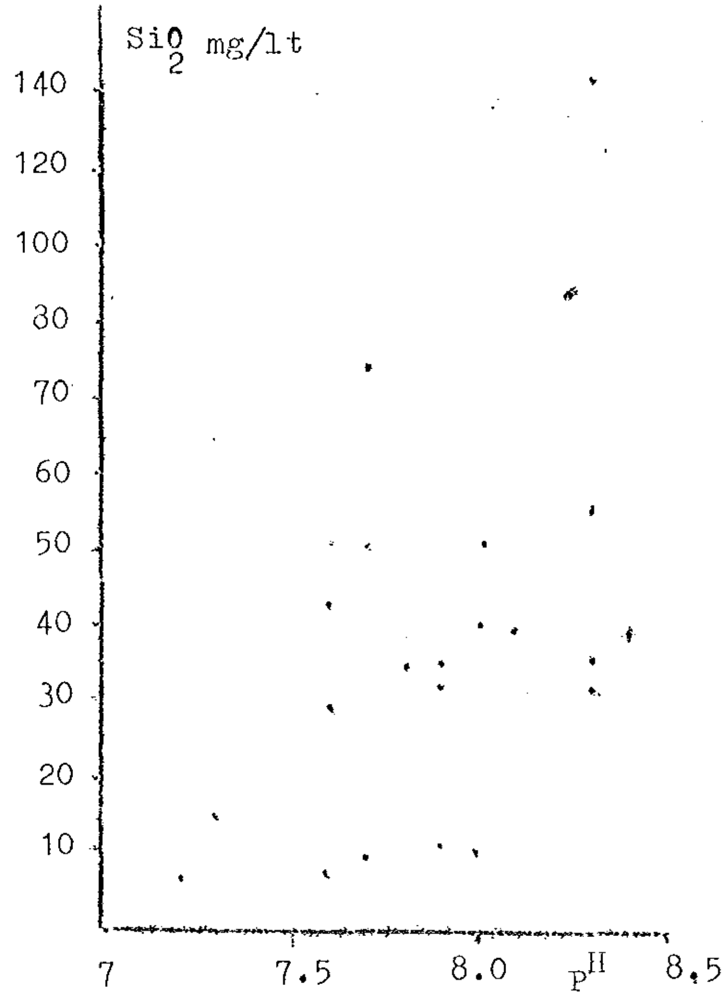
The hydrogen-ion concentration of a solution which is the measure of the acidity has been found out for the water samples taken from different parts of the basin both for ground and surface waters. The measurement is conducted by a $P^H$ meter fitted with glass electrodes. As value of 7.0 is neutral, $P^H$ ranging from 7.0 to 8.3, was recorded in the studied area, with the high values generally corresponding to the groundwaters. This shows that the groundwater in the area is slightly alkaline. The $P^H$ results for the drilled well water has a random value and can't be correlated to any of the hadrologic factors such as location, aquifer type etc. However, Barkena River water sampled at different sites i.e. in Kombolcha town, opposite Fontanina village, and by the outlet as it comes from the marsh showed $P^H$ values of 8.0, 7.7 and 7.8 respectively. Lower $P^H$ in Fontanina and immediate to the marsh is attributed to the acid environment due to organic material in the marsh.

The $P^H$ values of all the samples in the area had been plotted against the solubilities of silica (Fig. 13). From the figure, the concentration of silica, in solution for all the samples lies between $P^H$ values of 7.5 and 8.5. Mason (1966) suggested that the $P^H$ of an environment is especially significant for the transportation of silica and its ultimate redeposition and shows silica to be in solution significantly for $P^H$ values of 5.0 to 9.0. Total dissolved solids which is determined by the weight of the dry residue after the evaporation of the water sample at 180°C has been done during the analysis at the Mines Laboratory. This however doesn't take into account the dissolved gases in the sample or the bicarbonate which has been converted to carbonate with the loss of carbon dioxide.

The total dissolved solides for the samples in the basin range from 172.3 to 1097.6 ppm.(Appendix 10-A,B,C). The highest values of total dissolved solids (T.D.S.) was obtained from the hot spring waters while the lowest value comes from the only lake in the basin-Lake Mai Ebar.

One of the hot springs showed unusually very high content of $SiO_2$-122m. Geothermal report on Ethiopia (1973) indicates that high temperature sources are characterized by high content of $SiO_2$, low Na/k, Na/Li, Ca, $HCO_3$ and high Cl/total $CO_3$ species, Na/Ca, Cl/F ratios. Eventhough, the heat source at depth is not that significent in the basin the existence of potential geothermal resource in the vicinity can be speculated particularly in the Afar-Depression which is the eastern boundary of the studied area.

Fig. 13



5.1.1 Water Quality Criteria for Domestic Use

The chemical analysis of the groundwater samples in the basin have been compared with international standards set by water quality criteria California (1952), World Health Organization (1963), Australian Water Quality Criteria, Hart (1974). Most of the waters are well within the standard limits for human consumption except for some ions as flouride expressed as (F), and nitrate as ($NO_3$). Content of nitrate upto 85 ppm. has been observed in some of the dug wells in Dese and Kombolcha. According to Hart (1974) values of nitrate over 26 ppm is reported to have toxic effect in infants while W.H.O. recommends 45ppm to be the maximum allowable concentration. The high concentration is mostly attributed to the open pit laterines as there is no proper sewerage systems in the towns. Bicarbonate concentration on the other hand is very high compared to the maximum allowable limit of 150ppm as specified by World Health Organization (W.H.O), in most of the groundwaters in the basin. The origin of the bicarbonate concentration-as it is supposed to be Ca, Mg $(HCO_3)_4$ is speculated to be from the basalts. According to Hart (1974) the consumption of this ion over a concentration of 500ppm. is reported to cause gastro-intestinal irritation. The most hazardous ion to health, flouride which is common in most Ethiopian groundwaters, particularly in the Rift Valley area is well within the standard limits in this basin except in the hot spring waters, where values above the standard specification 1-1.5 ppm. has been observed. These hot spring waters are used for medical purposes by the community in the basin and temporary use can't be of danger.

