# AN APPRAISAL OF GROUND WATER RESOURCES
# OF
# ZALENGEI AREA, DARFUR PROVINCE
# SUDAN

by

Wilson Iskander

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## APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Eugene S. Simpson 13 February 1967

EUGENE S. SIMPSON Date
Professor of Hydrology

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ABSTRACT

Zalengei area, Darfur Province, Sudan, a semi-arid area, appears favorable in many respects for future agricultural development. The cultivation of new cash crops depends on the availability of adequate supplies of ground water of satisfactory quality to irrigate these crops.

The principal aquifer in the area is unconfined in the valley fill sediments which form the Lower Terrace and the Flood Plain formations. The average thickness of the aquifer is some 90 feet, and its average transmissivity and storage coefficient are 100,000 gallons/day/foot, and 0.2 respectively. The storage capacity of the ground water reservoir is some 140,000 acre feet. Ground water is discharged from the basin by evapotranspiration, effluent seepage, and underflow out of the basin. Recharge to the ground water is from direct precipitation over the basin area, by influent seepage, and by underflow into the basin.

The ground water supplies of the area have small amounts of dissolved solids, mostly bicarbonates and carbonates. The waters that underlie Wadi Aribo are generally rich in calcium and magnesium bicarbonates, whereas those underlying Wadi Azum are rich in sodium carbonates and bicarbonates. The ground water underlying Wadi Azum is

an approximate blend of the waters supplied by its tributaries and the water of the Large Dariba Lake. This lake has the highest content of fluoride yet known in natural waters.

The arable land in the area is 7200 acres. The amount of ground water needed to irrigate these lands is about 21,600 acre-feet per year. About 20 per cent of this amount can be recharged to the ground water body from the annual precipitation over the basin area; the rest can be recharged by influent seepage from the wadis during flood time. Most of the water supplies are of excellent to good quality for irrigation and domestic uses.

# INTRODUCTION

## Scope of Investigation and Purpose of Report

The Zalengei area, Darfur Province, a semi-arid area, seems favorable in many respects for the further development of irrigated croplands. The development depends to a great extent upon the availability of sufficient amounts of ground water, and its suitability for irrigation and domestic uses.

This report is the first appraisal of ground water resources in the area. Its main purpose is to determine the degree to which ground water of satisfactory quality is available to support future development of the area of Zalengei.

## Location and Extent of the Area

The area investigated, is slightly over a 100 square kilometers ($km^2$), or about 40 square miles ($mi^2$). The area is west of Jebel (J.) Marra, within the Western District of Darfur Province.

Zalengei Town (latitude 12° 54' N., longitude 23° 24' E.), is located at the southeastern corner of the area, and is the Western Darfur District headquarters. The adminstrative center of the Province of Darfur is in El-Fasher (latitude 13° 37' N., longitude 23° 24' E.). The international boundary between the Republic of the Sudan and the Republic of Chad is about 145 km (90 miles) west of Zalengei. Geographically Zalengei Town occupies a near central position in the whole continent of Africa. (figure 1).

## Transportation and Communication

Zalengei, being the principal town in the area, is connected to the rest of Darfur Province by an extensive network of roads. The distances between Zalengei and other important centers (figure 2) in Darfur Province are:

| | | | | |
|---|---|---|---|---|
| Zalengei | - | El-Fasher | 250 km | (160 miles) |
| Zalengei | - | Nyala | 190 km | (120 miles) |
| Zalengei | - | Genina | 145 km | ( 90 miles) |

The roads in Darfur Province, as well as in most parts of Sudan, are cleared tracks that are passable only during the dry season which is about 9 months a year. During the rainy season, when nearly all the wadis are full of water, the crossings become impassable and thus, the area of Zalengei, like all other parts of Darfur Province, remain isolated from the rest of the world for about two months (July and August) every year.

At the present time the railroad from Khartoum ends at Nyala Town. It is planned in the coming five years to extend this railroad through Zalengei to Genina. Zalengei has a post and telegraph office with a radio-telephone

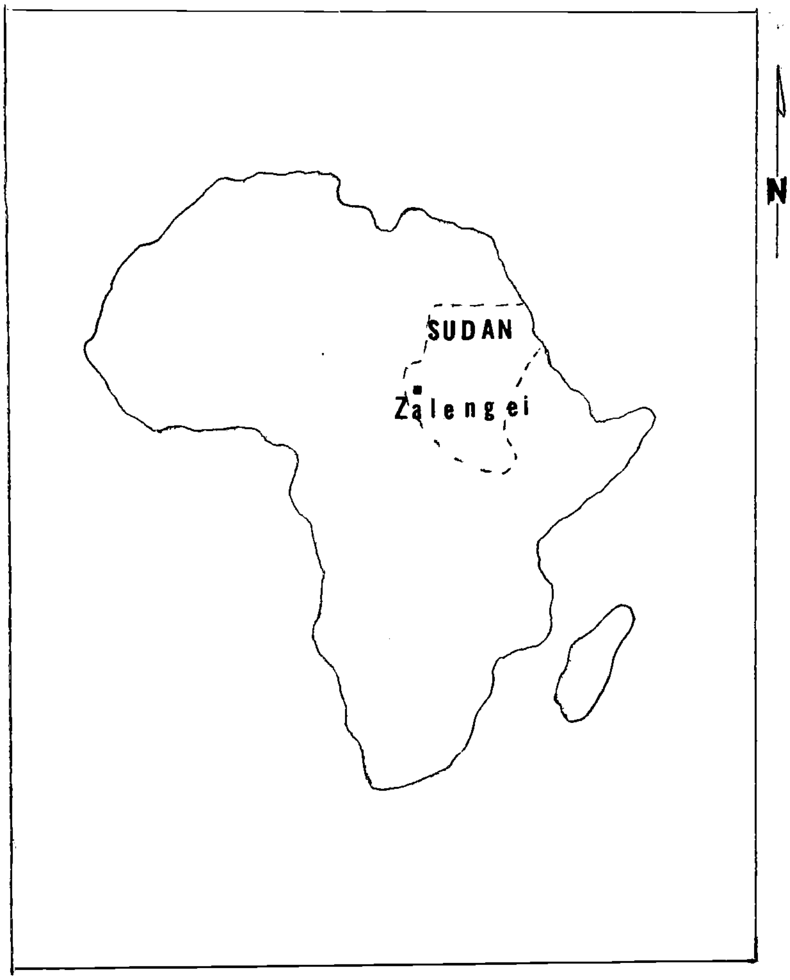



FIGURE 1. MAP OF AFRICA SHOWING LOCATION OF ZALENGEI

Scale
1:100,000,000

0 2500 5000 km

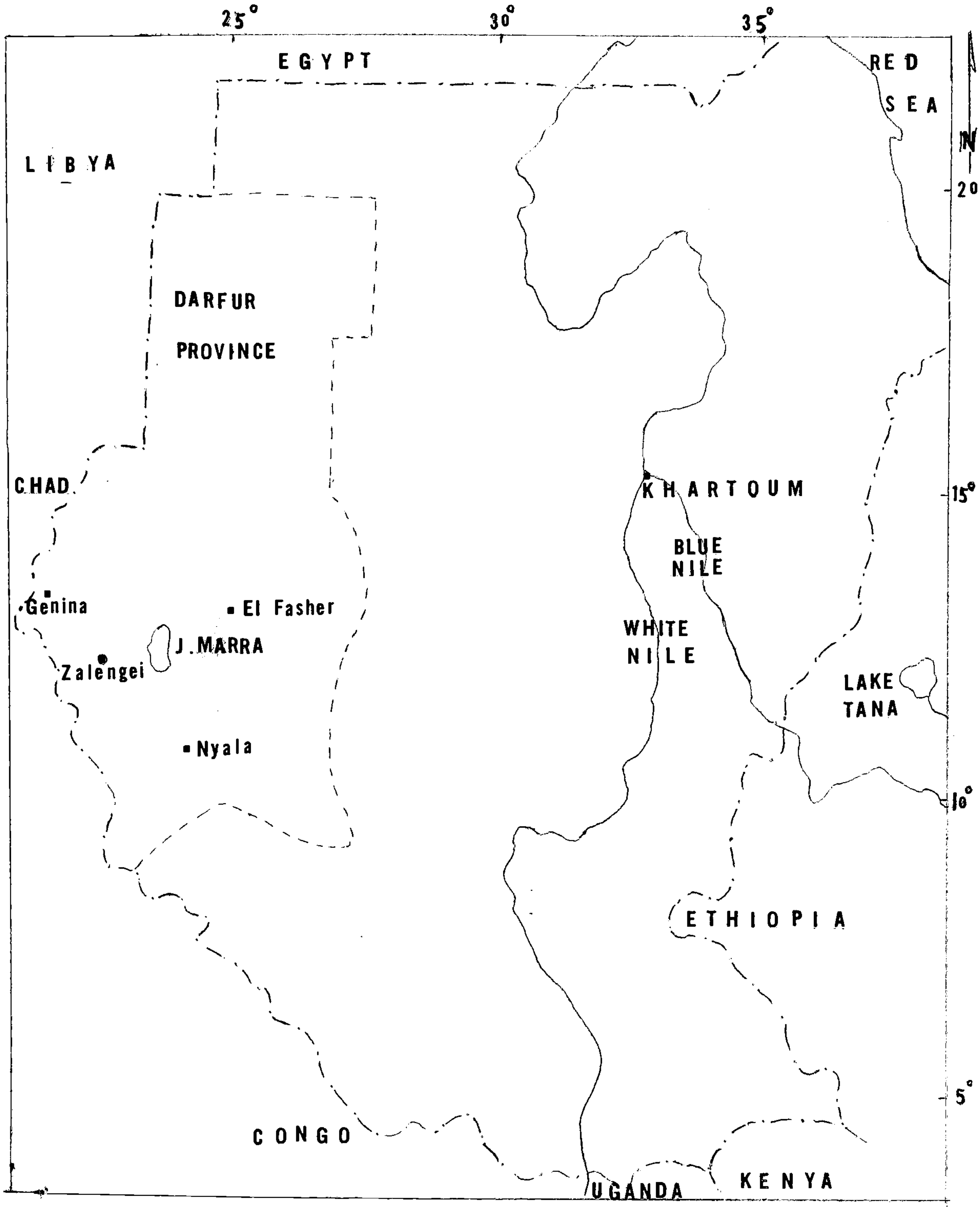



FIGURE 2. MAP OF SUDAN SHOWING LOCATION OF DARFUR PROVINCE

Scale

0 250 500 km

connecting it with El-Fasher and Nyala, the nearest stations with telephone communication.

## Population

The area is one of the most densely populated in western Darfur Province. According to the last census (1956), the density of population in the area is about 50 inhabitants per $km^2$. Zalengei Town has a population of about 5000 inhabitants. This large population is the result of the relatively large area of cultivable land, as well as the importance of the town as a center for Darfur Western District. The recent activities in the J. Marra Project to survey the land and water resources of J. Marra region has attracted a number of people to the area.

The majority of the population is Fur. The Fur are generally skilled farmers, and are naturally adaptable to small scale agricultural development in their land. The few Arabs living in the area are either Baggara nomads or Gallaba merchants.

## Climate

The climatological data in this report were collected by the Zalengei Meteorological Station which was established in 1921. Recently, climatological investigations were expanded as a part of the hydrological studies of the J.

Marra Project. The studies included the establishment of an intensive network of rain gauges. Special consideration was given to the area of Zalengei because of its importance and its relative accessibility to the surrounding area during the rainy season.

Generally, the dominant feature of the climatologic system of the Sudan is the movement of the boundary between the northerly and the southerly air masses, with the declination of the sun. The northern air masses are of continental origin; therefore, they are dry. The southern air masses originate from tropical high pressure areas over the Indian and the Atlantic Oceans; therefore, they are always moist. The critical boundary between the northern and the southern air masses moves to the north to about latitude 19° N. during summer, and returns south again during winter. Rain is particularly associated with the zone extending 800 km. south of this boundary. The area of J. Marra lies within this zone; therefore, it has a summer rainfall and winter drought.

According to Bakker (1964), "a main feature of the rainfall distribution west of J. Marra, is a strip of heavy rainfall extending westwards from the slopes of the jebel to Wadi Salih." Zalengei is situated a short distance to the north of this strip of heavy rainfall. The total amount of rainfall in a normal year in Zalengei area is about 650 millimeters (mm), or about 26 inches. The rainy season extends from April to October. Over 90 per cent of the total precipitation falls during the period from June to September, and about two thirds of this amount falls during July and August. The average monthly distribution of rainfall in Zalengei Town, over a period of 36 years is shown in figure 3.

The maximum mean temperature is 37.8°C. (100°F.) in April, and the minimum mean temperature is 5.7°C. (42°F.) in January. Night frosts, especially along wadis, are common during the period from December to February.

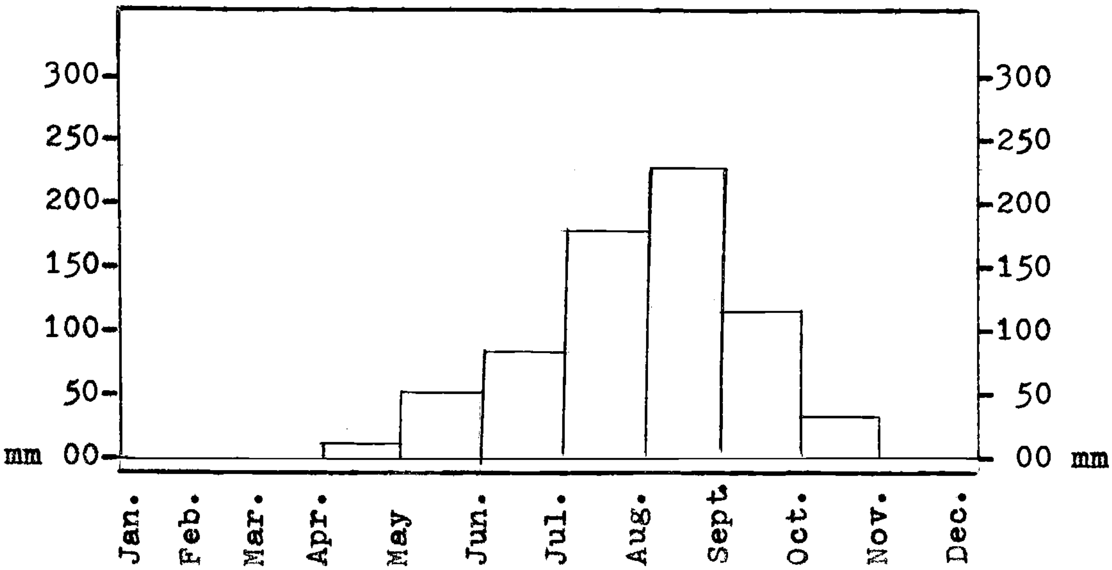



FIGURE 3. AVERAGE MONTHLY DISTRIBUTION OF RAINFALL IN ZALENGEI TOWN FOR THE PERIOD 1921 TO 1957.

The relative humidity ranges from an average low of 34 per cent in the dry season (March), to an average high of 93 per cent in the middle of the rainy season (August).

The prevailing winds in the winter are from the north, whereas during the rainy season they are from the southwest. Wind velocities are generally less than 11 km, or about 7 miles per hour.

## Topography and Drainage

The area is generally a gently undulating plain, bounded by protruding hills (jebels) on its northern and southern sides. The altitude of the land surface ranges from 900 to 1200 meters (m), or about 2950 to 3950 feet (ft) above mean sea level.

The area lies within the drainage basin of Lake Chad, figure 4. The local drainage within the area is towards the central wadis, namely Wadi (W.) Azum and W. Aribo. W. Azum is the major stream and it crosses the area from east to west. It begins as a perennial stream at the foothills of J. Marra, with the name of W. Toro, then becomes intermittent as it reaches the lowlands west of J. Marra. The average slope of the wadi in Zalengei area is about 1/500. W. Aribo, one of the principal contributors to W. Azum during flood time, is the second most important drainage system in the area. It begins south of the Dalia hills and joins W. Azum some 3 km northwest of Zalengei Town. W. Azum and W. Aribo flow for about 3 months every year, during and shortly after the rainy season. Other wadis which run through the area and join W. Azum are W.