The standard limit of ionic content of waters differs in different countries with respect to the availability of alternative sources. A general standard limit set by World Health Organization - W.H.O (1963) and Water Quality Criteria California (1952) is as follows. Data obtained from Ethiopian Water Resources Authority (EWRA) Technical Report (1977).

Table 9

International standards of Chemical Analysis of Waters for Domestic Use (values in ppm)

| | Max. Acceptable | Max. Allawance |
|---|---|---|
| Appearance | colorless | - |
| Colour | 5 | 50[xxx] |
| Odour | odourless | |
| Taste | tasteless | |
| Turbidity | 5 | 25[xxx] |
| $P^H$ | 6.5 | 9.2[xxx] |
| Flooting solids | Absent | |
| Suspended solids | Absent | |
| Disolved solids | Absent | |
| Total solids | 500 | 1,500[xxx] |
| Total Hardness as $CaCO_3$ | 100 | 500[xx] |
| Carbonate Alkalinity as $CaCO_3$ | | 120[xx] |
| Bicarbonate alkalinity | | 150[xx] |
| Dissolved ammonia | | 0.02[xx] |

| Cations | Max. Acceptable | Max. Allawance |
|---|---|---|
| $NH_4$ | - | $0.5^{xx}$ |
| Na | 10 | $115^{xx}$ |
| K | - | $2000^{xx}$ |
| Ca | 75 | $200^{xxx}$ |
| Mg | 50 | $150^{xxx}$ |
| Fe(total) | 0.3 | $1.0^{xxx}$ |
| Mn | 6.1 | $0.5^{xxx}$ |
| Zn | 5.0 | $15^{xxx}$ |

| Anions | Max. Acceptable | Max. Allowance |
|---|---|---|
| Cl | 200 | $600^{xxx}$ |
| $NO_2$ | - | $2^{xx}$ |
| $NO_3$ | | $45^{xxx}$ |
| F | | $1.5^{xxx}$ |
| $HCO_3$ | | $150^{xx}$ |
| $CO_3$ | | $20^{xx}$ |
| $SiO_2$ | $40^{xx}$ | $50^{xx}$ |
| $SO_4$ | $200^{xx}$ | $400^{xx}$ |

DATA: xx = Water Quality Criteria-California (1952)

xxx = W.H.O (1963)

Data = EWRA - Technical Report (1977)

### 5.1.2 Water Quality Criteria for Agriculture

The quality of chemical composition of waters is a major factor to be taken into account when considering a development in the field of Agriculture. To this effect, the chemical composition of both surface and groundwaters in the area has been analyzed so as to be able to set a criterion. The quality of the waters is determined by the total salt and ionic contents. Trace elements analysis was not possible to conduct, eventhough it plays a major role in plant growth. As the salts harm the growth of plants, sodium concentration in relation to magnesium and calcium concentration has been used to set the criteria. The sodium adsorption ratio (SAR) recommended by the U.S. Salinity Laboratory staff (1954) is an important factor in evaluating irrigation waters and has been used to classify the waters in the area under question. (TABLE 10)

It is expressed as:

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

where the concentration of the cations is expressed in equivalents per million. (Equivalent per million "epm" is calculated by dividing parts per million by the equivalent weight of the ion under consideration). Plants in different climatic and physiographic regions behave to different SAR ratios, however Johnson (1966) sets values of 18 or more to be high 10-18 medium below 10 offer little danger of creating a sodium problem

The SAR values of all waters in the Borkena R. range from 0.16 to 2.37 except for the hot spring waters (Table 10). The highest values are from the hot spring waters (SAR > 20), and the lowest value is from Cheffa marsh. The drilled wells, hand dug wells, streams, cold springs and the lake water all have values below 5.0 thus very favourable for plants. As the hot-spring waters are not big enough to be used for irrigation purposes the high

SAR ratio observed is not a problem for plant growth in the basin. As to the trace element analysis, future works have become necessary to set the criteria. The following table shows SODIUM ADSORPTION RATIO of some samples in the basin.

Table 10

| Drilled wells | SAR |
|---|---|
| Meat processing factory (Kombolcha) | 1.5 |
| Kombolcha Municipality well | 2.38 |
| Kombolcha Municipality (not in operation) | 4.9 |
| Kombolcha Municipality (not in operation) | 3.8 |
| Dese Municipality (hote Meda) | 1.24 |
| Kemise Municipality | 0.82 |
| Harbu Municipality | 2.87 |
| Cherete Municipality | 0.68 |
| **Springs** | |
| Kurkur (Dese) | 0.57 |
| Fontanina (Kombolcha) | 1.67 |
| **Rivers** | |
| Dirma | 0.73 |
| Felana | 0.92 |
| Borkena (at kombolcha) | 0.96 |
| Borkena (at Fontanina) | 1.34 |
| Borkena (at the outlet) | 1.57 |
| Cheffa Marsh | 0.16 |
| Lake Mai Ebar | 0.27 |

| | |
|---|---|
| Hartu (Hot spring) | 25.9 |
| Harbu (Hot spring) | 24.9 |

Another classification of suitability of waters for irrigation with respect to electrical conductivity and percent sodium has been established by Wilcox (1948), Fig.3. Here the sodium percentage is defined by

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

where the ionic content is expressed in milli-equivalent per liter. The electrical conductivity results have been calculated from the total dissolved solids of the samples by conversion where:

1 meq / liter of cations = 100 EC x $10^6$ and
1 ppm. = 1.56 EC x $10^6$

The EC denotes electrical conductivity for most waters with EC ranging between 100 and 5000 micromhos/cm at 25°C, Todd (1959).