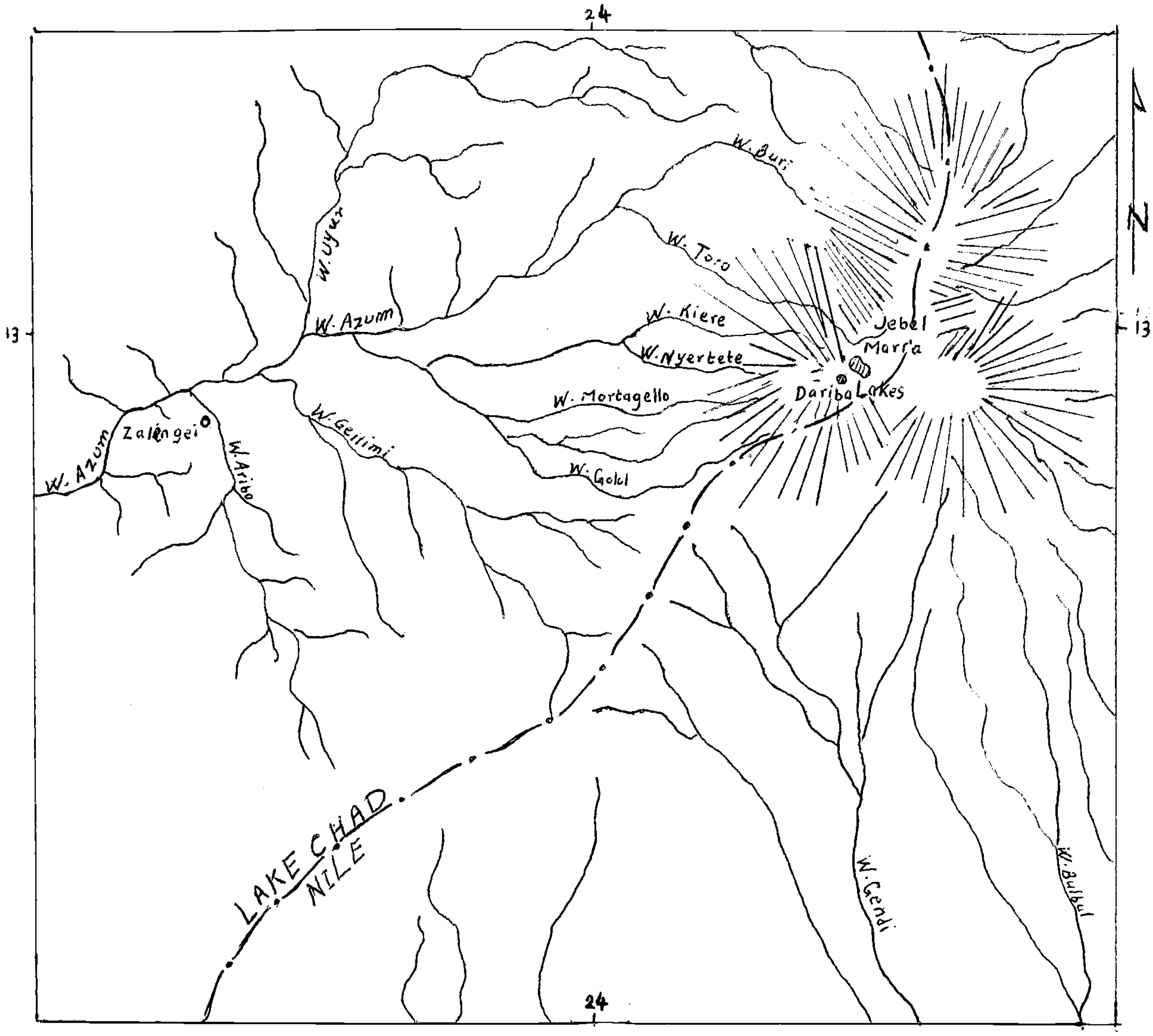
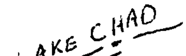



FIGURE 4. MAP OF JEBEL MARRA SHOWING MAJOR WADIS

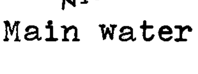
Scale 1:1,000,000

0 250 500 km

Explanation




Major wadis




Main water divide

Korradito, W. Dodo, and W. Korare. These streams have a smaller effect on the flow of W. Azum than does W. Aribo. This is because they have smaller catchment areas and a lesser amount of rainfall.

## Soil Cover and Vegetation

The soils in Zalengei area are mainly transported and usually rest over the uneven weathered surface of the Precambrian Basement Complex rocks. According to Hunting's (1958) classification of the soils of J. Marra, the soils in Zalengei area may be classified as:

A. Soils of the Flood Plain and Lower Terrace

The soils of the Flood Plain and Lower Terrace include the recent alluvial deposits of both W. Azum and W. Aribo. Such deposits are derived mainly from the Basement Complex rocks, west of J. Marra mass.

The soils of the Flood Plain are predominantly sandy, becoming coarser in grain size with depth and showing little stratification. The Flood Plain is usually level and is covered with tall reed grass, mainly wild Deccan hemp (Hisbiscus cannabinus), with some scattered large trees of Haraz (Acacia albida). The crops grown on the Flood Plains are Dura (Sorghum vulgare), Dukhn (Pennisetum typhoideum), Ful Sudani (Arachis hypogaca), and Tobacco (Nicotiana rustica).

The soils of the Lower Terrace range from sandy to clayey, and are highly stratified. The topography of the Lower Terrace ranges from level to gently undulating, but not usually exceeding the slope limits for successful irrigation. A large number of tall to medium high grass and herbs (including Hyperrhenia psendocymbaria and Leonatis africana), grow under the dense large trees of Haraz. The crops produced on the Lower Terrace form the mainstay of the economy of the area. This is mainly due to the fertility of the soil and the advantage of topographic suitability for cultivation and irrigation. The crops grown include vegetables such as tomato, potato, okra, and chili, and fruits such as mango, orange, lime, and grape-fruit.

B. Soils of the Upper Terrace

The soils of the Upper Terrace form the relatively older deposits derived from both the Pre-cambrian Basement Complex and the Tertiary volcanic rocks of J. Marra. The lower horizons of the Upper Terrace soil are composed chiefly of volcanic material. The topography of the Upper Terrace varies from gently undulating to highly uneven, unsuitable for irrigation. Grasses are much shorter than on the Lower Terrace and include Cymbopogen proimus and Pennisetum pedicallatum. The trees are widely scattered and include Talh (Acacia seyal) and Higlig (Balanites aegyptica). A small area of the Upper Terrace land is cultivated, and the most common crop is Dukhn.

C. Grey Cracking Clay

The grey cracking clay covers a relatively small area near W. Aribo south of Zalengei. The texture of this soil ranges from sandy clay to clayey sand. Layers rich in sand or gravel are not uncommon. The bed rock is at about one meter deep, and consists mostly of weathered graphite or mica schist. The area is not cultivated and vegetation is mainly tall grass with some scattered trees of Talh.

## Previous Investigation

The investigations in Darfur Province, in general, were part of an expanded program of the Geological Survey Department of the Sudan, to evaluate and explore the ground water resources of the country. Although ground water studies of local problems have been carried out in Darfur Province since the beginning of the century, it was not until 1934, that the general occurrence of ground water in the province was described by Grabham (1934). Sanford (1935) described the geology and the related ground water conditions in the area west of J. Marra. A more detailed report on the geology of the Sudan by Andrew (1948), includes a description of the water bearing characteristics of the various rock units in the province. An unpublished regional geologic map (scale 1:250,000), and a typescript report devoted exclusively to the relationship between the geology and the occurrence of ground water in the District of Western Darfur was prepared by Mansour and Karkanis (1958).

The most detailed study done in the Zalengei area was carried out by Hunting Technical Service (1958), as a part of their phase (I) studies of J. Marra Investigations. The area investigated was 30,750 $km^2$ (12,000 $mi^2$) mainly west of J. Marra mass. Their field work started in October 1957 and ended in February 1958. The investigations were concentrated on the geological and hydrological aspects of the area, with the aim of locating possible dam sites on W. Azum and its tributaries. Their studies also included a soil survey, forestry investigation, and studies of the other economic potentialities of the area. Their report included some recommendations for a second and more detailed study phase. Some of Hunting's recommendations are being carried out in the present investigation.

## Present Investigation

The present study is a part of phase (II) of the investigation of J. Marra area. The project as a whole is called the Land and Water Survey of J. Marra, and is conducted jointly by the United Nations Special Fund and the Government of the Sudan. The main scope of the project is to provide the Government of the Sudan with basic technical data required for the future agricultural development of J. Marra area.

The present investigation covers an area of 100 $km^2$ (40 $mi^2$) north and northwest of Zalengei Town as shown on plate 1 and 2 . The field work was started late in January 1964, and ended early in May 1965. During this period the writer spent nine months on field and laboratory work.

Sources of Data

The base map on which the geologic and hydrologic data were compiled was prepared by the stereo-templet method from aerial photographs of approximate scale of 1:40,000. The geologic investigation included mapping and sampling the major rock units and examining their field relations. Special emphasis was placed upon the mapping and differentiation of the alluvial deposits.

The ground water investigation included surveying and drilling of 50 auger holes of 4-inch diameter to a maximum depth of about 10 m. (33 ft). The holes were arranged in a grid covering most of the area of the alluvium. From the data obtained the boundary of the aquifer was delineated and a water-table contour map was plotted. The drilling program also included two wells of 10-inch diameter, with a maximum depth of 41 m (135 ft). The two wells penetrated the entire thickness of the aquifer near W. Azum (Bore Hole No. 1) and W. Aribo (Bore Hole No. 2). Cuttings were collected at 5 ft intervals and 24 samples obtained from Bore Hole No. 1 were sieved. The results of the mechanical analyses were plotted as cumulative curves. The investigations included the installation of two Stevens type F water-level recorders. The fluctuations in the water table were observed over a period of about 8 months. Some 35 ground water and surface water samples were analyzed chemically. These, together with the results of 14 additional analyses available from Hunting's report (1958), determined the quality of the ground water in Zalengei area and its suitability for various uses.

# GEOLOGY

## Stratigraphy and Geologic History

The rock formations represented in the area of Zalengei may be divided into two general categories:

1. The Basement Complex of Precambrian age, and
2. The surficial deposits of Quaternary age

These formations and their water-bearing characteristics are described briefly in table 1. The surficial distribution of each formation is shown in the geological map, plate I.

The oldest rocks in the region that now constitute the Basement Complex were formed during the Precambrian age. Following their formation, the region was subjected to a period of prolonged erosion that reduced the whole area to a gently undulating peneplain. A few isolated hills and low ranges, which were more resistant to erosion and weathering, rise above the plain as inselbergs on the old erosion surface.

In Tertiary times (Miocene) active vulcanism built up the mass of J. Marra. This changed the topography, drainage, and climate of the whole region of West Darfur. The mass of J. Marra forms a water divide which separates the drainage system into an easterly system flowing into the Nile, and a westerly system flowing into Lake Chad.

TABLE 1. SUMMARY OF THE LITHOLOGY AND WATER BEARING PROPERTIES OF THE GEOLOGIC UNITS IN THE ZALENGEI AREA

| Age | Formation | Thickness (m.) | Lithology | Water Bearing Properties |
|---|---|---|---|---|
| Recent | Flood Plain Deposits | 0 to 5 | Coarse sand and gravel; poorly stratified. | Very porous (45%) and permeable; depth to water ranges from 0.5 to 1.5 m.; water quality is excellent; salinity about 100 ppm. |
| | Lower Terrace Deposits | 0 to 40 | Sands and clays with small content of volcanic material; highly stratified. | Highly porous (35% to 40%) and permeable, depth to water ranges from 3 to 5 m.; water quality is excellent; salinity about 270 ppm. |
| Pleistocene | Upper Terrace Deposits | 0 to 10 | Mainly rounded pumice, volcanic ash, and tuff; poorly stratified. | Highly porous with low permeability; higher than the water table; dry. |
| Pre-cambrian | Basement Complex | | Quartz veins, Pegmatites, Graphite schist, Mica schist, Acid gneiss, Meta-quartzite. | Primary permeability very low; water occurs locally in the weathered zone and in the joints and fractures; water is often saline (4120 ppm) with high content of sulphate and fluoride. |

One of the major streams that came into existence following the formation of J. Marra, was W. Azum. The wadi originates from the northern slopes of the jebel, and runs westward through the area of Zalengei to the swampy center of Chad. In its early stages, the wadi course was blocked by a quartz vein at Adjkari Constriction, about 4 km northwest of Zalengei. The blocking of the wadi created a lake that covered about 1/3 of the area of Zalengei. In it considerable amounts of pumice, tuffs, and other light volcanic materials were dumped forming the Upper Terrace deposits.

By late Pleistocene and Recent times most of the light volcanic materials on the top of J. Marra mass were eroded, and the amount of sediments carried by W. Azum decreased. It is believed that during this time W. Aribo and the other wadis within Zalengei area joined W. Azum, and the wadi started its course westwards through the Adjkari Constriction. This stage was marked by an intense phase or phases of erosion of the existing Upper Terrace deposits along the stream channels and the deposition of a comparatively recent alluvium, derived mainly from the Basement Complex rocks. This Recent alluvium accumulation is what is now called the Lower Terrace and Flood Plain deposits. In some places, especially along the stream channels, the Upper Terrace deposits were completely removed by erosion and the Lower Terrace and the Flood Plain deposits lie directly over the weathered surface of the Basement Complex rocks.

Between the stream channels relics of the Upper Terrace occur in the form of dissected plateaus and isolated islands capping the old Precambrian rocks that were not affected by stream erosion.

## Geologic Units and their Characteristics

### Basement Complex (Precambrian)

The Basement Complex in the Zalengei area crops out in the inter-stream areas, and forms the subsurface bed rock over which the alluvium was deposited. The Basement Complex is generally of Precambrian age, and consists of metamorphosed sediments cut by a series of pegmatites and quartz veins.

The metamorphosed sediments occur in the form of paraschists, para-gneisses, and meta-quartzites. These represent sediments of original pelitic, psamo-pelitic, and psammetic composition. A north-south section across W. Azum, at Adjkari Constriction shows the following sequence of formations which have been folded into an east-west syncline, or synclinorium:

Graphite Schist (stratigraphically highest)
Mica Schist and Acid Gneiss
Meta-quartzite (stratigraphically lowest).

The graphite schists occur on both sides of W. Azum. They generally form low lying, highly weathered outcrops that show no sharp contacts with the adjacent rock formations. The graphite schists have a well developed east-west foliation with moderate to rather steep dips, varying in direction on both sides of the syncline. Very often the foliation in the graphite schist is wavy and contorted and shows minor folds.

The graphite schist vary in color from dark grey to almost black, depending on the amount of carbon present in the rock. In thin section the rock is essentially composed of graphite and quartz, with chlorite, epidote, sericite, and disseminated pyrite as accessories. The graphite occurs in small disseminated linear patches following the general trend of foliation. Quartz occurs as parallel bands or lenses of elongated sub-parallel crystals occasionally showing wavy extinction.

The mica schists and the acid gneisses are older than the graphite schist and represent the original psammo-pelites in the area. Their outcrops are generally low lying and highly weathered. Schistosity is well developed, except in the more psammetic layers, which now show a pronounced gneissic structure. The regional trend of foliation is almost east-west, parallel to that of the graphite schist. The dips are always to the north, and less steep than those of the graphite schist.

The mica schists vary in color from light to dark brown. Under the microscope they are seen to be formed exclusively of a schistose ground mass of reddish-brown biotite with subordinate quartz and feldspars. Quartz is present as rounded or elongated crystals with undulose extinction. Iron oxides and epidote are present as accessories.

The acid gneisses are usually lighter in color than the mica schists. In thin section the acid gneiss has a gneissose structure with alternating white and dark parallel bands. The white bands are formed mainly of elongated crystals of quartz showing wavy extinction. The dark streaks are composed mainly of parallel laths of reddish-brown biotite.

The meta-quartzites are the oldest Precambrian rocks in the area of Zalengei, and represent the purer types of the old psammites. Being more resistant to weathering than the surrounding rock formation, the meta-quartzites stand out in relief in the form of long discontinuous chains of hills.

The meta-quartzites are generally massive, well jointed, of white to brown color. On fresh surface they have a granular texture with a vitreous luster. In thin section the meta-quartzites are seen to be exclusively formed of mosaic-textured, clear crystals of quartz showing undulose extinction. Fine flakes of muscovite, and to a lesser extent biotite, are always present as accessories. In some specimens where the meta-quartzites are highly sheared, the quartz crystals occur in an augen shape embedded in a matrix of fine grained mylonised mixture of quartz and cryptocrystalline silica.

The pegmatites usually occur as small irregular masses, the majority of which cut across the regional foliation of the meta-sediments. In most cases they are more resistant to weathering than the adjacent country rocks and, therefore, they stand out as knolls a little higher than their surroundings.

The pegmatites are always pale pink, with a brown tarnish on the weathered surface. All the pegmatites are of granitic composition being made up essentially of quartz, alkali feldspar, and muscovite. In a pegmatite west of Adjkari Constriction, the quartz encloses books of transparent, clear muscovite, which may be of commercial value.

The quartz veins are of widespread occurrence in the area. They are generally short, ranging in width from a few centimeters to about 5 m. In the field they appear as small ridges, and reefs cutting across the regional foliation of the meta-sediments.

The quartz veins vary in color from milky white to dark smokey, due to the presence of graphite inclusions.

The quartz veins examined in the area of Zalengei are barren of any other mineralisation, except for small flakes of muscovite that have no commercial value.

Surficial Deposits (Quaternary)

The surficial deposits include all the alluvial and colluvial deposits lying over the hard, uneven surface of the Precambrian rocks. The surficial deposits cover about one third of the mapped area. Their thicknesses range from a few to about 40 m. The surficial deposits in Zalengei area may be classified as:

1. Lower Terrace and Flood Plain Deposits
2. Upper Terrace Deposits.

The Lower Terrace and Flood Plain deposits form the most recent alluvium in the Zalengei area. Both deposits vary in texture and thickness; but they are derived mainly from the Basement Complex rocks west of J. Marra.

The Flood Plain deposits are mainly sands and gravels. The sand fraction consists of quartz, feldspars, and some mica. The Lower Terrace deposits consist of highly stratified sands and clays. Mica is normally present in the clayey fraction, and quartz and feldspar dominate the sand fraction.

The Upper Terrace deposits form the older alluvium in Zalengei area. These sediments were derived from both the Precambrian Basement Complex and the Tertiary volcanics of J. Marra mass. The lower horizons of the Upper Terrace are exclusively composed of volcanic materials. It is believed that they were formed as a result of an intensive phase or phases of erosion following the ejection of J. Marra. The major constituents of the lower horizons are rounded, water-worn pumice with sizes as large as 20 cms. in diameter. The pumice is cemented with volcanic ash and tuff. The upper horizons of the Upper Terrace are less rich in volcanic constituents than the lower horizons. They are usually formed of nearly equal proportions of fine rounded pumice and ash, together with angular quartz, feldspars, and mica. Stratification is generally well marked in the upper horizons of the Upper Terrace, whereas it is poor in the lower horizons.

# HYDROLOGY

The present investigation in the Zalengei area included few quantitative hydrological measurements. In addition to the field study of the writer, this chapter reviews the work done by the Sudan Ministry of Irrigation and Hydro-electric Power on the area west of J. Marra, during the period from 1958 to 1961 (Sudan Ministry of Irrigation open file and Mageed, 1958). Some of the data, especially the discharge measurements of the wadis during flood time were made by approximate methods. These measurements vary widely, and in general seem to fail to account for the large quantities of rainwater that falls over the catchment area of W. Azum during summer time. This chapter also provides estimates of the factors affecting the water balance in the area of Zalengei. A good deal of assumption and speculation are involved, and the figures quoted in the following discussion should be studied in this light. The collection of accurate and basic hydrological data over a period of years is considered essential for the successful future development of the area of J. Marra.