Based on the above fact, representative samples for the drilled wells, hand dug wells, streams, cold and hot springs was taken to calculate the sodium percentage and the EC applying:

1 meq / lt. cations = 100 EC x $10^6$, (Talbe 11).

Coming into conclution, by plotting the two parameters in Wilcox's diagram (Fig. 14), most of the natural waters in the basin are excellent to permissible except for the hot spring waters where the field representing the physico-chemical character of these waters lie in the doubtful to unsuitable region. The basis for classification is expressed by the following table, after Todd (1959)

| Water Class | Per Cent Sodium | EC x $10^6$ at 25°C |
|---|---|---|
| Excellent | 20 | 250 |
| Good | 20-40 | 250-750 |
| Permissible | 40-60 | 750-2000 |
| Doubtful | 60-80 | 2000-3000 |
| Unsuitable | 80 | 3000 |

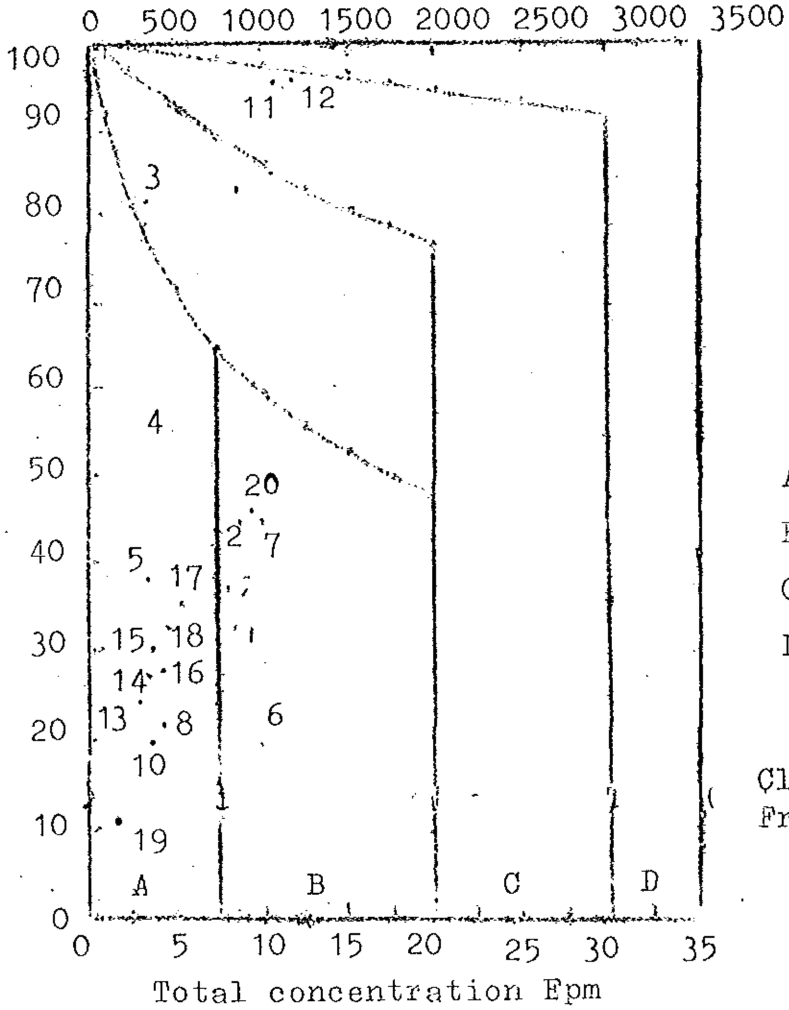
Table 11

| Drilled Wells | % Na | EC x $10^6$ at 25°C |
|---|---|---|
| 1. Meat Factory (Kombolcha) | 32.6 | 748 |
| 2. Municipality Well (Kombolcha) | 44.4 | 824 |
| 3. Kombolcha Municipality Well (not in operation) | 80.3 | 382 |
| 4. Kombolcha Municipality Well (not in operation) | 54.6 | 562 |
| 5. Dese Municipality (Hote Meda) | 37.3 | 348 |
| 6. Kemise Municipality | 18.1 | 1105 |
| 7. Harbu Municipality | 44.4 | 1181 |
| 8. Cherete Municipality | 22.1 | 503 |
| **Springs** | | |
| 9. Fontanina | 36.6 | 927 |
| 10. Kurkur (Dese) | 18.8 | 372 |
| 11. Hartu Hot spring | 46.7 | 1178 |
| 12. Harbu Hot spring | 96.3 | 1250 |

| | Rivers | % Na | EC x $10^6$ at 25°C |
|---|---|---|---|
| 13. | Dirma | 24.7 | 372 |
| 14. | Felana | 27.0 | 480 |
| 15. | Borkena (at Kombolcha) | 30.4 | 398 |
| 16. | Borkena (at Fontanina) | 24.2 | 499 |
| 17. | Borkena (at the outlet) | 35.1 | 710 |
| | **Miscellaneous** | | |
| 18. | Cheffa Marsh | 33.1 | 661 |
| 19. | Lake Mai Ebar | 12.3 | 210 |
| 20. | Agricultural School Dug Well (Kombolcha) | 46.7 | 905 |

Fig. 14

Electrical Conductivity, ECx$10^6$




Quality of Water

A= Excellent to good

B= Good to permissible

C= Doubtful to unsuitable

D= Unsuitable

Classification and Figure From Todd (1959)

5.1.3 Water Quality Criteria for Industry

In the past no industry of major importance existed in the basin except for the soft drinks factory and the meat processing plant. With present governments plan to decentralize industry to different parts of the country, construction of a textile mill and a food and oil factories is presently underway. With this in mind, water quality assessment for use in industry has been considered based on the type of industries already present within the basin.

For food processing, canning and freezing industries, Australian Water Quality criteria-Hart (1974) sets 85 to 170 mg/l disolved solids, for soft drink manufacture. However for tanning - leather industry where processes of preservation, soaking, unhairing, fleshing etc. take place a limit exists for different types of anions and cations. And the following table shows the allowable limits.

Table 12

Water Quality for tanning and Finishing Industry in ppm.

| Characteristic | Tanning process | Units in General finishing process | ppm coloring |
|---|---|---|---|
| Hardness ($CaCO_3$) | 150 | - | not detectable |
| $P^h$ - units | 6.0 - 8.0 | 6.0 - 8.0 | 6.0 - 8.0 |
| Calcium (Ca) | 60 | - | not detectable |
| Chloride (Cl) | 250 | 250 | - |
| Sulphate ($SO_4$) | 250 | 250 | - |
| Iron (Fe) | 50 | 0.3 | 0.1 |

Table 12 (contd.)

| | | | |
|---|---|---|---|
| Manganese (Mn) | - | 0.2 | 0.01 |
| Coliform bacteria Turbidity | 10 in 100mg of $H_2O$ not detecable | 10 in 100 mg of $H_2O$ not detectable | 10 in 100 mg of $H_2O$ not detectable |

As observed from the analysis of the waters in the meat and tanning industry in Kombolcha town, the above parameters are not within the standard limitations. Due to this the quality of the items may be below standards and with the present plan to enlarge the plant precautions should be taken.

6.2 Bacteriological Criteria for Domestic Use

Wagner (1959) stresses much on the health problems of most of the developing countries to be due to diseases carried by bacteria associated to drinking waters. To this effect the bacteriological quality of the ground and surface waters in the basin were attempted to be determined. But due to short time needed (24 hrs) to transport the samples from the site to a laboratory the author was unable to carry out this task. However from studies carried out for the groundwaters in Dese, Ketema (1978) the nitrate (as $NO_3$) content was reported to be high. High $NO_3$ is a common pollution observed in most groundwaters due to poor sewerage systems. The same case applies to most of the small towns in the basin where there is no proper sewerage system. As previously said $NO_3$ over 26 ppm is reported to have a toxic effect in infants, Hart (1974).

Other indicators for the occurrence of bacteria in waters is coliform count, a bacteria mainly associated with faecal wastes. E.Coli count of over 10 in 100mg./$H_2O$ is the maximum allowable in drinking waters. In the sewerage system at Dese a major town in the basin, presence of E.Coli count in some of the well waters to a limited amount has been indicated according to a laboratory data obtained from the Municipality.

## 6. WATER BALANCE

The water balance of the studied area - Borkena River Basin has been calculated based on the precipitation data of Dese, Kombolcha and Cheffa. Runoff values was obtained from the Borkena River measured at the outlet before leaving the basin and potential evapotranspiration data from Cheffa. Individual potential evapotranspiration values have not been calculated for Dese and Kombolcha due to lack of temperature data to apply Thornthwaites formula. Thus the water balance calculations (Tables 1, 2 and 3 ) have been done for the three sub-basins assuming the evapotranspiration data of Cheffa- the only one available. In Cheffa Sub-Basin, due to the low topography, the temperatures are supposed to be higher than in the other sub-basins and the evapotranspiration (Et) loss calculated for Dese and Kombolcha would be higher than the actual values. Consequently, the surplus values obtained for the two sub-basins is expected to be lower. The purpose of this calculation is to give an idea of the minimum water potentialities of the whole basin, despite a lack of data. Calculations based on overage data from Cheffa were considered less useful as separate precipitations data were available. Anyway both methods give results of the same order.

A soil moisture accretion of 100 mm. has been assumed for all the sub-basins as sands, silts, clays and poorly weathered volcanics predominate the soil types in the basin. Based on

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the above assumption a surplus value of 321.2 mm. 186.0 and 190.8 mm. is available for infiltration and runoff in Dese, Kombolcha and Cheffa Sub-Basins respectively. Applying a lower soil moisture accretion would have given a higher surplus value.

An average surplus value from the precipitation which accounts for both infiltration and runoff, caloulated from the above figures is 232.66 mm. and is equivalent to 403.66 x $10^6$ $m^3$ in the basin with an area of 1735 sq. kms. This value is estimated to be low as a high potential evapotranspiration data calculated for Cheffa has been used for the other sub-basins. The surface runoff for the Borkena River at the outlet has been caluclated to be 218.55 x $10^6$ $m^3$ (Appendix 5).