## Precipitation

The mean annual rainfall in the 100 square kilometers around Zalengei, is 650 mm (26 inches). This amounts to a total quantity of 65 x $10^6$ $m^3$ (about 52,000 acre feet) of rain water every year. More than 90 per cent of the annual precipitation falls during the period from June to September, in the form of heavy thunder storms of short duration.

## Evapotranspiration

Evaporation losses from soils depends on the nature of the soil and the depth to the water table, provided that they are subjected to the same conditions of wind, air temperature, and relative humidity. In the area of Zalengei, the relatively shallow ground water body occurs in the bottom sediments along the principal wadis. The depth to the water table, depending on the time of the year, ranges from a few centimeters to nearly a half meter. The channel deposits are generally coarse grained sediments with a porosity of 40 to 45 per cent. The evaporation losses from such sediments is expected to be high in places where the water table is 30 cms (one foot) or less below the ground surface. In places where the water table is deeper, the evaporation losses fall sharply. The water table in the Lower Terrace deposits is deeper, and ranges from 3 to 5 m below the ground surface. Under such conditions evaporation losses from the Lower Terrace deposits are expected to be much lower than from the channel deposits.

Transpiration losses would appear to be a major factor in the hydrologic cycle in the area of Zalengei. Before the rainy season the density of vegetation is a minimum and thus, the transpiration losses at this time of the year are expected to be small. After the first rains, the grass begins to grow and the majority of the trees come into leaf, increasing the amount of transpiration losses.

The amount of potential evapotranspiration in an area depends upon the mean monthly temperature and the number of hours in the day between sunrise and sunset (Thornthwaite, 1957). The duration of sunlight varies with the season and with latitude. Applying Thornthwaites method to estimate the potential evapotranspiration in the area of Zalengei, the results given in table 2 were obtained:

TABLE 2. ESTIMATION OF POTENTIAL EVAPOTRANSPIRATION IN THE AREA OF ZALENGEI BY THORNTHWAITE METHOD

| Month | Mean Temp. $t^{o}C$. | Potential Evapotranspiration cm. |
|---|---|---|
| Jan. | 19.9 | 9.2 |
| Feb. | 20.9 | 9.2 |
| March | 23.7 | 11.8 |
| April | 26.2 | 13.7 |
| May | 27.2 | 15.3 |
| June | 27.1 | 15.2 |
| July | 25.2 | 14.0 |
| Aug. | 23.7 | 12.9 |
| Sept. | 24.6 | 13.5 |
| Oct. | 24.0 | 12.2 |
| Nov. | 21.4 | 10.4 |
| Dec. | 19.1 | 8.4 |
| Year | | 145.8 |

## Infiltration

About 30 per cent of the area of Zalengei is covered by a thick mantle of alluvial deposits. Over the rest of the area the soil cover is either shallow or absent, with the Precambrian Basement Complex rocks close or exposed at the surface. The predominant topsoil in the Zalengei area is a highly porous and permeable sandy loam, with the exception of a few limited patches of grey cracking clays covering the local depressions. The infiltration rate is expected to be rather high in the top sandy soil. In the grey cracking clays, the rate of infiltration would be high at the beginning of the inflow of water and decreases considerably after wetting and swelling of the clay.

From the values of the potential evapotranspiration in table 2, a rough estimation of the amount of infiltration that recharges the ground water body in Zalengei area can be computed.

From table 3 the amount of excess rainfall is estimated as 14.6 cm, or about 23 per cent of the annual precipitation. This figure of excess rainfall is believed to be rather conservative, as the values of potential evapotranspiration were computed on a monthly basis. If the values of potential evapotranspiration for the period between the beginning of June to the end of August were computed on a daily basis, and the records of daily

TABLE 3. ESTIMATION OF THE AMOUNT OF RAINFALL EXCESS IN THE AREA OF ZALENGEI

| Month | Potential Evapo-transpiration cm. | Precipitation cm. | Rainfall Excess cm. |
|---|---|---|---|
| Jan. | 9.2 | 0 | 0 |
| Feb. | 9.2 | 0.1 | 0 |
| March | 11.8 | 0.1 | 0 |
| April | 13.7 | 0.6 | 0 |
| May | 15.3 | 3.6 | 0 |
| June | 15.2 | 7.5 | 0 |
| July | 14.0 | 18.5 | 4.5 |
| Aug. | 12.9 | 23.0 | 4.5 |
| Sept. | 13.5 | 10.4 | 0 |
| Oct. | 12.2 | 1.8 | 0 |
| Nov. | 10.4 | 0 | 0 |
| Dec. | 8.4 | 0 | 0 |
| Year | 145.8 | 65.6 | 14.6 |

precipitation were available, the estimated amount of excess rainfall would be greater.

If it is assumed that 8 per cent of the annual precipitation becomes surface runoff, then the amount of excess rainfall that infiltrates through the topsoil down to the ground-water body will be 15 per cent of the annual precipitation. Assuming also that half of this amount is held as soil moisture in the zone of aeration; the amount of rainwater that reaches the ground-water body will be about $7\frac{1}{2}$ per cent of the annual precipitation. This gives an amount of infiltration of about 5 cm, and a total yearly recharge from direct rainfall to the ground-water body in the Zalengei area of about $5 \times 10^6$ $m^3$ or about 4000 acre feet. This portion of recharge is about 20 per cent the amount of water needed to irrigate all the arable land in the Zalengei area. The main source of recharge to the ground-water body is by influent seepage from the wadis during flood time, as mentioned later.

## Runoff

The mass of J. Marra acts as a water divide separating two major drainage basins (figure 4). The eastern basin drains toward the Nile whereas the western basin toward Lake Chad. The area of Zalengei lies within the drainage basin of Lake Chad and W. Azum and W. Aribo are the major wadis that cross the area. Other less important streams that join W. Azum within the area are

W. Korradito, W. Dodo, and W. Korare. These streams usually flow for periods ranging from two to three months a year, during or shortly after the rainy season. The duration of flow, and the amount of discharge of each stream depends on many factors such as catchment area, intensity of rainfall, time of distribution, slope, temperature, moisture content of soil, type of soil, and type of vegetative cover.

Wadi Azum is the largest stream in the area west of J. Marra. It begins as a perennial stream, locally known as W. Toro near the northern outlet of the Large Dariba Lake in the crater of the J. Marra extinct volcano. W. Toro then runs through a series of waterfalls before it is joined by W. Buri, another stream of nearly the same magnitude as W. Toro, and originating on the northern slopes of J. Marra. Other perennial streams that originate on the western slopes of J. Marra, and join W. Toro at the piedmont zone to form W. Azum are W. Kiere, W. Nyertete, W. Mortagello, and W. Golol. The perennial flow of W. Azum ceases a few miles after its junction with W. Golol, where the stream reaches the lowlands which are covered with a thick alluvial mantle. The intermittent streams that join W. Azum before it reaches the area of Zalengei and join W. Aribo, are W. Uyer, and W. Gellimi.

The catchment area of W. Azum at its junction with W. Aribo is about 6500 $km^2$ (2500 $mi^2$). The average rainfall according to recent data (Bakker, 1964) is about 750 mm (29.5 inches) per year. Unfortunately, there are no measurements of the annual discharge of W. Azum before it joins W. Aribo in the Zalengei area.

The catchment area of W. Azum at Adjkari Gaging Station, 2 km downstream from the junction of W. Azum with W. Aribo, is slightly over 8000 $km^2$ (3090 $mi^2$). The average rainfall is about 720 mm (28.3 inches) per year. The annual discharge of W. Azum, as measured in Adjkari weir site, over the period from 1958 to 1961 ranges from $120 \times 10^6$ to $150 \times 10^6$ $m^3$ ($9.75 \times 10^5$ to $1.2 \times 10^6$ acre feet). In 1961, about 57 per cent of a total discharge of $150 \times 10^6$ $m^3$, occurred during August, and about 85 per cent of the total discharge occurred during July and August.

Wadi Aribo is one of the most important and main suppliers of water to W. Azum. Wadi Aribo originates on the northern slopes of the igneous and metamorphic rock complex south of Dalia and joins W. Azum two km northwest of Zalengei. The catchment area of W. Aribo is approximately 1500 $km^2$ (580 $mi^2$). The average rainfall is about 600 mm (23.6 inches) per year. The annual discharge of W. Aribo measured north of Zalengei over the period from

1958 to 1961 ranges from $90 \times 10^6$ to $114 \times 10^6$ $m^3$. In 1961 about 65 per cent of a total discharge of $90 \times 10^6$ $m^3$ occurred during August, and about 95 per cent of the total discharge occurred during July and August.

# GROUND WATER CONDITIONS

## Occurrence of Ground Water

The principal aquifer in the Zalengei area is unconfined in the alluvial deposits forming the Lower Terrace and the Flood Plain. The upper surface of the ground water body forms the water table. The valley fill below the water table varies in its storage, transmitting, and drainage capabilities. This is because of the variation in the lithologic character of the water-bearing materials. The water-bearing characteristics of the material depend on grain size, sorting, and compaction. The more permeable zones in the valley fill are the relatively coarse grained and well sorted alluvium. These permeable zones are interconnected with each other either directly, or by seepage through less permeable zones; thus, the ground water body has a single main water table.

Within a few months after the rainy season, when the surface flow ceases, the depth to water in the Flood Plain deposits ranges from a few centimeters to 0.5 m (about 1.6 ft). The maximum depth to water in the Flood Plain deposits never exceeds 1.5 m (about 5 ft) at any time of the year. In some sites, where the wadi surface is below the water table, there are marshes, or wet areas.

At Adjkari Constriction where the ground water course is intercepted by a quartz vein, ground water emerges in the form of a pool that remains nearly all the year round.

The surface of the Lower Terrace is generally higher than that of the Flood Plain, and hence the water table in the Lower Terrace is relatively deeper. Depending on the time of the year, and the relative altitude of the ground surface, the depth to water ranges from 3 to 5 m (about 10 to 16 ft). In a few localities at the fringes of the aquifer, where the Lower Terrace deposits overlie the colluvial deposits of the Upper Terrace, small amounts of ground water are tapped at a depth of 6 to 6.5 m (20 to 21.5 ft). Wells dug in this part of the aquifer usually go dry a few months after the rainy season.

The ground water in Zalengei Town occurs principally in the weathered zones of the Basement Complex rocks where the joints and fractures in the hard rock conduct and store small quantities of water. The irregularity in the level of the water table reflects both the irregularity of the distribution of the joints and fractures, as well as the effect of the ground water withdrawal from the wells in the center of the town. In the northern part of the town where the hard rock is water bearing and is in contact with the valley fill, the water table extends from the valley fill to the weathered hard rock without appreciable interruption. The depth to the water level in the hard rock varies considerably in the different season of the year. About 20 wells out of 90 open wells dug in Zalengei go dry two or three months after the rainy season. The depth to water as measured in January 1965 ranges from about 4 to 18 m (13 to 59.5 ft).

## Movement of Ground Water

The general movement of ground water in the valley fill in the Zalengei area, may be deduced from the water table contour map shown in plate 2. The direction of movement is down slope and at right angles to the water table contours. The contours indicate that recharge occurs from the Basement Complex rocks. At the time the contour map was plotted (April 1965), it appeared that both W. Azum and W. Aribo behaved as effluent rather than as influent streams.

The volume rate of ground water movement depends upon the gradient of the water table and the transmissivity of sediments through which the ground water moves. In general, the water-table contour lines are more closely spaced in the areas near the Basement Complex rocks than in the bulk of the aquifer area. The close spacing of the water-table contours in this particular case may be indicative of thin, though permeable sediments with low rates of transmissivity. The wide spacing of the contours south of W. Azum, in the northeastern sector of the area indicates a northeastern strip of sediments with high rates of transmissivity. This strip is believed to be an old buried channel of W. Azum which had been filled with thick, coarse-grained valley fill. The water table contours in the bulk of the aquifer are more or less uniformly spaced; thus, indicating equal transmissivity values among the water-bearing materials.

The average slope of the water table in Zalengei area is about 1.8 m per km, or 10 ft per mile. In the region of W. Aribo the gradient is slightly steeper and is of the order of 2.3 m per km, or about 12 ft per mile. The gradient is much steeper along the northern and southern boundaries of the aquifer, and is of the order of about 3 m per km.

## Fluctuation of the Water Table

A balance exists between water that is recharged to the ground water basin in the Zalengei area, and the water that is discharged from the basin. The recharge to the basin is believed to be principally by influent seepage from the wadis during their flood time, and to a lesser extent from direct precipitation over the area of the basin. The discharge from the basin is mainly due to evapotranspiration losses, surface, and subsurface outflow. The water table in the basin fluctuates in response to the balance between the water recharged and the water discharged to or from the ground water basin. During the rainy season, when the total recharge to the ground water basin exceeds the total discharge from the basin the water table rises, increasing the storage in the ground water reservoir. After the rainy season is over the amount of discharge exceeds the amount of recharge, and the water table declines. The present manmade activities in Zalengei area does not radically disturb this natural balance, as the cultivated area is limited and depends to a great extent on rainwater.

Unfortunately there are no yearly records of the water level in the different parts of the basin. The data in hand are only those observed in two wells north and south of W. Aribo for the period from September 1964 to April 1965. The observations were made using Stevens type F water-level recorders installed on the wells. The fluctuation of the water table in the two wells is shown graphically in figure 5.

The water table in the valley fill in the Zalengei area appears to reach its maximum level during the second half of August. As precipitation and surface flow decreases or stops by the end of September, the water-table begins to decline regularly. Abnormal climatic

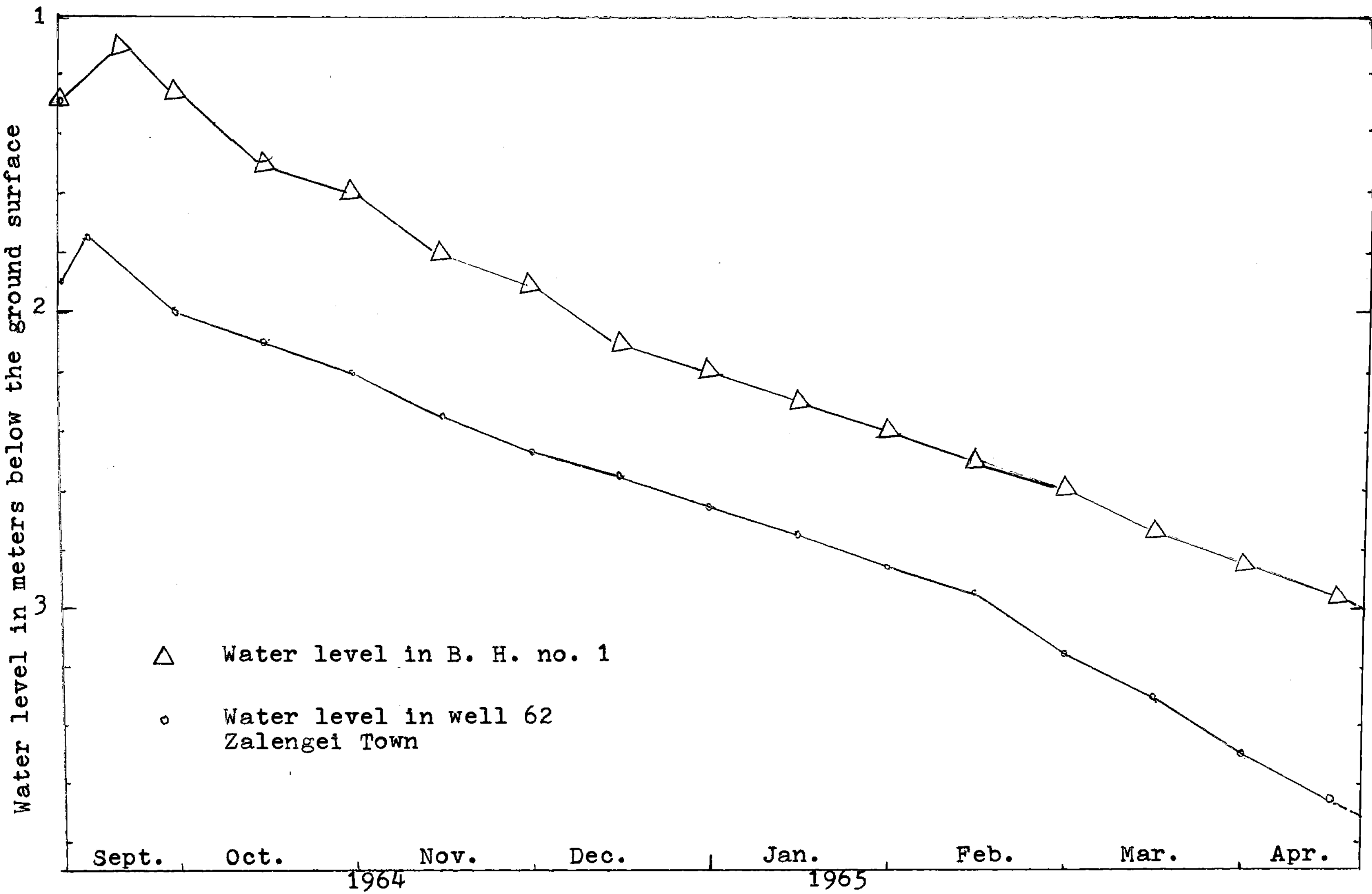



FIGURE 5. GRAPHS SHOWING FLUCTUATION OF WATER LEVEL IN TWO OBSERVATION WELLS.

conditions may cause an adjustment of the water table in the form of oscillation in its level in response to the changed situation.

The decline in the level of the water table in the valley fill in Zalengei area, in the first 3 months following the rainy season is rather sharp. The average decline in the water table from the middle of September 1964 to the middle of December 1954 was about 33 cms (about one foot) per month. During the rest of the dry season, the decline in the level of the water table was more gentle and regular. The average decline in the water table from the middle of December 1964 to the middle of April 1965 was about 21 cms (about 0.7 ft) per month. The total decline in the water table during the dry season of 1964 - 1965 was about 2.2 m or about 7.25 ft.