The direct infiltration is therefore:

Infiltration = Surplus - Runoff

= (403.66 x $10^6$) - 218.55 x $10^6$)

= 185.11 x $10^6$ $m^3$ of water taking a soil moisture accretion of 100 mm.

Any way it has to be taken into account that Dese Sub-Basin Actually differs from the others in values of precipitation, temperature and grain size of the alluvial sediments. Furthermore, it constitutes to the general runoff and as the alluvial sediments are not in continuity with that of the other two sub-basins, the groundwater stored into these sediments do not participate to the general underground circulation.

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Based on the precipitation, calculated for each sub-basin, the total rainfall in the whole sub-basin is $1848.1 \times 10^5$ $m^3$ in the given area of 1735 sq. kms. (Table 2). The calculated infiltration of $185.11 \times 10^6$ $m^3$ in the basin compared to the precipitation expressed as a percentage is 10.02%.

According to Johanson's (1967), compilation works, the following table shows the average specific yield of various sediments.

Table 13

| Material | Average Specific Yield (in%) |
|---|---|
| clay | 2 |
| Silt | 8 |
| Sandy Clay | 7 |
| Fine Sand | 21 |
| Medium Sand | 26 |
| Coarse Sand | 27 |
| Gravely Sand | 25 |
| Gravel | 23 |

From the grain size analysis in the basin, the silts and clay account to 51%, while the sand and gravel accounts to 49%. Based on the above data, a specific yield value of 15% has been assigned to represent both the volcanic rocks and the sediments. Specific yield of a rock or a sediments, with respect to water indicates, the ratio of the volume of water

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that will drain by gravity from a saturated material to the total volume.

In the Borkena River Basin, therefore, a 15% of the infiltrated water can be safely discharged from the aquifers and is equivalent to $27.76 \times 10^6$ $m^3$. The present maximum consumption for domestic use from this reserve, obtained from borewells (at 100 lit/sec. continuous discharge) is equivalent to $3.15 \times 10^6$ $m^3$ per year, and accounts for only 11.3% of the disposable water and the remaining 88.7% is not in use. The discharge from major springs does not exceed a total of 50 lit/sec. and is equivalent to $1.6 \times 10^6$ $m^3$ which accounts to 5.6% of the reserve.

Assuming a population of half a million people in the basin (present population is $<$ 200,000 according to information from the private sources) and consume 50 lit/day only for domestic use, the annual consumption would be $9.125 \times 10^6$ $m^3$.

This consumption is only 32.8% of the reserve. The total reserve cannot, however, guarantee large scale irrigation farms entirely dependent on groundwater.

On the basis of the data (Tables 1, 2, and 3), the precipitation, actual evapotranspiration and potential evapotranspiration relations have been plotted (Figs. 15, 16 and 17). The field of "deficit" indicates, the necessity of imported waters for plants growth during the respective month, the field of "consumption of reserve" indicates the month when the stored