Taking into consideration the surface area of the aquifer as 7200 acres, and assuming an average specific yield of 20 per cent for the aquifer; the seasonal depletion in storage of the ground water reservoir in Zalengei area will be:

$$7200 \times 7.25 \times 0.2 = \text{about } 9000 \text{ acre feet}$$

This forms about 6.5 per cent of the gross storage of the ground water reservoir in the Zalengei area.

No monthly water-level observations were made in the wells dug in the hard rock in Zalengei Town. From the field observations, as well as from personal contacts with the owners of the wells about 20 per cent of the wells dug in Zalengei Town go dry two or three months after the rainy season as the water table declines.

## GROUND WATER APPRAISAL

### Hydrologic Properties of the Aquifer

The field investigation in Zalengei area did not include any pumping tests to determine the aquifer coefficients. However, these coefficients were estimated from the examination of 55 sediment samples obtained from the drilling of two deep bore holes that penetrated the whole thickness of the aquifer. The first bore hole (B. H. No. 1) was drilled 200 m. south of W. Azum, 4 km upstream of its junction with W. Aribo. The well went through valley fill deposits till it struck the weathered bed rock at a depth of 38 m (125 ft), and the fresh hard rock at a depth of 41 m (135 ft). The second bore hole (B. H. No. 2) was drilled some 250 m north of W. Aribo 3 km upstream of its junction with W. Azum (see plate 2). The well went through valley fill deposits striking the weathered bed rock at 20 m (65 ft) and the fresh rock at 26 m (85 ft). The description of the logs of the two holes is given in table 4 and 5.

Both wells were drilled with a 10-inch diameter bit using a Ruston Bucyrus cable tool rig. The samples were obtained at 5-foot intervals by bailing inside the 8-inch casing. Extreme care was used to make sure that

TABLE 4. LOG OF TEST HOLE B. H. NO. 1

| Depth Interval Feet | Thickness Feet | Material Description |
|---|---|---|
| 0 - 10 | 10 | Sandy clay, hard. |
| 10 - 15 | 5 | Clayey sand, coarse. |
| 15 - 40 | 25 | Clayey sand, fine. |
| 40 - 50 | 10 | Clayey sand, medium to coarse. |
| 50 - 80 | 30 | Gritty sand, medium to coarse. |
| 80 - 95 | 15 | Pebbly sand, medium to coarse. |
| 95 - 100 | 5 | Silty sand, medium to coarse. |
| 100 - 115 | 15 | Sand, medium to coarse. |
| 115 - 127 | 12 | Gritty sand, with large cobbles. |
| 127 - 130 | 3 | Gritty sand, with weathered rock fragments. |
| 130 - 135 | 5 | Rock fragments, weathered to fresh. |
| | Depth to water is 15 ft., April 1965 | |

TABLE 5. LOG OF TEST HOLE B. H. NO. 2

| Depth Interval Feet | Thickness Feet | Material Description |
|---|---|---|
| 0 - 5 | 5 | Sand, medium to coarse. |
| 5 - 15 | 10 | Sandy clay, hard. |
| 15 - 30 | 15 | Gritty sand, medium to coarse. |
| 30 - 35 | 5 | Pebbles, large, sub-angular to rounded. |
| 35 - 45 | 10 | Gritty sand, coarse, with pebbles. |
| 45 - 50 | 5 | Pebbly sand, fine to medium. |
| 50 - 65 | 15 | Gritty sand, coarse, with pebbles. |
| 65 - 80 | 15 | Clayey sand, with weathered rock fragments. |
| 80 - 85 | 5 | Rock fragments, weathered to fresh. |
| | Depth to water is 6 ft., April 1965 | |

the bailer was picking up the material from the bottom of the well. Additional lengths of casing were added progressively as the well deepened, to avoid upward heave and mixing of the samples from the different horizons. The samples obtained can be considered as representative of the particle size characteristics of the aquifer at the two drilled sites.

Particle-Size Characteristics of the Aquifer

Twenty-four samples of the water-bearing alluvium in the Zalengei area were collected from B. H. No. 1, for mechanical analysis. The results of these mechanical analysis are shown in table 6. The percentage of the particles smaller than a given grain size of some selected samples are plotted cumulatively on semi-logarithmic plots, figures 6 and 7.

The plots of the samples show a wide variation among both the grain sizes and their distribution in the material of the aquifer, which is a normal situation among alluvial deposits. The effective grain size of a granular material is the diameter of the grains in an assumed granular material that has the same transmission constant as the material under consideration, and is composed of spherical grains of equal size and arranged in a specified manner. The uniformity coefficient is a measure of the spread in

TABLE 6. PARTICLE-SIZE ANALYSES OF THE SAMPLES OF TEST HOLE B. H. NO. 1

| Depth | Size of grain (per cent by weight) | | | | | | |
|---|---|---|---|---|---|---|---|
| | SAND | | | GRAVEL | | | |
| Interval in ft. | Fine silt, less than 0.25 mm | Medium 0.25 to 0.5 mm | Coarse 0.5 to 1 mm | Very Coarse 1 to 2 mm | Very Fine 2 to 4 mm | Fine 4 to 6.5 mm | Medium & Coarse larger than 6.5 mm |
| 0 - 5 | 55.20 | 32.50 | 5.65 | 4.00 | 1.75 | 0.15 | |
| 5 - 10 | 34.60 | 55.55 | 4.34 | 2.15 | 1.35 | 0.25 | |
| 10 - 15 | 37.00 | 50.00 | 4.80 | 3.00 | 1.95 | 0.85 | |
| 15 - 20 | 19.30 | 39.20 | 4.50 | 2.35 | 5.00 | 12.70 | 16.4 |
| 20 - 25 | 20.00 | 32.40 | 7.50 | 6.00 | 8.70 | 16.50 | 7.6 |
| 25 - 30 | 90.90 | 3.35 | 1.50 | 0.50 | 0.70 | | |
| 30 - 35 | 89.50 | 4.00 | 1.85 | 1.30 | 0.70 | 0.80 | |
| 35 - 40 | 89.05 | 6.50 | 4.35 | 2.70 | 1.58 | | |
| 40 - 45 | 12.30 | 9.28 | 6.40 | 9.90 | 15.70 | 19.70 | 25.10 |
| 45 - 50 | 9.00 | 14.00 | 9.20 | 11.20 | 15.10 | 19.50 | 22.40 |
| 50 - 55 | 5.45 | 15.00 | 16.00 | 11.60 | 9.00 | 6.70 | 36.35 |
| 55 - 60 | 0.25 | 0.85 | 5.60 | 20.85 | 29.35 | 26.65 | 16.35 |
| 60 - 65 | 0.90 | 2.40 | 10.10 | 22.66 | 31.86 | 26.15 | 6.18 |
| 65 - 70 | 3.75 | 8.40 | 11.50 | 16.50 | 19.90 | 20.20 | 23.00 |
| 70 - 75 | 0.30 | 0.90 | 3.10 | 12.00 | 23.00 | 25.75 | 35.25 |
| 75 - 80 | 12.95 | 39.04 | 20.60 | 9.00 | 7.50 | 5.70 | 5.00 |
| 80 - 85 | 3.23 | 17.40 | 20.35 | 14.55 | 10.42 | 12.42 | 21.65 |
| 85 - 90 | 4.95 | 3.60 | 50.30 | 10.85 | 22.70 | 29.60 | 33.00 |
| 90 - 95 | 4.50 | 5.40 | 9.15 | 18.00 | 17.59 | 11.50 | 33.45 |
| 95 - 97 | 59.00 | 14.75 | 6.20 | 3.60 | 1.45 | 1.00 | 13.70 |
| 97 - 100 | 22.50 | 27.10 | 25.20 | 10.60 | 6.00 | 3.45 | 4.75 |
| 100 - 105 | 19.27 | 35.00 | 30.75 | 10.50 | 2.85 | 0.50 | 1.00 |
| 105 - 110 | 2.75 | 8.30 | 25.50 | 26.00 | 12.30 | 11.95 | 13.40 |
| 110 - 115 | 4.80 | 10.75 | 21.00 | 17.60 | 14.25 | 21.85 | 10.05 |

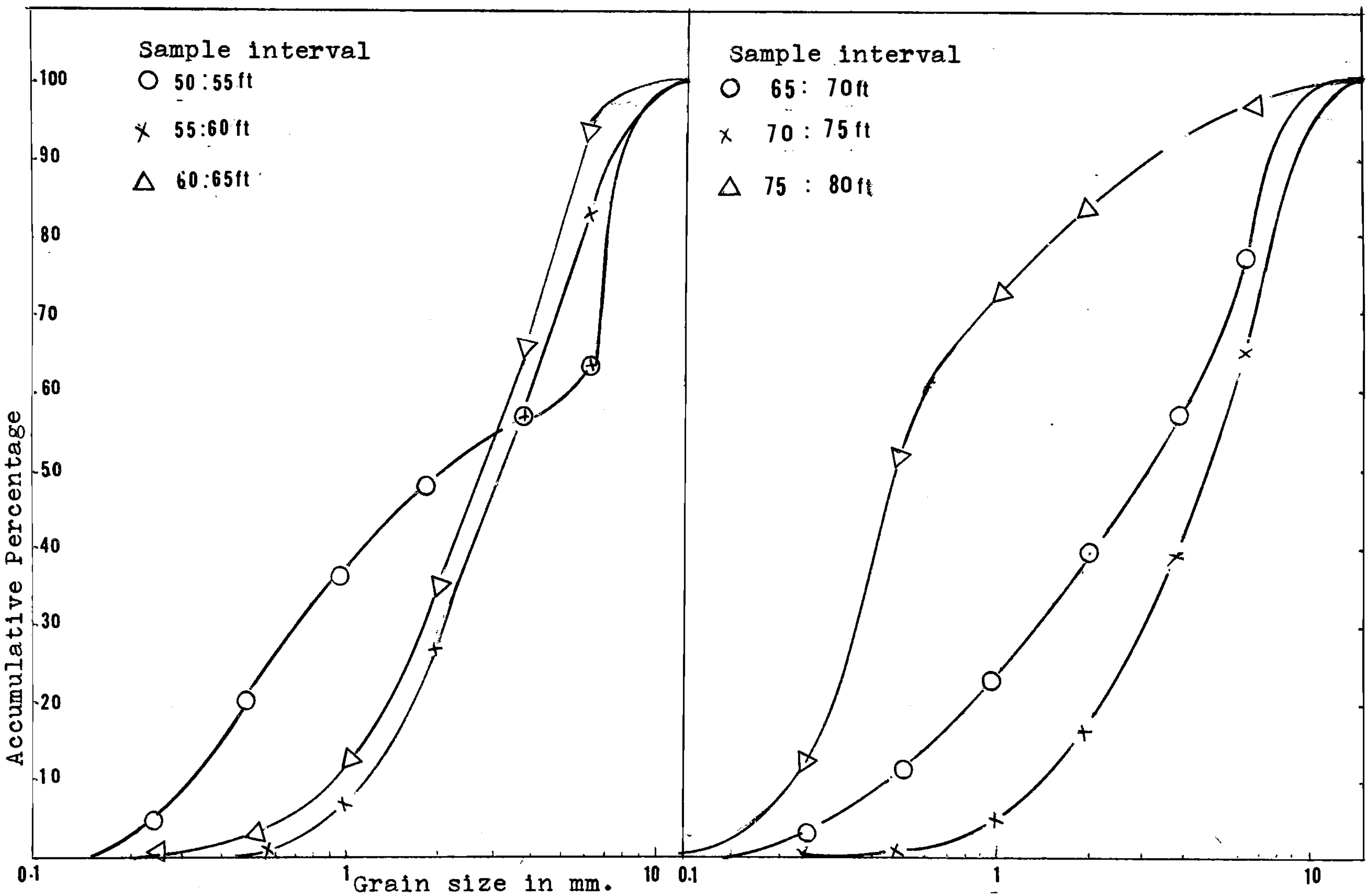



FIGURE 6. CUMMULATIVE CURVES OF PARTICLE SIZE ANALYSES OF TEST HOLE B.H.NO. 1.

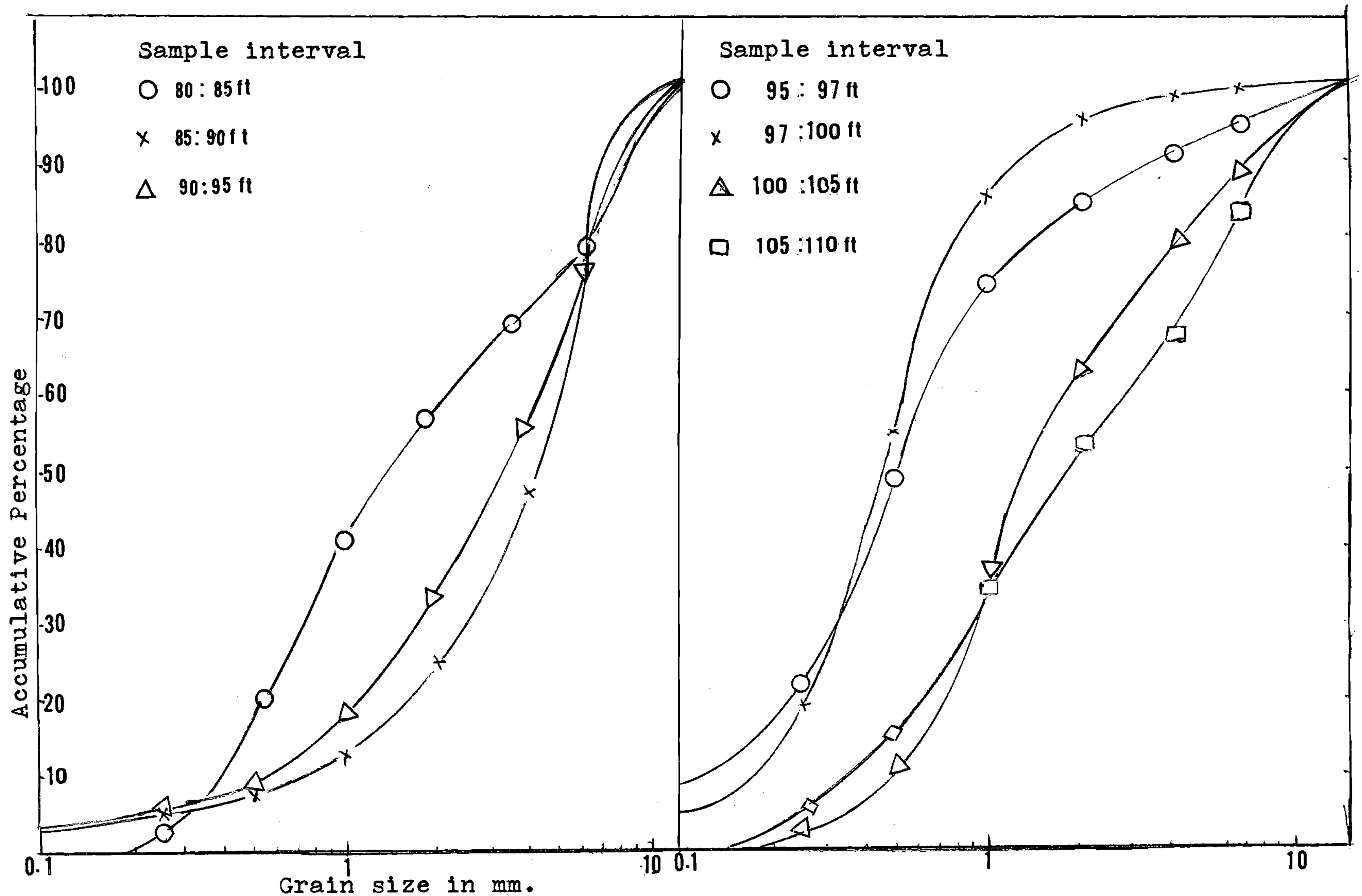



FIGURE 7. CUMMULATIVE CURVES OF PARTICLE SIZE ANALYSES OF TEST HOLE B.H.NO. 1.

the sizes of the grains that constitute the material (Meinzer, 1923, p. 45). The smaller the coefficient the more uniform the material. The effective grain size and the uniformity coefficients of the samples obtained from B. H. No. 1 are shown in table 7.

TABLE 7. EFFECTIVE GRAIN SIZES AND UNIFORMITY COEFFICIENTS OF SELECTED SAMPLES FROM B. H. NO. 1

| Sample Interval ft. | Effective Grain Size mm | Uniformity Coefficient |
|---|---|---|
| 50 - 55 | 0.35 | 14.3 |
| 55 - 60 | 1.20 | 3.6 |
| 60 - 65 | 0.85 | 4.1 |
| 65 - 70 | 0.45 | 10.0 |
| 70 - 75 | 1.50 | 4.0 |
| 75 - 80 | 0.20 | 4.0 |
| 80 - 85 | 0.35 | 8.0 |
| 85 - 90 | 0.65 | 8.3 |
| 90 - 95 | 0.50 | 9.6 |
| 97 - 100 | 0.10 | 6.6 |
| 100 - 105 | 0.16 | 3.6 |
| 105 - 110 | 0.48 | 3.7 |

The average effective size in the samples analysed is about 0.56 mm, and the average uniformity coefficient is about 6.6.

## Estimation of the Aquifer Coefficient of Transmissivity (T)

The capacity of a water-bearing material to transmit water is known as its permeability. The coefficient of permeability or meinzer (K) is defined as the rate of flow in gallons per day through a cross-sectional area of one square foot under a hydraulic gradient of one foot per foot, at a temperature of 60° F. The coefficient of transmissivity (T) is a similar measure for the entire thickness of the aquifer. It is defined as the rate of flow of water in gallons per day through a vertical strip of the aquifer, one foot wide extending the full height of the aquifer, under a hydraulic gradient of 100 per cent, and at the prevailing water temperature. Therefore, the coefficient of transmissivity is the sum of the different permeabilities of the aquifer through its entire thickness.

An estimate of the coefficient of transmissivity in the Zalengei area, may be made by examining each lens or layer of the water-bearing material and assigning to it an approximate coefficient of permeability, within the following ranges (Sniegocki, 1964).

| Type of Material | K (meinzer) |
|---|---|
| Clay, silt, or bed rock | 0 |
| Sand, very fine, silty | 100 - 900 |
| Sand, very fine | 900 - 1400 |

| Type of Material | K (meinzer) |
|---|---|
| Sand, fine to medium | 1400 - 1500 |
| Sand, medium | 1500 - 1600 |
| Sand, medium to coarse | 1600 - 1900 |
| Sand, coarse | 1900 - 2000 |
| Sand, very coarse | 2000 - 2100 |
| Gravel | 2100 - 3000 |

This classification is rather empirical, as it does not account for sorting, particle shape, packing, and other factors affecting the value of permeability. However, higher or lower values of permeability were assigned to particular layers by comparing their cumulative curves with other curves of materials whose coefficients of permeability were obtained experimentally. The cumulative curves usually form a sounder basis for comparing the values of permeability, as they represent both the grain size and the degree of sorting of the material.

The coefficient of transmissivity of each column of sediments of similar characteristics, is obtained by multiplying the assigned coefficient of permeability by the thickness of the material in feet. The transmissivity of the entire aquifer is the sum of all the individual transmissivities of the different lenses or beds forming the aquifer. Table 8 shows the permeability and transmissivity of the different beds and of whole aquifer at the site of B. H. No. 1.

TABLE 8. ESTIMATED PERMEABILITY (K) AND TRANSMISSIVITY (T) COEFFICIENTS OF THE AQUIFER AT THE SITE OF B. H. NO. 1

| Sample Interval ft. | Material Description | Thickness Feet | K meinzer | T g.d.ft. |
|---|---|---|---|---|
| 15 - 40 | Fine sand and silt, sorted | 25 | 100 | 2,500 |
| 40 - 45 | Medium to coarse sand with clay poorly sorted | 5 | 300 | 1,500 |
| 45 - 50 | Same, but less clayey | 5 | 500 | 2,500 |
| 50 - 55 | Medium to coarse sand, poorly sorted | 5 | 700 | 3,500 |
| 55 - 60 | Gritty coarse sand, sorted | 5 | 3000 | 15,000 |
| 60 - 65 | Medium to coarse sand, sorted | 5 | 2000 | 10,000 |
| 65 - 70 | Same, but less sorted | 5 | 1500 | 7,500 |
| 70 - 75 | Coarse gritty sand, sorted | 5 | 3000 | 15,000 |
| 75 - 85 | Same, but poorly sorted | 10 | 1000 | 10,000 |
| 85 - 95 | Pebbly coarse sand, poorly sorted | 10 | 1200 | 12,000 |
| 95 - 100 | Silty medium sand, poorly sorted | 5 | 600 | 3,000 |
| 100 - 105 | Medium to coarse sand, poorly sorted | 5 | 1000 | 5,000 |
| 105 - 110 | Medium to very coarse sand, poorly sorted | 5 | 1500 | 7,500 |
| 110 - 115 | Fine to coarse sand, poorly sorted | 5 | 1000 | 5,000 |
| 115 - 127 | Gritty sand with large cobbles | 12 | 2000 | 24,000 |
| 127 - 130 | Gritty sand with some weathered rock fragments | 3 | 300 | 900 |
| | Total | 115 | about | 125,000 |

The thickness of the aquifer at the site of B. H. No. 1 is some 115 ft. The estimated coefficient of transmissivity of the whole aquifer is about 125,000 gallons per day per foot (g/d/ft). This gives an average of about 1100 meinzers through the entire thickness of the aquifer.

The transmissivity of the aquifer is not constant over Zalengei basin. From the water-table contour map, plate 2, the close spacing of the water-table contour lines near the northern and southern boundary of the aquifer may indicate lower values of transmissivity, because of the wedging of the aquifer. The uniformly spaced contours at the centeral part of the aquifer may indicate a uniform rates of transmissivity through the main bulk of the aquifer.

The thickness of the aquifer at the site of B. H. No. 2 is about 74 ft. Applying the same average of permeability at the site of B. H. No. 1, the transmissivity of the aquifer at B. H. No. 2 will be about 81,000 g/d/ft. Averaging the values obtained at B. H. No. 1 and B. H. No. 2 the transmissivity of the aquifer over Zalengei area can be conservatively considered as 100,000 g/d/ft.

Estimation of the Aquifer Coefficient of Storage (S)

The coefficient of storage of an aquifer is the volume of water it takes into, or releases from storage per unit surface area of the aquifer, per unit change in head component normal to that surface. Under free water-table (unconfined) conditions, such as those prevailing in the area of Zalengei, the coefficient of storage is practically equal to the specific yield of the material dewatered during pumping.

The specific yield of an aquifer as defined by Meinzer (1923) is the ratio of the volume of water which will yield by gravity, after the aquifer is saturated, to the total volume of the water bearing material. The ratio is stated in terms of percentage. The specific yield may also be expressed as the difference between the porosity and the specific retention. The porosity of a material is the percentage of the volume occupied by voids to the total volume of the material. The specific retention of a material is the ratio of the volume of water being saturated, it will retain against gravity, to the total volume of the material. (Meinzer 1923).

Piper and others (1939, p. 121) made a series of experiments to determine the specific yield of undisturbed samples taken from 13 localities in Mokelumne area in California. The methods used were:

a. direct volumetric method by alternate addition and withdrawal of measured volumes of water to the material.

b. Difference between the porosity and the specific retention of the material.

Piper's results are summarised as follows:

| Material Description | Drainage Method | Volumetric Method | Average Specific Yield |
|---|---|---|---|
| Gravel and coarse sand | 35.0 | 34.5 | 34.8 |
| Medium and fine sand | 26.0 | 22.6 | 24.2 |
| Very fine sand, silt and clay | 3.5 | 5.0 | 4.2 |

Kues and Twogood (1954, p. 33) tested several core samples obtained from the drilling of 64 test holes in the San Joaquin Valley, California. Their results are summarised as follows:

| Material Description | Number of Wells | Mean Specific Yield | Probable Deviation Percent |
|---|---|---|---|
| Well sorted sand | 24 | 34 | 2.7 |
| Poorly sorted sand | 21 | 24 | 3.9 |
| Well sorted silt | 18 | 14 | 6.2 |
| Poorly sorted silt and very poorly sorted silty sand | 28 | 8 | 3.7 |
| Clayey silt, silty clay, and clay | 26 | 2 | 1.7 |

The results obtained by Piper (1939) and by Kues and Twogood (1954) are taken as guide lines in estimating the specific yield of the different material of the aquifer in Zalengei area. The estimation is done by examining each lens or layer in the aquifer and assign to it an approximate value of specific yield. The estimation of the specific yield will be based upon the grain size and degree of sorting of the materials and within the following range.

| Type of Material | Assigned Specific Yield (percent) |
|---|---|
| Gravels, sands and gravel, gritty sand | 25 |
| Sands, medium to coarse, well sorted | 25 |
| Sands, medium to coarse, poorly sorted | 20 |
| Fine sand, clayey coarse sand, clay and gravel | 10 |
| Silt, sandy clay, gravelly clay, weathered bed rock | 5 |
| Crystalline fresh bed rock | 0 |

Applying these values of specific yield on the aquifer at the site of B. H. No. 1, where the mechanical analyses of the water-bearing material are available, the following results (table 9) can be obtained.

The average specific yield through the whole thickness of the aquifer is about 0.20 per cent. The assigned values of specific yield to the valley fill deposits in Zalengei area are rather conservative, compared with those suggested by Piper or Kues and Twogood. This is mainly due to the fact that the valley fill deposits in Zalengei are more recent (Pleistocene to Recent) and less compact than the samples used by Piper, Kues, and Twogood.

TABLE 9. MAJOR GROUPS OF WATER-BEARING MATERIALS AND THEIR APPROXIMATE SPECIFIC YIELD, AT THE SITE OF B. H. NO. 1

| Sample Interval ft. | Material Description | Thickness ft. | Assigned Specific Yield |
|---|---|---|---|
| 15 - 40 | Clayey fine sand | 25 | 5% |
| 40 - 45 | Clayey medium to coarse sand | 10 | 10% |
| 45 - 55 | Medium to coarse sand | 10 | 20% |
| 55 - 75 | Medium to coarse, gritty sand | 20 | 25% |
| 75 - 85 | Medium to coarse gritty sand | 10 | 20% |
| 85 - 95 | Sands and gravels | 10 | 25% |
| 95 - 105 | Medium to coarse sand | 10 | 20% |
| 105 - 110 | Medium to very coarse sand | 5 | 25% |
| 110 - 115 | Fine to coarse sand | 5 | 20% |
| 115 - 127 | Gritty sand with large cobbles | 12 | 25% |
| 127 - 130 | Gritty sand with weathered bed rock | 3 | 10% |
| 130 - 135 | Weathered to fresh bed rock | 5 | 0 |

## Ground Water Storage Capacity

The ground water storage capacity of a certain segment of the aquifer can be defined as the volume of water that would be drained by gravity or by pumping from the water-bearing materials occupying the segment. It may also be defined as the volume of water to resaturate these materials after they are drained.

### Method of Computation

The ground water storage capacity of an aquifer is computed by multiplying the total volume of deposits occupying each segment of the aquifer by the estimated average coefficient of storage of the deposits occupying this segment. For the purpose of this report, the average specific yield of the deposits is taken as identical to their average coefficient of storage.

The first element in the estimation is to know the physical dimension of the aquifer and thus, the volume of the saturated material can be evaluated. This involves knowing the surface area of the aquifer, as well as its average thickness.

The boundary of the aquifer is changeable; therefore, its surface area, because of the rise or the fall of the water table at the different seasons of the year. The data in hand only permits rough approximation of the position of the aquifer boundary during April 1965.

The thickness of the saturated material can be estimated by knowing the upper and the lower limits of the zone of saturation, at the different localities of the aquifer. The level of the water table during April 1965 will be taken as the upper limit of the zone of saturation, whereas the hard bed rock, at the base of the alluvium will be taken as its lower limit. Only two wells, (B. H. No. 1 and B. H. No. 2) were drilled through the entire thickness of the aquifer in Zalengei area. This makes it difficult to estimate even the approximate average thickness of the aquifer. However, from the geologic observations in the area, and from the equal spacing of the water table contour lines in the bulk area of the aquifer, plate 2, it can be suggested that there are no drastic differences in the thickness of the aquifer through its main area. For the purpose of this report, the arithmetic mean of the thickness of the aquifer at the site of the two wells will be taken as its average thickness through its whole area.

The second element in estimating the ground water storage capacity is to apply a figure for the specific yield to the different successions of the aquifer, and to determine the average specific yield of the whole aquifer. However, this has been done in table 9, page 57, in which estimated values of specific yield were assigned to each column of similar water-bearing material of the aquifer at the site of B. H. No. 1.

Estimation of the Storage Capacity

The surface area of the aquifer in Zalengei area at April 1965, was about 29 $km^2$, or about 7200 acres. The thickness of the aquifer at the site of B. H. No. 1 is 115 ft., and its thickness at the site of B. H. No. 2 is 74 ft. Taking the arithmetic mean, the average thickness of the aquifer in Zalengei ground water reservoir will be about 95 ft. The average specific yield of the aquifer, as estimated at the site of B. H. No. 1 is 20 per cent. This average is assumed as representing the average specific yield of the aquifer through its whole area.

The gross storage capacity of the ground water reservoir, in acre-ft of water is the result of multiplying its surface area, by the average thickness of the aquifer, by the average specific yield of the water-bearing material in the aquifer. Accordingly, the storage capacity of the ground water reservoir in Zalengei area will be:

Surface area X average thickness X average specific yield

7,200 X 95 X 0.2 = about 140,000 acre-ft.

## CHEMICAL QUALITY OF WATER

In recent years, as greater development and use of ground water increases, combined with the reuse of water, quality suffers unless special consideration is given to protect it. Invariably the increasing demand for ground water for industrial use, and the dumping of the wastes at or near by ground water bodies increases the chances of pollution. Therefore, it is now recognised that the conservation of water quality is an essential part of water management.

The quality required of a ground water supply depends upon the purpose it is going to be used for; thus the specifications for drinking water, irrigation water, and industrial water vary widely. To establish quality criteria, the chemical and physical properties of the ground water should be specified. By chemical analysis, it is possible to identify the most important substances in the water, and to determine their absolute concentrations. With this knowledge, water can be classified to its suitability for any of its various uses.

To study the chemical quality of the ground waters in Zalengei area, two types of analyses were carried out.

A. Seventeen surface and ground water samples were tested in the field. The tests included measurements of the specific conductance and volumetric determination of the total hardness of the water sample in terms of parts per million (ppm) of calcium carbonate. According to Hem (1959), the relationship between the specific conductance and the amount of dissolved salts in waters with normal composition is:

Total dissolved solids in ppm is equal to:

Specific conductance in mocromhos at $25^{\circ}$ C X A

where A is a constant with a value between 0.55 to 0.75.

B. Sixteen surface and ground water samples were completely analysed. The analysis included measurements and determination of pH, specific conductance, total dissolved solids, total alkalinity, and total hardness. The analyses also included quantitative determination of the more important cations and anions present in the water. The analyses were made in Welcome Laboratories, Sudan Ministry of Health, Khartoum.

The chemical analyses of some surface and ground water samples in Hunting's report of Phase I, Jebel Marra Investigations (1958) are also used in this report for studying the quality of water in the Zalengei area. A complete tabulation of all the analytical data available is given in tables 10 to 12.

TABLE 10. SPECIFIC CONDUCTANCE AND TOTAL HARDNESS OF SURFACE AND GROUND WATER SAMPLES, WEST OF JEBEL MARRA

| Source | Depth of Sample | Conductivity as micromhos at 25°C | Total Hardness as Ca CO3 ppm |
|---|---|---|---|
| W.Toro, N of Koronga | Surface | 1390 | 136 |
| W.Toro, near Buronga | Surface | 1265 | 160 |
| W.Toro - W.Buri junction | Surface | 1090 | 200 |
| W.Kiere-W.Nyertete junction | Surface | 750 | 180 |
| W.Nyertete | Surface | 190 | 160 |
| W.Balah | Surface | 435 | 150 |
| W.Mortagello | Surface | 204 | 120 |
| W. Gellimi | Surface | 47 | 30 |
| W. Uyer | 6 ft. below surface | 99 | 45 |
| W.Azum at B.H.I. | 12 ft. below surface | 456 | 110 |
| W.Aribo at B.H.II | 6 ft. below surface | 150 | 60 |
| Zalengei Well no. 35 | 17 ft. below surface | 1452 | 330 |
| Zalengei Well no. 39 | 20 ft. below surface | 1589 | 212 |
| Zalengei Well no. 48 | 21 ft. below surface | 1580 | 160 |
| Zalengei Well no. 61 | 14 ft. below surface | 285 | 100 |
| Zalengei Well no. 69 | 12 ft. below surface | 338 | 110 |
| Zalengei Well no. 86 | 30 ft. below surface | 3368 | 470 |

TABLE 11. CHEMICAL ANALYSES OF THE GROUND WATER IN ZALENGEI TOWN AND WADI ARIBO

| Number | Locality | Depth m | Date | p H | Total solids ppm | Hardness as $CaCO_3$ ppm | Alkalinity as $CaCO_3$ ppm | Silicate as $SiO_2$ ppm | Calcium as Ca ppm | Calcium as Ca epm | Magnesium as Mg ppm | Magnesium as Mg epm | Other cations as Na ppm | Other cations as Na epm | Sulfate as $SO_4$ ppm | Sulfate as $SO_4$ epm | Chloride as Cl ppm | Chloride as Cl epm | Bicarbonate as $HCO_3$ ppm | Bicarbonate as $HCO_3$ epm | Fluoride as F ppm | Nitrate as $NO_3$ ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W.Z.1 | Zalengei | 18.0 | 2/4/64 | 8.0 | 330 | 154 | 140 | 18 | 37 | 1.85 | 15 | 1.23 | 60 | 2.60 | 62 | 2.61 | 16 | 0.45 | 232 | 3.80 | 0.5 | 10 |
| W.Z.2 | Zalengei | 16.6 | 2/4/64 | 8.0 | 2680 | 120 | 200 | 20 | 364 | 18.16 | 241 | 19.82 | 96 | 4.18 | 1793 | 37.29 | 30 | 0.85 | 244 | 4.00 | 0.2 | |
| W.Z.3 | Zalengei | 6.4 | 2/4/64 | 8.2 | 4020 | 350 | 1000 | 20 | 64 | 3.19 | 46 | 3.78 | 1260 | 54.81 | 1880 | 39.14 | 70 | 1.97 | 1219 | 19.98 | 3.0 | |
| W.Z.4 | Zalengei | 10.3 | 2/4/64 | 8.0 | 312 | 176 | 270 | 20 | 38 | 1.90 | 20 | 1.65 | 89 | 3.48 | 58 | 1.21 | 12 | 0.34 | 329 | 5.39 | | |
| W.Z.5 | Zalengei | 13.7 | 2/4/64 | 8.1 | 400 | 200 | 350 | 18 | 50 | 2.50 | 18 | 1.48 | 90 | 3.92 | 21 | 0.44 | 14 | 0.40 | 427 | 7.00 | 1.0 | |
| W.Z.8 | Zalengei | 3.0 | 2/20/64 | 8.2 | 530 | 212 | 440 | 18 | 53 | 2.65 | 19 | 1.56 | 133 | 5.79 | 29 | 0.60 | 16 | 0.45 | 536 | 8.79 | 3.2 | |
| W.Z.38 | Zalengei | 6.0 | 2/20/64 | 8.1 | 780 | 340 | 400 | 18 | 76 | 3.79 | 34 | 2.80 | 156 | 6.79 | 156 | 3.25 | 70 | 1.97 | 488 | 8.00 | 0.8 | 30 |
| W.Z.60 | Zalengei | 3.5 | 2/20/64 | 8.1 | 1000 | 140 | 760 | 20 | 60 | 2.99 | 5 | 0.41 | 356 | 15.49 | 25 | 0.52 | 90 | 2.54 | 926 | 15.18 | 3.6 | |
| W.Z.62 | Zalengei | 2.8 | 2/20/64 | 8.0 | 90 | 54 | 60 | 18 | 15 | 0.75 | 4 | 0.33 | 14 | 0.61 | 17 | 0.35 | 4 | 0.11 | 73 | 1.20 | 0.4 | |
| W.Z.66 | Zalengei | 9.0 | 2/20/64 | 8.2 | 270 | 130 | 237 | 20 | 33 | 1.65 | 12 | 0.99 | 54 | 2.35 | 20 | 0.42 | 2 | 0.06 | 289 | 4.74 | 0.6 | 2 |
| W.Z.70-a | Zalengei | 7.0 | 2/20/64 | 8.1 | 325 | 122 | 270 | 20 | 23 | 1.15 | 16 | 1.32 | 80 | 3.48 | 12 | 0.25 | 12 | 0.34 | 329 | 5.39 | | |
| W.Z.70-b | Zalengei | 7.1 | 2/20/64 | 8.3 | 1200 | 220 | 1120 | 4 | 52 | 2.60 | 119 | 9.79 | 305 | 13.27 | 41 | 0.85 | 80 | 2.26 | 1365 | 22.37 | 2.30 | |
| W.Z.73 | Zalengei | 3.3 | 2/20/64 | 8.0 | 400 | 196 | 280 | 10 | 56 | 2.79 | 14 | 1.15 | 75 | 3.26 | 61 | 1.27 | 8 | 0.23 | 341 | 5.59 | 1.1 | 5.7 |
| W.Z.83 | Zalengei | 2.8 | 2/22/64 | 8.1 | 380 | 252 | 290 | 18 | 56 | 2.79 | 27 | 2.22 | 51 | 2.22 | 41 | 0.85 | 20 | 0.56 | 354 | 5.80 | .6 | |
| W.Z.85 | Zalengei | 9.5 | 2/22/64 | 8.1 | 720 | 232 | 580 | 20 | 55 | 2.75 | 23 | 1.89 | 205 | 8.92 | 33 | 0.69 | 44 | 1.24 | 707 | 11.59 | 1.8 | |
| W.Z.75 | Zalengei | 1.9 | 3/1/64 | 8.1 | 250 | 134 | 210 | 20 | 38 | 1.90 | 9 | 0.74 | 49 | 2.13 | 16 | 0.33 | 8 | 0.23 | 256 | 4.20 | 1.1 | |
| Ar.1 | W.Aribo | 1.3 | 1/58 | 8.1 | 140 | 82 | 90 | 20 | 26 | 1.30 | 2 | 0.16 | 20 | 0.87 | 20 | 0.42 | 4 | 0.11 | 110 | 1.80 | 0.6 | 3.1 |