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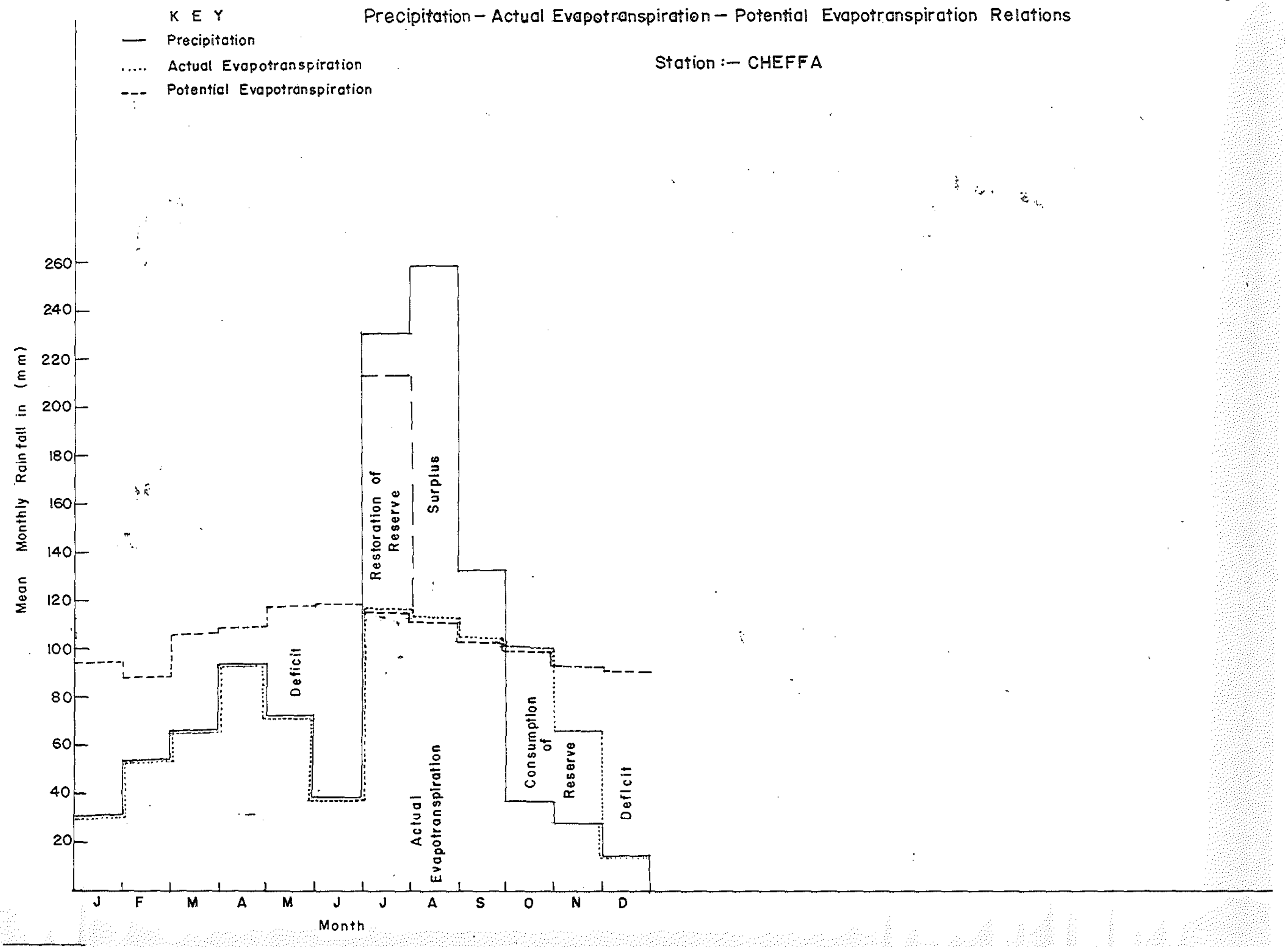
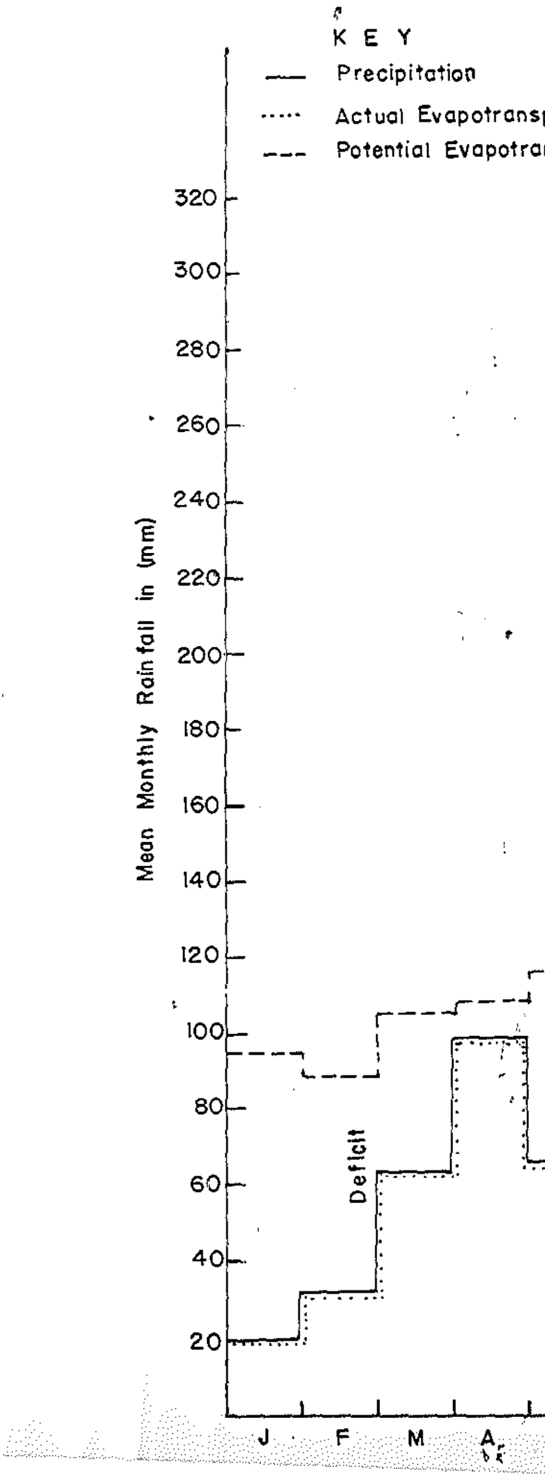
Fig. 15

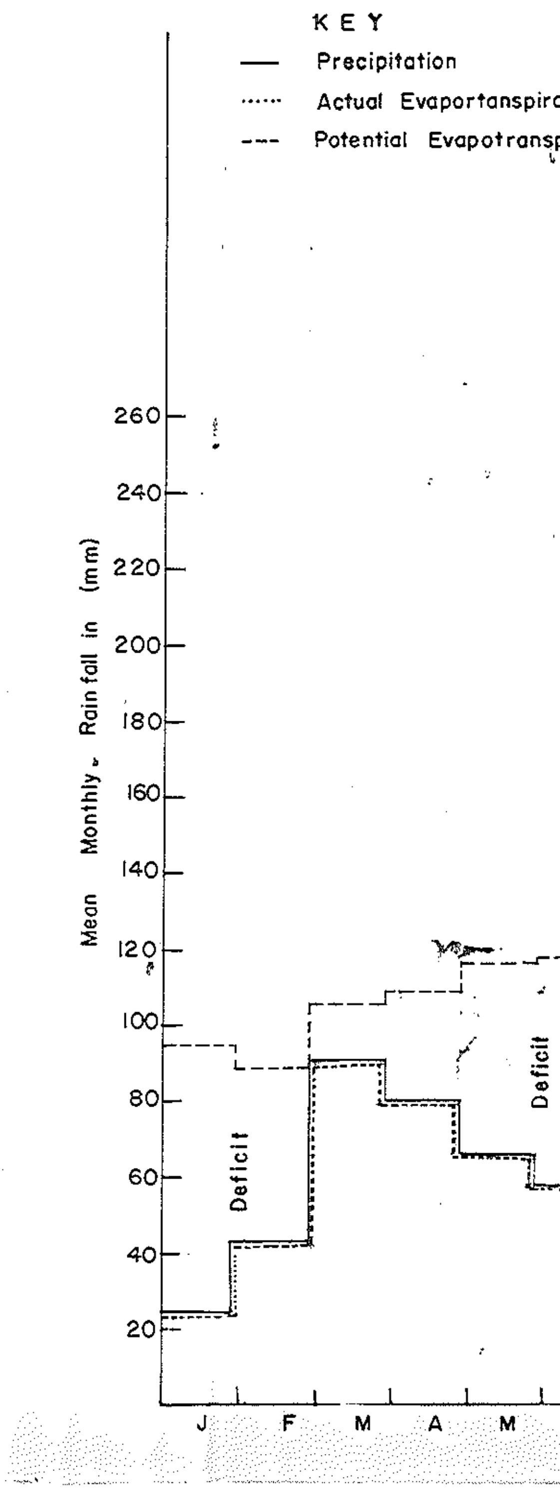
Precipitation – Actual Evapotranspiration – Potential Evapotranspiration Relations