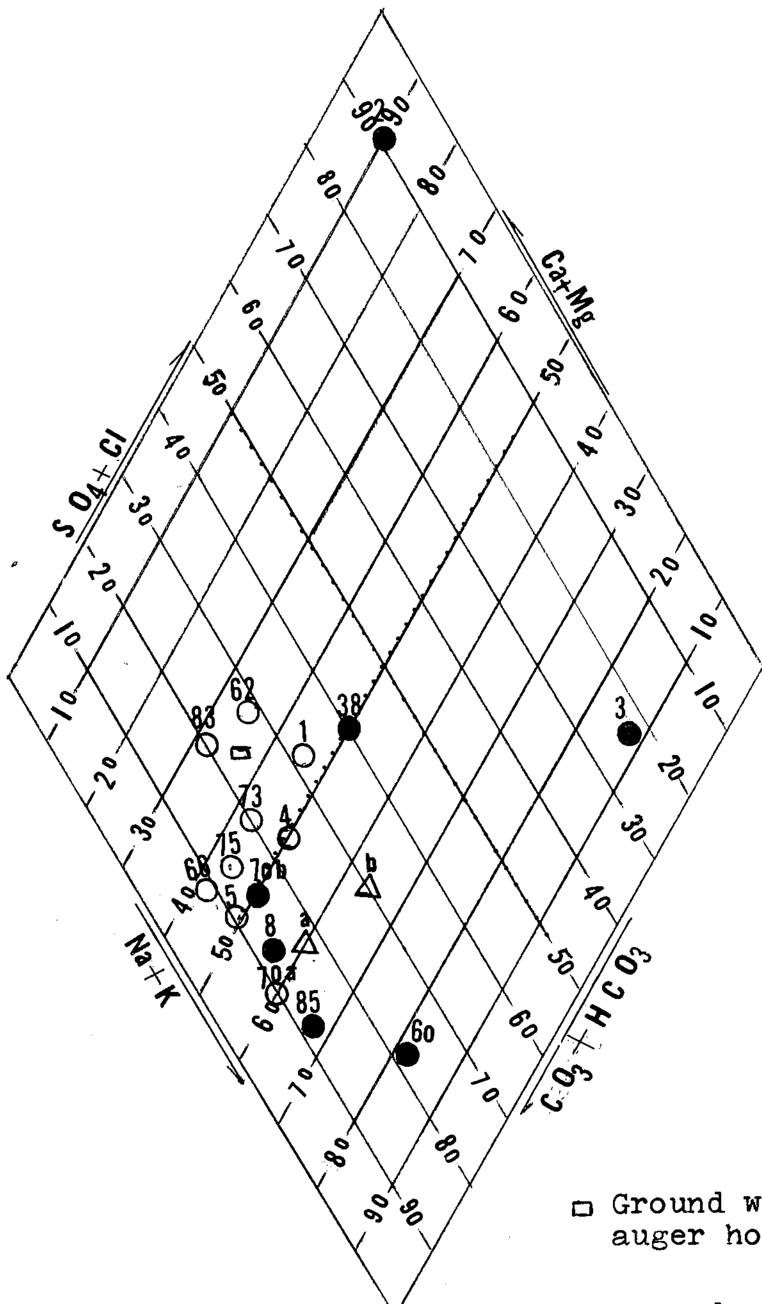
TABLE 12. CHEMICAL ANALYSES OF THE WATER OF WADI AZUM AND ITS TRIBUTARIES

| Locality | Depth m | Date | pH | Total solids ppm | Hardness as $CaCO_3$ ppm | Alkalinity as $CaCO_3$ ppm | Silicate as $SiO_2$ ppm | Calcium as Ca ppm | Calcium as Ca epm | Magnesium as Mg ppm | Magnesium as Mg epm | Other cations as Na ppm | Other cations as Na epm | Sulfate as $SO_4$ ppm | Sulfate as $SO_4$ epm | Chloride as Cl ppm | Chloride as Cl epm | Bicarbonate as $HCO_3$ ppm | Bicarbonate as $HCO_3$ epm | Fluoride as F ppm | Nitrate as $NO_3$ ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Large Dariba Lake | Surface | 12/57 | 9.6 | 13920 | 56 | 8445 | 100 | 12 | 0.60 | 6 | 0.60 | 5670 | 246.65 | 10 | 0.21 | 2580 | 72.76 | 10294 | 168.72 | 100 | 2.6 |
| Small Dariba Lake | Surface | 12/57 | 9.2 | 4200 | 66 | 2528 | 100 | 9 | 0.45 | 110 | 0.82 | 1710 | 74.39 | 15 | 0.31 | 780 | 22.00 | 3082 | 50.51 | 48 | 2.0 |
| W. Kiere | Surface | 1/58 | 8.8 | 2320 | 236 | 1156 | 40 | 21 | 1.05 | 45 | 3.70 | 881 | 38.32 | 10 | 0.21 | 690 | 19.46 | 1409 | 23.10 | 4.8 | 2.0 |
| W. Toro | Surface | 1/58 | 8.6 | 780 | 132 | 435 | 30 | 14 | 0.70 | 24 | 1.98 | 221 | 9.61 | 15 | 0.31 | 180 | 5.08 | 530 | 8.69 | 0.3 | 2.0 |
| W. Toro | Surface | 1/64 | 8.8 | 1000 | 136 | 390 | 12 | 22 | 1.10 | 20 | 1.65 | 210 | 9.14 | 8 | 0.17 | 260 | 7.33 | 475 | 7.79 | 1.4 | |
| W. Nyertete | Surface | 12/57 | 8.3 | 190 | 114 | 148 | 30 | 19 | 0.95 | 16 | 1.32 | 29 | 1.26 | 10 | 0.21 | 12 | 0.34 | 180 | 2.95 | 0.8 | 2.0 |
| W.Mortagello | Surface | 12/57 | 8.0 | 140 | 76 | 109 | 40 | 14 | 0.70 | 10 | 0.82 | 27 | 1.17 | 15 | 0.31 | 6 | 0.17 | 133 | 2.18 | 0.6 | 1.7 |
| W. Golol | Surface | 1/58 | 8.2 | 194 | 92 | 148 | 20 | 25 | 1.25 | 7 | 0.58 | 40 | 1.74 | 20 | 0.42 | 4 | 0.11 | 180 | 2.95 | 0.9 | 3.9 |
| W. Uyer | 1 | 1/58 | 6.6 | 130 | 34 | 40 | 20 | 8 | 0.40 | 3 | 0.25 | 17 | 0.74 | 20 | 0.42 | 4 | 0.11 | 49 | 0.70 | 0.2 | 19.5 |
| W.Azum N-E Zalengei | 0.3 | 1/58 | 7.5 | 216 | 80 | 158 | 10 | 23 | 1.15 | 25 | 0.41 | 55 | 2.40 | 20 | 0.42 | 10 | 0.28 | 193 | 3.16 | | 5.8 |
| W.Azum N-W Zalengei | 1.5 | 1/57 | 7.1 | 174 | 54 | 100 | 20 | 6 | 0.3 | 9 | 0.74 | 47 | 2.05 | 40 | 0.84 | 8 | 0.23 | 122 | 2.00 | 1.0 | 2.7 |

Figure 8 shows one-point plotting of substantially all the analytical data on the ground water in Zalengei area. These waters include native waters, or those whose chemical character is natural to a particular water-bearing horizon, such as the valley fill deposits, or the weathered graphite schists, or blended waters such as those from wells tapping both horizons. The blending here may be partly natural due to the mingling of the native waters in the two aquifers, or due to mixing of the dissimilar waters during the process of withdrawal from the well.

From figure 8 two distinct types of water can be quickly discriminated by their plottings in certain sub areas in the diamond shaped diagram.

1. Carbonate and bicarbonate rich waters in which the amount of weak acids exceed the amount of strong acids. These waters are characteristic of the native waters in the valley fill, and some blended waters from the wells tapping both the alluvium and the graphite schists. In composition they range from water with excess amounts of calcium and magnesium bicarbonate, to water with excess sodium bicarbonate. All samples except from well 2 and 3 fall in this category.




□ Ground water sample from auger hole at W. Aribo

△ Ground water sample from auger hole at W. Azum

a Upstream of W. Aribo junction

b Downstream of W. Aribo junction

62 ○ Ground water samples from Zalengei wells with less than 500 ppm solids

38 ● Ground water samples from Zalengei wells with more than 500 ppm solids

FIGURE 8. WATER ANALYSIS DIAGRAM OF THE GROUND WATERS IN ZALENGEI AREA

2. Non-carbonate rich waters, in which the amount of strong acids exceed the amount of weak acids. These waters are characteristic of the native waters tapped from the weathered graphite schists. In composition, they range from permanently hard waters with excess calcium and magnesium sulfate (well 2) to waters with excess sodium sulfate (well 3).

Carbonate and Bicarbonate Rich Waters

The carbonate and bicarbonate rich waters are characteristic of the main bulk of the ground water resources in the Zalengei area. They include the water body or bodies of which the Lower Terraces and Flood Plain deposits are the main aquifers. These water bodies occur on both banks and in between W. Azum and W. Aribo. The bicarbonate rich waters are also characteristic of a rather limited supply of some blended water tapped from both the alluvium and the graphite schists in the centeral and eastern sector of Zalengei Town.

The bicarbonate rich waters range from 90 to 1200 ppm in dissolved solids, and from 54 to 340 ppm in total hardness. Their range in chemical character is rather remarkable. The plotting of both the native and blended waters in Figure 8 , shows a full gradation in chemical composition from water high in calcium and magnesium bicarbonate to water high in sodium bicarbonate. Using the classification introduced by Palmer (1911, p. 13, 14) and Hill (1940, p. 47), the composition of these waters ranges from 70.80 (where 70 refers to the percentage of the reacting values of calcium and magnesium, while 80 refers to the percentage of the reacting values of carbonate and bicarbonate) to 18.80.

According to the predominant cation the bicarbonate waters may be divided into two sub-classes, each having a characteristic type locality:

Calcium-Sodium Bicarbonate Waters

The calcium-sodium bicarbonate waters are characteristic of the supplies underlying W. Aribo and the north and northeastern sectors of Zalengei Town. These waters have low amounts of dissolved solids ranging from 90 to 400 ppm, and a total hardness from 54 to 252 ppm. According to Palmer's classification they range in composition from 70.80 to 50.80.

Chemical Quality of the Ground Water of Wadi Aribo.--Wadi Aribo is one of the most important tributaries of W. Azum. The chemical quality of the ground water underlying W. Aribo, is generally the best compared with the other types of water found in the area of Zalengei.

Ground water samples analysed show a total amount of dissolved solids ranging from 90 to 140 ppm, and a total hardness ranging from 54 to 82 ppm. The water is slightly alkaline (pH about 8) and is an excellent source for irrigation and domestic uses.

The bicarbonates and carbonates are the predominant anions generally constituting about 80 per cent of the total anion concentration. The rather high content of silica (20 ppm) may be because of the fact that the drainage basin of W. Aribo is underlain mainly by acid igneous and metamorphic rocks. Calcium and sodium are the predominant cations in the ground water of W. Aribo. They generally constitute about 50 per cent and 38 per cent respectively of the total cation concentration. Magnesium is subordinate and only constitutes 12 per cent of the total cation concentration.

Chemical Quality of the Ground Water of North Zalengei.--The waters tapped from the wells north and north-east of Zalengei are essentially identical in chemical character with the water underlying W. Aribo, from which presumably they are derived. The amount of dissolved solids increases from 90 to 400 ppm, in nearly parallel segments, inland from W. Aribo, toward the center of the town (plate 3). The increase in the amount of dissolved solids is accompanied by a relative gain in the concentration of both sodium and bicarbonate ions. Thus; the water composition changes from 70.80 as in well 83, to 52.90 in well 5, or from 65.70 in well 62 to 55.90 in well 66.

Sodium-Calcium Bicarbonate Waters

The sodium-calcium bicarbonate waters are characteristic of the supplies tapped from the alluvium on both banks of W. Azum. They are also characteristic of some limited supplies tapped from the central and southeastern sectors of Zalengei Town, where the upper water-bearing alluvium has a minor effect on changing the quality of water tapped from the weathered graphite schist. These waters have low to moderate amounts of dissolved solids, ranging from 174 to 1200 ppm, and a total hardness from 54 to 232 ppm, with the exception of well 38 which has a total hardness of 340 ppm. The chemical composition of these waters ranges from 48.85 to 18.78.

Chemical Quality of the Ground Water of Wadi Azum.--Wadi Azum starts as a perennial stream, with the name of W. Toro, at the northern slopes of J. Marra. Other streams that originate from J. Marra mass and join W. Toro at the piedmont zone to form W. Azum are W. Buri, W. Kiere, W. Nyertete, W. Mortagello, and W. Golol.

The waters of most of the wadis that originate from or near the northern outlet of the crater of J. Marra, are characterised by rather high amount of dissolved solids, ranging from 1000 to 2320 ppm, mostly sodium bicarbonate and sodium chloride. The total hardness of these waters range from 132 to 236 ppm. The high mineral content is due to the thick volcanic ash and tuff, rich in soluble mineral salts, covering the northern region of J. Marra, and to outflow from the highly saline Large Dariba Lake that occupies the northeastern sector of the crater of J. Marra.

The total amount of dissolved salts in the water of the Large Dariba Lake is 13,920 ppm. The other lake that occupies the crater, is smaller, deeper and less saline than the Large Dariba Lake. The total amount of dissolved salts in the Small Dariba Lake is 4,200 ppm mostly sodium bicarbonate and sodium chloride. The most striking fact in the chemical composition of the waters of the Dariba lakes is their exceptionally high content of fluoride. The smaller lake has a content of fluoride of 40 ppm, while the larger lake has a content of 100 ppm. The latter appears to be the highest content of fluoride in natural waters on record. The next highest is 67 ppm in a water from the Union of South Africa (Bond 1964). Other exceptionally high contents are 32 ppm in San Simon, Arizona, and 22 ppm in Idaho (Hem 1957). According to

Hem (1957, p. 113), natural waters, with a fluoride content exceeding 10 ppm are quite rare in the world.

The relation between the chemical composition of the Dariba lakes and that of the streams flowing on the northern slopes of J. Marra, is reflected in their relatively high salinity, high content of bicarbonate, chloride, fluoride, and silica, as shown by table 13.

The perennial streams that originate on the western slopes of J. Marra mass, usually have a low concentration of dissolved mineral salts ranging from 140 to 194 ppm, mostly calcium and sodium bicarbonates. The total hardness ranges from 70 to 114 ppm. This can be explained from the fact that the western slopes of J. Marra are steeper than the northern slopes and occupied by fresh basalts and trachytes. The other fact is that there is no direct connection between the waters of these streams and that of the saline lake occupying the crater of J. Marra.

The two major streams that join W. Azum in the lowlands, before it reaches Zalengei area, are W. Gellimi and W. Uyer. These are ephemeral streams that run for a period of two to three months during and shortly after the rainy season. Each wadi has a catchment area of about 1500 $km^2$, covered mainly with quartzites, acid gneisses and

TABLE 13. SOME CHEMICAL CONSTITUENTS OF THE WATER OF THE DARIBA LAKES AND THE WADIS NORTH OF J. MARRA.

| Source of Water | Total Solids ppm | Bicarbonate $HCO_3$ ppm | Chloride Cl ppm | Silica $SiO_2$ ppm | Fluoride F ppm |
|---|---|---|---|---|---|
| Large Dariba Lake | 13920 | 10294 | 2580 | 100 | 100 |
| Small Dariba Lake | 4200 | 3082 | 780 | 100 | 40 |
| W. Kiere | 2320 | 1409 | 690 | 40 | 4.8 |
| W. Toro | 1000 | 475 | 260 | 12 | 1.4 |

granites. The average rainfall of W. Gellimi is about 700 mm (28 inches) while that of W. Uyer is about 650 (25.5 inches).