Station :— CHEFFA





KEY
Precipitation
Actual Evapotransp
Potential Evapotran
Mean Monthly Rainfall in (mm)
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Deficit
J
F
M
A


KEY
Precipitation
Actual Evaportanspira
Potential Evapotransp
Mean Monthly Rainfall in (mm)
260
240
220
200
180
160
140
120
100
80
60
40
20
Deficit
Deficit
J
F
M
A
M

moisture is used for evapotranspiration by plants and the fields of "restoration of reserve" shows the month when a portion of the precipitation is used to reach the maximum soil moisture accretion ( 100 mm. in the case of the present assumption). From the figures it can be observed that there is surplus precipitation which takes care of infiltration and runoff only in the months of July, August and September. Maximum surplus is shown by the figure in the Dese Sub-Basin compared to Kombolcha and Cheffa Sub-Basins.

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## 7. CONCLUSIONS AND RECOMMENDATIONS

The studied area, the Borkena River Basin corresponds to a graben structure related to the Ethiopian Rift with volcanic rock outcrops of Miocenic age. These are represented mainly by basalts and subordinately by acidic rocks outcropping in the uplifted blocks forming the higher elevated areas. The floor of the graben is covered by Quaternary alluvial sediments.

The precipitations vary in different localities of the basin and ranges from 1052-1156 mm. 800-850 mm. of the precipitation is lost as actual evapotranspiration while 186 to 321 mm. of the precipitation is a surplus in the different sub-basins. Of the surplus value of the precipitation, 218.55 x $10^6$ $m^3$ of water from the Borkena River leaves the basin by the outlet.

The alluvial sediments are the main aquifers in the basin particularly in the northern part where gravel and sand predominate. A higher value of transmissivity 94 $m^3$/d/m and permeability of 3.58 x $10^{-3}$cm/second have been recorded in the Dese Sub-Basin while transmissivity and permeability values of 28.1 $m^3$/d/m and 1.25 x $10^{-3}$cm. /second have been calculated in the Cheffa Sub-Basin respectively. The rhyolitic rocks lack primary and secondary permeability and are considered poor aquifers. The basalts, however, have well developed secondary permeability eventhough the morphological setting of the outcrops discourages infiltration and thus groundwater occurrence.

The groundwater storage in the basin has been calculated to be 185.11 x $10^6$ $m^3$ of which 27.76 x $10^6$ $m^3$ of water can be

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recovered from the aquifers, where as the present groundwater consumption is only 11.3% of the above value. The authorities in the region have therefore, to see to it to exploit the groundwater in the basin both for the urban and rural water supply as there is shortage of water for domestic water supplies in the basin. However, as signs of groundwater pollution have been recognized in some of the groundwaters in Dese due to poor sewerage systems, this problem should be taken into consideration. The groundwater in the basin, otherwise has a good quality.

The present water supply, in most of the wells is carried out by direct pumpage and the distribution is limited by the quantity of the discharge. It is recommended to construct reservoirs to meet the increasing supply of water with proper chlorination chamber attached to it.

Future locations of wells should be at least 300 m. apart to take care of possible groundwater interference by overpumping.

Proper geophysical surveys and well performance tests should be made in the whole basin to have a good idea of the aquifer in the region substantiated by a periodical monitoring of wells. This would help in understanding the exact amount of water in the aquifers and would give early warnings when shortages arise.

The present study shows that the groundwater reserve is sufficient for domestic and industrial uses and the Borkena River can be used for irrigation. The dam site for the river is recommended to be opposite Fontanina village where the volcanics outcrop to minimize loss of water by seepage, and construction cost.

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Subject : Precipitation (m

Station : Dese

Latitude: : 11° 08'

Longitude: 39° 57'

Elevation: 2365 m.

| | Jan. | Feb. | March |
|---|---|---|---|
| 1966 | 0.0 | 20.0 | 19.0 |
| 1967 | 0.0 | 0.0 | 99.0 |
| 1968 | 0.0 | 79.5 | 75.0 |
| 1969 | 108.5 | 112.0 | 124.0 |
| 1970 | 21.5 | 19.5 | 77.0 |
| 1971 | 31.5 | 0.0 | 50.0 |
| 1972 | 0.0 | 0.0 | 68.0 |
| 1973 | 14.3 | 0.0 | 0.0 |
| 1974 | 0.0 | 64.0 | 103.9 |
| 1975 | 57.0 | 43.6 | 18.8 |
| 1976 | 16.5 | 14.9 | 48.6 |
| 1977 | 0.7 | 25.5 | 133.8 |
| 1978 | 0.0 | 14.0 | 19.5 |
| | 19.3 | 30.2 | 64.4 |

Subject : Precipitation

Station : Kombolcha

Latitude : 11° 04'

Longitude: 39° 58'

Elevation: 1870 m.

| | Jan. | Feb. | Ma |
|---|---|---|---|
| 1966 | 0.0 | 40.3 | 5 |
| 1967 | 0.0 | 0.0 | 16 |
| 1968 | 71.9 | 60.1 | 15 |
| 1969 | 91.6 | 178.1 | 9 |
| 1970 | 18.0 | 51.2 | 27 |
| 1971 | 40.4 | 0.3 | 3 |
| 1972 | 9.3 | 44.0 | 2 |
| 1973 | 4.2 | 0.0 | [illegible] |
| 1974 | 0.0 | 22.5 | 11 |
| 1975 | 52.1 | 74.4 | 3 |
| 1976 | 10.3 | 24.4 | 99 |
| 1977 | 21.1 | 4.8 | 7 |
| 1978 | 0.0 | 58.0 | 6 |
| | 24.5 | 42.9 | 9 |

Precipitation: im mm.

Station : Cheffa

Latitude : 10° 54'

Longitude : 39° 47'

Elevation : 1490 m.

| | Jan. | Feb. |
|---|---|---|
| 1966 | 6.0 | 105.3 |
| 1967 | 0.0 | 3.0 |
| 1968 | 10.5 | 163.9 |
| 1969 | 157.6 | 138.6 |
| 1970 | 69.1 | 54.5 |
| 1971 | 36.5 | 0.0 |
| 1972 | 0.0 | 75.0 |
| 1973 | 28.4 | 0.0 |
| 1974 | 0.0 | 22.6 |
| 1975 | 23.2 | 28.7 |
| 1976 | 2.3 | 5.4 |
| 1977 | 64.8 | 6.6 |
| 1978 | 0.2 | 113.6 |
| | 30.7 | 55.2 |

Mean monthly evaporatio

Station: Cheffa

| | Jan. | Feb. | Ma |
|---|---|---|---|
| 1966 | 187.0 | 121.3 | |
| 1967 | 189.0 | 196.0 | 19 |
| 1968 | 197.4 | 181.4 | 18 |
| 1969 | 111.6 | 87.6 | 1 |
| 1970 | 123.6 | 252.0 | 28 |
| 1971 | 159.5 | 222.5 | 27 |
| 1972 | 165.0 | 132.0 | 22 |
| 1973 | 246.4 | 233.0 | 35 |
| 1974 | 200.0 | 173.6 | 26 |
| 1975 | 197.2 | 161.7 | 24 |
| 1976 | 205.3 | 225.4 | 22 |
| 1977 | 115.8 | - | 22 |
| 1978 | 208.8 | 185.0 | 22 |
| | 176.9 | 185.6 | 23 |

De

BORKENA RIVER (Swamp ou

Hydrometric Discharge

| | Jan. | Feb. |
|---|---|---|
| 1963 | 3.42 | 1.00 |
| 1964 | 12.31 | 6.84 |
| 1965 | 11.93 | 6.66 |
| 1966 | 0.54 | 0.71 |
| 1967 | 0.31 | 1.30 |
| 1968 | 3.69 | 9.81 |
| 1969 | - | - |
| 1970 | - | - |
| 1971 | - | - |
| 1972 | 1.58 | 0.74 |
| 1973 | 0.11 | 0.11 |
| 1974 | 0.01 | 0.09 |
| 1975 | 1.55 | 3.13 |
| 1976 | 2.26 | 1.53 |
| 1977 | 3.35 | 2.7 |
| 1978 | 1.92 | 1.97 |
| 1979 | 3.15 | 6.40 |
| | 3.31 | 3.10 |

Station: BORKENA River- opposi

HYDROMETRIC DISCHARG

| YEAR | | JAN | FEB |
|---|---|---|---|
| | I - | | |
| 1976 | II | | |
| | III | | |
| | I | 1.136 | 0.697 |
| 1977 | II | 0.525 | 0.355 |
| | III | 0.355 | 0.231 |
| | I | 0.482 | 0.609 |
| 1978 | II | 0.231 | 0.475 |
| | III | 0.155 | 0.155 |

I. MONTHLY RUNOFF IN MI

II. MAXIMUM DISCHARGE IN

III. MINIMUM DISCHARGE IN

Subject : Tempera

Station : Cheffa

Latitude : 39° 49

Longitude: 10° 54

Elevation: 1490 m.

| | Jan. | Fe |
|---|---|---|
| 1966 | 18.2 | 19. |
| 1967 | 18.2 | 21. |
| 1968 | 17.3 | 19. |
| 1969 | 20.4 | 19. |
| 1970 | 20.1 | 22. |
| 1971 | - | - |
| 1972 | 19.3 | 19. |
| 1973 | 20.6 | 21. |
| 1974 | 19.0 | 20. |
| 1975 | 18.1 | 20. |
| 1976 | 18.6 | 21. |
| 1977 | 19.0 | 18. |
| 1978 | 18.6 | 19. |
| | 18.9 | 20. |