A water sample collected 3 ft. below the bed of W. Uyer shows an amount of 130 ppm of total dissolved salts, and a total hardness of 34 ppm. Most of the dissolved solids occur in the form of calcium and sodium bicarbonate and sulfate. A surface water sample collected from W. Gellimi showed specific conductance of 47 micromhos at 25°C. Therefore, the amount of the total dissolved solids in the water of W. Gellimi will be on the order of 35 ppm.

From figure 9, the ground water underlying W. Azum in the area of Zalengei can be considered as a blend of the different types of water carried by the wadi and its tributaries. The chemical composition of the ground water is expected to be highly affected by the quantity and quality of the water of each tributary. In this respect the ground water underlying W. Azum is much more identical in chemical character with the waters of the streams west of J. Marra, rather than with the waters of the streams north of J. Marra.

The chemical analysis of a water sample collected one foot below the wadi bed in January 1958, shows a 216 ppm of total dissolved solids, and a total hardness

FIGURE 9

WATER ANALYSIS DIAGRAM OF THE WATERS

OF W. AZUM AND ITS TRIBUTARIES

| Sample No. | Location | Depth | Total Solids ppm |
|---|---|---|---|
| 1 | Large Dariba | Surface | 13920 |
| 2 | Small Dariba | Surface | 4200 |
| 3 | W. Kiere | Surface | 2300 |
| 4 | W. Toro | Surface | 780 |
| 5 | W. Nyertete | Surface | 190 |
| 6 | W. Mortagello | Surface | 140 |
| 7 | W. Golol | Surface | 149 |
| 8 | W. Uyer | 3 ft. | 130 |
| 9 | W. Azum, N-E Zalengei | 1 ft. | 216 |
| 10 | W. Aribo | 4 ft. | 140 |
| 11 | W. Azum, N-W Zalengei | 5 ft. | 175 |

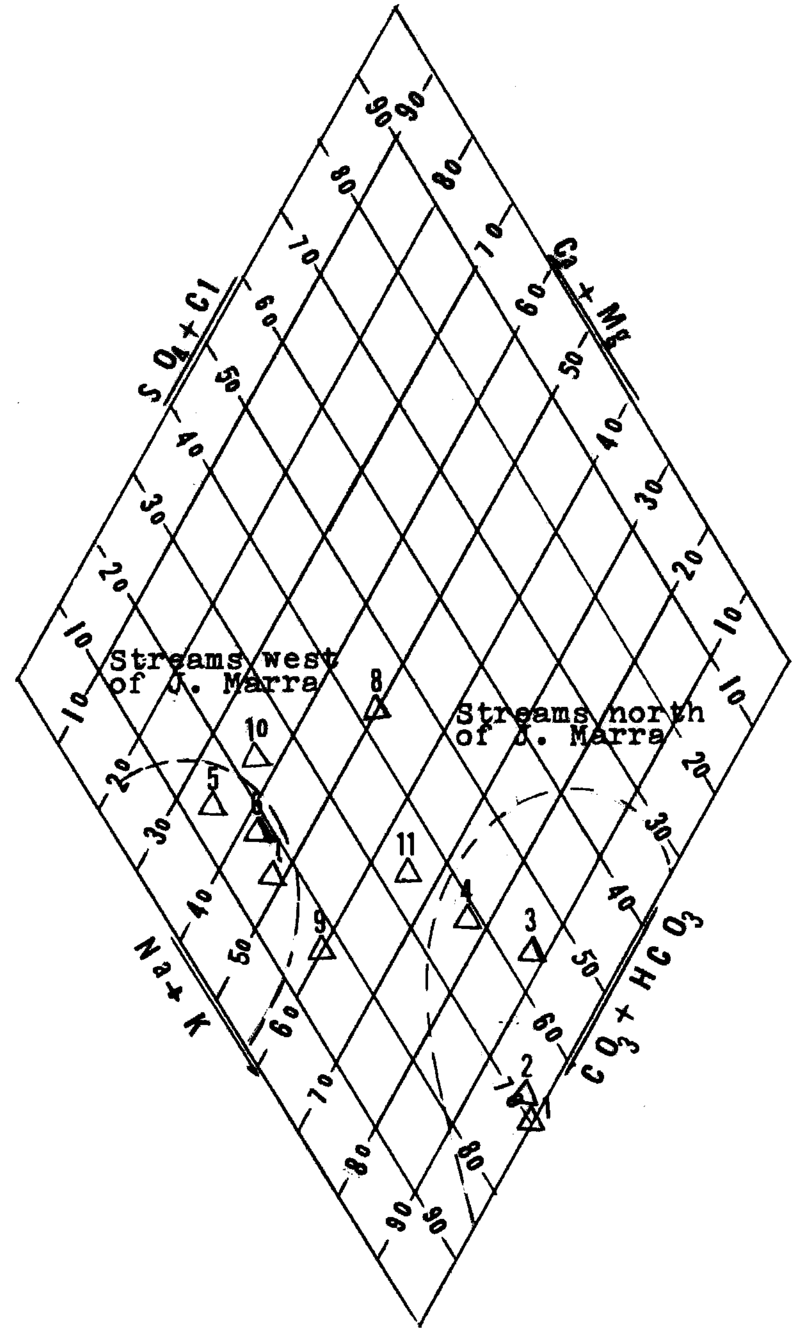



FIGURE 9. WATER ANALYSIS DIAGRAM OF THE WATERS OF W. AZUM AND ITS TRIBUTARIES

of 80 ppm. Another sample taken after the drilling of B. H. No. 1 gave a specific conductance of 456 micromhos at 25°C, and a total hardness of 110 ppm. The ground water of W. Azum can be described as slightly to moderately hard, rather alkaline, and is good for irrigation and domestic uses.

The bicarbonates and carbonates are the most predominant anions, while the sulfates, chlorides, and nitrates are subordinates. The fluoride content is less than 1 ppm. Sodium and calcium are the predominant cations. They form about 94 per cent of the total cation concentration. Magnesium is subordinate and only constitutes 6 per cent of the total cation concentration.

A water sample taken 5 ft. below the stream bed of W. Azum, west of Zalengei Town and downstream of its junction with W. Aribo, shows a decrease in the amount of dissolved solids from 216 to 174 ppm. The total hardness also decreased from 80 to 54 ppm. The change of the quality of water is marked by a relative change in its ionic concentrations. In the anions, there is a considerable increase in the concentration of the silicates and sulfates, and a decrease in the concentration of the bicarbonate, chloride and nitrate. The increase in the concentration of silica is a diagnostic feature of water of areas with acid igneous or metamorphic rocks, the same type of rocks that underlies W. Aribo drainage basin. The increase in the concentration of the sulfates may be due to the presence of some disseminated pyrite in the graphite schist underlying the valley fill at this part of W. Azum. As for the cations, sodium is still predominant and forms about 65 per cent of the total cation concentration. Magnesium and calcium are subordinate, and form 26 per cent and 8 per cent of the total cation concentration respectively.

Chemical Quality of the Ground Water of Central and Southeastern Zalengei.--The sodium-calcium bicarbonate waters of Zalengei Town are generally more saline than those of W. Azum. From the data in hand, the salinity increases from 400 to 800 ppm in nearly parallel segments towards the center of the town. However, there are more saline wells in the southeastern sector of the town, with salinity up to 1200 ppm as in well no. 70-b. The total hardness ranges from 122 to 340 ppm. The range in chemical character of these wells is rather remarkable, taking into consideration the relatively small extent of the area. The change is from water with a composition 48.85 as in well 70-b to water with a composition of 18.78 as in well 60, to water with a composition of 48.60 as in well 38. The relatively high concentration of sulfates and nitrates (156 and 30 ppm respectively) in the water of well 38, may be due to the occurrence of some decaying organic matter.

## Non-Carbonate Rich Waters

The non-carbonate waters are characteristic of the native waters tapped in the extreme western sector of Zalengei Town, where the graphite schist crops out at the surface, and its weathered zone is the only productive water-bearing horizon. Water tapped from this zone is very limited in quantity and unfit for both human and irrigation usage. In some cases the local farmers use the water from this zone for occasional watering of their cattle.

From the analyses of the two wells (2 and 3) dug in this zone, the water composition ranges from 2680 to 4020 ppm in dissolved solids, and from 120 to 350 ppm in total hardness, Most of hardness is permanent or non-carbonate hardness. In case of well 2, 90 per cent of the dissolved solids occur as non-carbonate hardness principally in the form of calcium, magnesium sulfates. In case of well 3, about 70 per cent of the dissolved solids occur as non-carbonate alkalies mainly in the form of sodium sulfate, while the remaining 30 per cent of the dissolved solids occur in the form of sodium, calcium and magnesium bicarbonates. Other than the high salinity of the water of well 3, it also contains a concentration of fluorides 2.9 ppm which makes it undesirable for human consumption.

## AGRICULTURAL DEVELOPMENT OF THE AREA

The future agricultural development of the area of Zalengei, requires a carefully planned and thoroughly executed program of investigation and accumulation of scientific, economic, and social studies. Such studies should not be confined to the area of the report, but should extend to the surrounding areas, and tied in with the general plan of development of the whole country. However, the following discussion deals only with the area of Zalengei and is based on the data now available as regards the area of arable land, the crops that can be grown, the amount of ground water available, and its suitability for irrigation and domestic purposes.

The area of arable land in Zalengei area sums up to 25 $km^2$ or about 6,200 acres. This land mainly occurs as irrigable plots not larger than 500 acres in the areas underlain by Lower Terrace deposits. According to the U. S. Bureau of Reclamation general specifications for land classification, the arable land in Zalengei area ranges from class 1 to class 3. This means that this land is suitable for farming and is expected to have an adequately high productive capacity. Some 1000 acres, mainly of class 4 can be added to the preceding area, if the economic and agricultural engineering studies prove them to be arable. These 1000 acres occur in areas mainly underlain by Flood Plain deposits, and have been downgraded to class 4 on account of coarse-textured soil, high water table or flood hazards. Taking this area of land into consideration, the estimation of arable land in Zalengei area may rise up to 7,200 acres.

The greater part of the arable land in Zalengei area is not now under any form of cultivation, and is mainly covered with medium to tall savanna grass or large haraz trees. The crops grown on the small cultivated plots in the area include dura, dukhn, simsim, wheat and a wide variety of vegetable and spices. Fruit growing has been stimulated by the Government, and now there are a few small-scale planting in and around Zalengei Town, carried out by private farmers. The fruits grown are mainly citrus fruits, mangos, and pawpaw, all of excellent quality, and irrigated either manually using buckets and ropes or by small diesel pumps. Sweet potatoes, potatoes, onions, and tobacco are grown on less than half acre plots as winter crops on the Flood Plain soils.

Generally speaking, the area is now self-sufficient in food crops, but rainfall is not sufficient to grow substantial cash crops for export. The scope of future development should be the growing of cash crops by dry-season irrigation. These crops as suggested in Hunting's J. Marra investigations (1958) include sugar, coffee, wheat, cotton, Virginia tobacco, and some varieties of fruits and vegetables. These crops, when grown in the whole region of J. Marra, will reduce the country imports, and contribute to its prosperity.

## Water Requirements

The total water requirement for a certain crop consists of the water needed by the crop plus the losses associated with the delivery and application of water. The best source of information on overall water requirement is the experience of good irrigators operating under conditions similar to those of the project area. If no direct determination of the total water requirement is possible, an evaluation may be made by first estimating the consumptive use of the crop less the effective precipitation, and adjusting the difference to account for the other losses.

Crop irrigation in the Zalengei area is needed only during the dry season. Therefore, the water requirements can be estimated as the consumptive use in 9 months plus a certain factor of this amount to account for the other losses during the process of irrigation. As the greater part of the arable land in Zalengei area is not now under any form of cultivation, and as a safety measure, the water requirements will be computed as the average yearly consumptive use plus 50 per cent to account for losses during the irrigation process. Table 14 gives values of consumptive use for selected crops that can be grown in the area of Zalengei.

TABLE 14. VALUES OF CONSUMPTIVE USE FOR SELECTED CROPS (after Linsley and Frazini, 1964)

| Crop | Region | Consumptive use ft/yr | Method |
|---|---|---|---|
| Alfalfa | Los Angeles, Calif. | 3.1 | Field |
| Beets | Scottsbluff, Nebr. | 2.0 | Field |
| Citrus | Los Angeles, Calif. | 1.9 | Field |
| Cotton | Sandues Valley, Colo. | 1.3 | Tank |
| Wheat | Sanluis Valley, Colo. | 1.2 | Tank |

Taking the average consumptive use as 2 ft. per year, the average amount of irrigation water required per acre; per year will be

$$2 + (.5 \times 2) = 3 \text{ acre feet}$$

The total amount of water required to irrigate all the arable land in Zalengei area for the dry season will be,

$$7{,}200 \times 3 = \text{about } 21{,}600 \text{ acre feet}$$

This amount of water approximately constitutes about 16 per cent of the gross storage capacity of the ground water reservoir in Zalengei area, at the end of the dry season (page 60).

## Suitability of Water for Irrigation

According to Eaton (1954), the growing plant consumes a very small part of the mineral salts dissolved in the irrigation water. This minor fraction consumed, consists essentially of calcium and magnesium salts. The rest of the dissolved salts remain in the soil. Therefore, highly mineralised waters are not recommended for continuous use, if long-term economy is desired. Salt accumulation impairs plant growth, and a time is reached when it will be impossible to continue agriculture in the same area. The salt balance is considered favorable if the same amount of salt added to the soil in irrigation water is subsequently removed from the soil. The favorable balance can be maintained if the drainage conditions and the texture of the topsoil allow the dissolved salts to pass away or pass down to the sub-soil zone. The amount and distribution of rainfall play a major role in leaching the accumulated salt from the topsoil, thus, improving its salt balance. The U. S. Department of Agriculture (1954), has classified irrigation waters on the basis of their specific conductance into four groups:

1. Low-Salinity Water (C1), with specific conductance ranging from 100 to 250 micromhos/cm at 25°C. This water can be used for the irrigation of most crops on most soils without fear of salinity hazard.
2. Medium-Salinity Water (C2), with specific conductance ranging from 250 to 750 micromhos/cm at 25°C: This water can be used if a moderate amount of leaching occurs. Crops with moderate salt tolerance such as vegetables, wheat, corn, or alfalfa can be grown without special practices for salinity control.
3. High-Salinity Water (C3), with specific conductance ranging from 750 to 2250 micomhos/cm at 25°C: This water can not be used on soil with restricted drainage. Special management for salinity control is required, and crops with good salt tolerance such as rice, beets and cotton should be grown.
4. Very High-Salinity Water (C4), with specific conductance higher than 2250 micromhos/cm at 25°C: This water is not suitable for irrigation.

In addition to salinity problems in irrigation water, there are certain constituents which are considered as undesirable and may be damaging to the plant growth if present even in only small concentration.

Selenium, when present in small concentration in irrigation water this element is toxic to animals grazing on the grass of the area irrigated.

Boron, is necessary in very small quantities for the normal growth of all plants, but becomes toxic to some plants when present in amounts as low as 1.0 ppm in irrigation water. Among the plants most sensitive to excess boron are the citrus fruits, the most important fruit crop in the whole area of J. Marra. The water samples collected from the area of Zalengei were not analysed for boron, but according to Sudan Ministry of Agriculture, the citrus fruits are the most successful crop in the area. The yield is all the year round, and the quality is excellent compared with types grown elsewhere in the Sudan. This is enough proof that the concentration of boron in the soil, or in the irrigation water is within the safe limits, even with respect to the most sensitive crops.

Magnesium, is toxic to the plant if present in high concentration. However, its effect is highly alleviated in the presence of calcium.

Calcium, is harmful to the plant if present in the form of calcium chloride, over certain concentrations, depending somewhat on the other constituents present.

Sodium, in irrigation water has an indirect effect on the plant. Sodium carbonate if present in considerable amount in water, increases the p H. of the soil; thus, dissolves some of the organic matter forming a hard black crust on the top of the soil. If present in the form of sodium chloride or sodium sulfate, forms a white crust on the top of the soil. Accordingly, excess sodium affects the soil structure, destroying its permeability, causing low aeration, and low seepage of water down to the plant root.

Sodium Adsorption Ratio (SAR), The sodium adsorption ratio is one of the most important factors in evaluating irrigation water. This ratio refers to the amount of sodium, potassium and other monovalent cations adsorped by the soil from the irrigation water. The ratio is calculated by the following formula, where the cations are expressed in equivalents per million (epm).

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

The classification of irrigation waters with respect to the SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. According to the SAR value water can be divided into four classes:

1. Low Sodium Water (S1): This water can be used in all types of cultivable soils, without any fear of alkali hazard.

2. Medium Sodium Water (S2): This type of water will present to a certain extent a sodium hazard especially in fine textured soil, under low leaching conditions. However, this water may be used on highly permeable coarse textured soil.
3. High Sodium Water (S3): This water is hazardous to most soils, and usually forms a hard crust, nearly impermeable to water, Such water can only be used on coarse textured soils with good drainage, and high leaching. Chemical additives such as calcium sulfate (gypsum) to counter the high effect of sodium are sometimes necessary.
4. Very High Sodium Water (S4): This type of water is generally avoided and if used requires extreme low salinity, perfect drainage, high leaching, addition of considerable amounts of gypsum.

The U. S. Dept. of Agriculture, (1954, p. 80) published a widely distributed and utilised diagram for the evaluation of irrigation waters. This diagram is based on plotting the specific conductance against the sodium adsorption value of the water on a semi-logarithmic scale. According to this diagram (Figure 10) the ground waters in Zalengei area can be classified into four types:

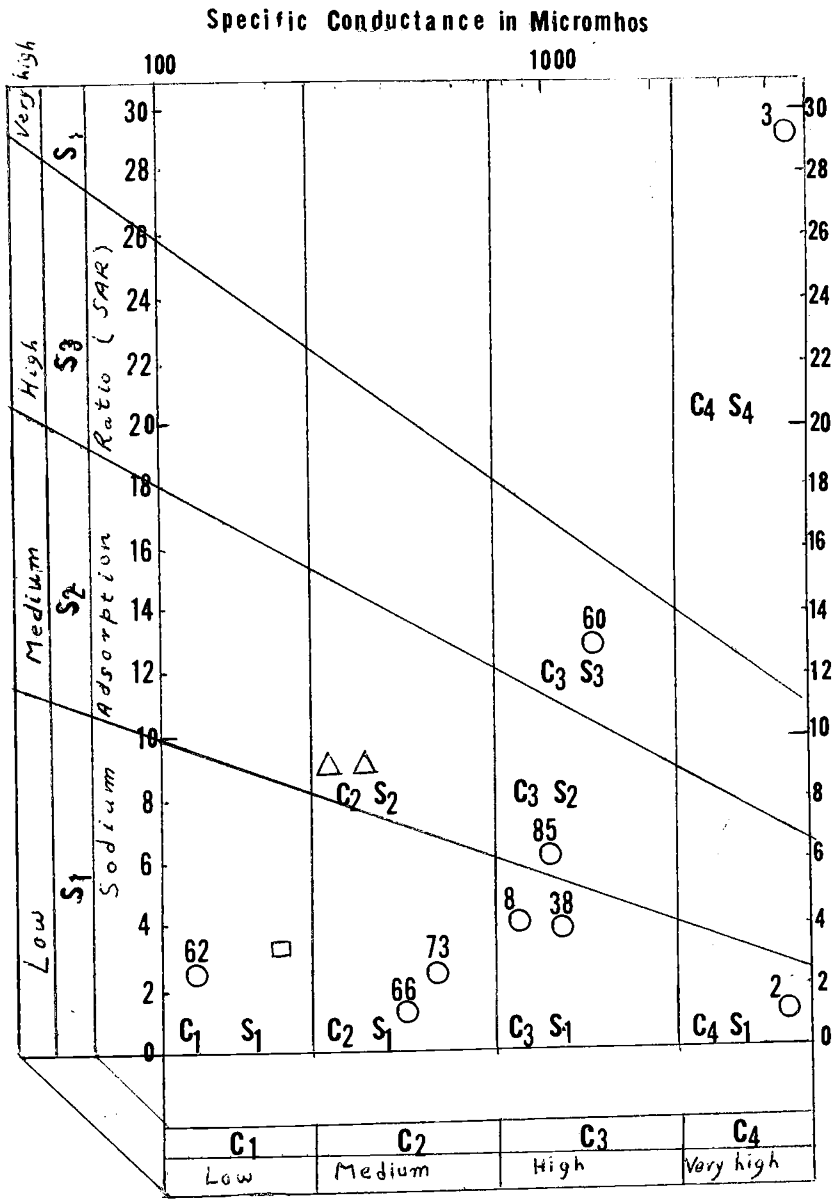



FIGURE 10. SUITABILITY OF THE GROUND WATERS OF THE ZALENGEI AREA FOR IRRIGATION

△ Ground water of W. Azum

□ Ground water of W. Aribo

○ Ground water of Zalengei

1. Excellent Waters (C1S1): These waters can be tapped the valley fill close to W. Aribo. Such type of water can be used on any type of soil and for any crop, without any fear of salinity or alkali hazard.
2. Good Waters: The value of these waters ranges from C2 S1 to C2 S2. Such waters can be tapped from the area close to W. Azum and from the wells dug in the northern and eastern sectors of Zalengei Town. This type of water can also be used in Zalengei area without special practices for salinity or alkali control. The annual rainfall in Zalengei area (650 mm) is enough to leach out any amount of salts built up in the soil during the process of irrigation. However, such water can be safely used to irrigate crops with moderate salt tolerance such as vegetables, regardless of the amount of leaching that occurs every year to the soil.
3. Fair Waters: The value of these waters ranges from C3 S1 to C3 S3. Such waters are tapped in limited quantities from the centeral sector of Zalengei Town. The arable land in this sector of town is rather scarce. However,

water tapped from well no. 8 and 38 in Zalengei Town has a value of C3 S1, and can be used in coarse textured soil and for crops with high salt tolerance. Water tapped from wells no. 85 (value C3 S2) and no. 60 (value C3 S3) can be used on the same type of soil, for the same type of crops, with careful control and frequent addition of gypsum to the soil.

4. Poor Waters with values C4 S1 and C4 S4: These waters are tapped in limited supply from the wells in the western sector of Zalengei Town. However there are no arable lands in this region, as the graphite schist crops out on the surface. Such waters are not suitable and should be avoided as sources for irrigation.

From the preceding, most of the water resources of Zalengei area are of good quality. For comparison, it can be stated that they are as good as the water of the Nile, which is of course, widely used for irrigation.

## Suitability of Water for Domestic Uses

The principal uses of ground water in all the areas far from the Nile in the Sudan are for domestic, stock, and municipal supplies, and only a very small quantity is used for irrigation. In Zalengei area, except for the few months during the rainy season, the people and their cattle depend solely on ground water for drinking purposes for the rest of the year. Water is generally tapped manually from open, brick-lined, permanent wells or by temporarily excavating some of the sand in the wadi bed, till the water is reached.

The general specifications established by Welcome Chemical Laboratories, Sudan Ministry of Health, for drinking water are less strict than the specification used in the United States as far as the amount and type of dissolved solids are concerned. This is due to the limited amounts of good ground water in the Sudan and the relatively high consumption of salts by the human body in the tropical regions. The following specifications have been adopted to indicate the nature of ground water used for drinking purposes.

1. Water should be free from color, turbidity, and unpleasant odor or taste.
2. The total dissolved solids should not exceed 2500 ppm unless there is no better water available, then water containing up to 3500 ppm can be used. For cattle and other live-stock, water containing up to 7000 ppm can be used for drinking purposes.
3. The concentration of certain ions should not exceed the harmful limit such as;

| Constituent | Upper Limit in ppm |
| --- | --- |
| Fluoride as F. | 1.50 |
| Lead as Pb | 0.10 |
| Arsenic as As | 0.05 |
| Selenium as Se | 0.05 |
| Hexavalent chromium Cr | 0.05 |

These limits are mandatory, and any excessive concentration of any of them, constitutes a basis for the rejection of the supply.

Other limits are;

| Constituent | Upper Limit in ppm |
| --- | --- |
| Magnesium (Mg) | 125.00 |
| Chloride (Cl) | 750.00 |
| Sulfate (SO4) | 500.00 |
| Nitrate ($NO_3$) | 50.00 |
| Ammoniacal Nitrogen (N) | 0.06 |
| Albuminoid Nitrogen (N) | 0.10 |
| Total alkalinity ($CaCO_3$) | 650.00 |

Under certain circumstances, water containing up to 1000 ppm of chloride and 750 ppm of sulfate is allowed to be used for drinking purposes.

From the chemical analyses of the ground water of both W. Azum and W. Aribo, it is clear that both waters contain considerably lower amounts of dissolved mineral salts than those quoted in the above standards. All the ion concentrations are also far below the harmful limits. Accordingly, the ground water of both wadis provides excellent sources for drinking and other domestic uses.

From the limited analyses of ground water of Zalengei Town, it can be concluded that the water tapped from the northern and eastern sectors of the town, is suitable for human and animal consumption. The ground water tapped from the central and western sectors of the town, often has a content of fluoride ranging from 1.8 to 3.2 ppm; thus, making it unsuitable for drinking purposes.

## SUMMARY AND CONCLUSION

1. The two geologic formations in the Zalengei area are the Basement Complex of Precambrian age and surficial deposits of Quaternary age. The Basement Complex is formed of graphite schist, mica schist, acid gneiss, meta-quartzite, pegmatites, and quartz veins. The surficial deposits occur as the dry Upper Terrace formed mainly of volcanic materials derived from J. Marra, and as the water-bearing Lower Terrace and Flood Plain formed mainly from minerals derived from the Basement Complex rocks.

2. The annual precipitation over the area is about 650 mm, and mainly falls in a 3 month period from July to September. Fifty mm of this rainfall is expected to infiltrate through the topsoil and recharge the ground water body, while the rest is mainly lost as evapotranspiration.

3. The principal aquifer in the Zalengei area is the alluvium of the Lower Terrace and Flood Plain, The general movement of ground water is westwards downstream of W. Azum. The average slope of the water table ranges from 10 to 12 ft. per mile. The water table reaches its maximum height at the end of the rainy season (September).

During the dry season the water table declines at a rate of about one foot per month.

4. The average transmissivity of the aquifer through the entire area is estimated to be about 100,000 g/ft/d, whereas the average coefficient of storage is about 0.2. The storage of ground water in the reservoir is changeable according to the time of the year. The capacity of the basin during April 1965 was 140,000 acre-feet of water.

5. The ground water tapped from the alluvium in the Zalengei area generally contains low amounts of dissolved solids, mostly bicarbonates and carbonates. The waters tapped from the weathered zone of the Basement Complex usually have considerable amounts of dissolved solids which are mainly sulfates and chlorides. The carbonate rich waters show a gradation in their chemical composition from waters with dissolved calcium and magnesium bicarbonates, such as the water underlying W. Aribo, to waters with dissolved sodium carbonates and bicarbonates, such as the water underlying W. Azum. The ground water underlying W. Azum is a blend of the waters of its tributaries and the water of the Large Dariba Lake occupying the crater of J. Marra, which has a fluoride content of 100 ppm, the highest yet known in natural waters.

6. The future agricultural development of the Zalengei area is promising. The amount of arable land is about 7,200 acres. The amount of ground water needed to irrigate these lands is about 21,600 acre ft. per year. This water constitutes about 16 per cent of the storage capacity of the ground water reservoir in the Zalengei area. About 20 per cent of the amount of ground water needed for irrigation can be recharged to the ground water body from rainwater through infiltration, whereas the rest can be recharged from the wadis during flood time.

7. Most of the water resources of Zalengei area are of good to excellent quality and can be used safely for irrigation and domestic uses.

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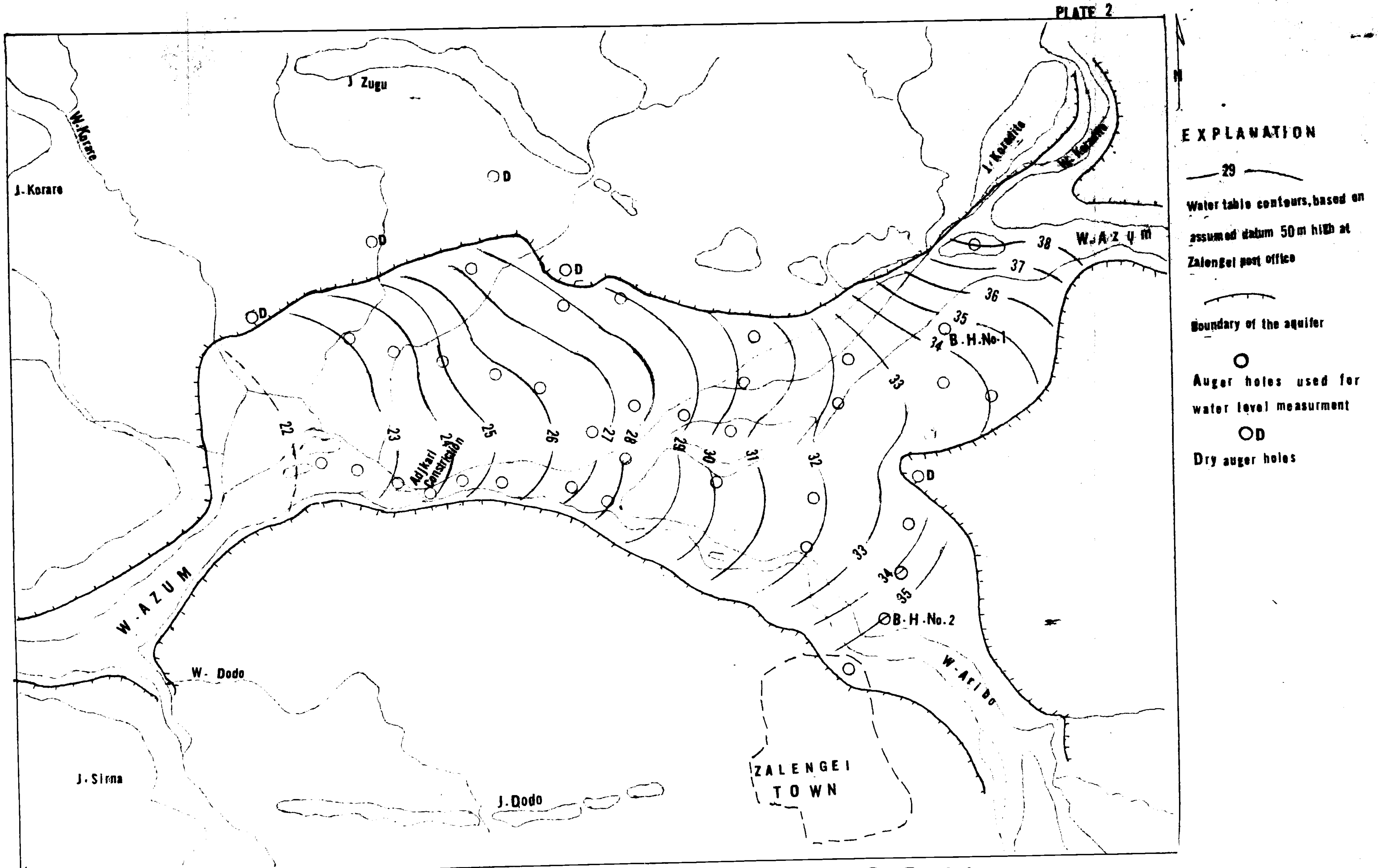
E9791
1967
114

PLATE 2




# MAP OF ZALENGEI AREA SHOWING GENERAL WATER-TABLE CONTOURS

April 1965

Scale

1:40,000

0 1 2 Km

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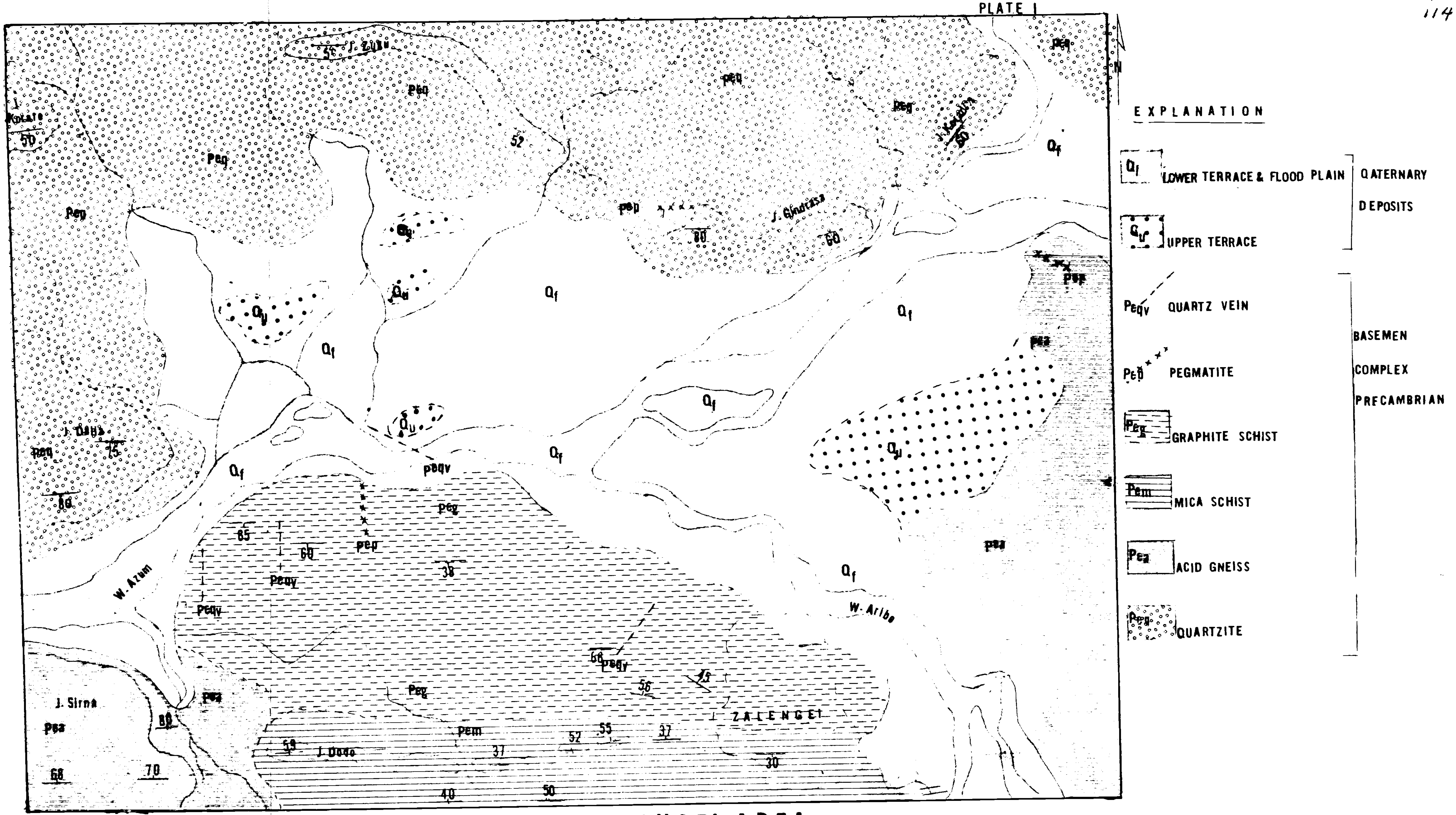
1967
114

PLATE I




# GEOLOGIC MAP OF ZALENGEI AREA

Scale

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0 1 2 Km

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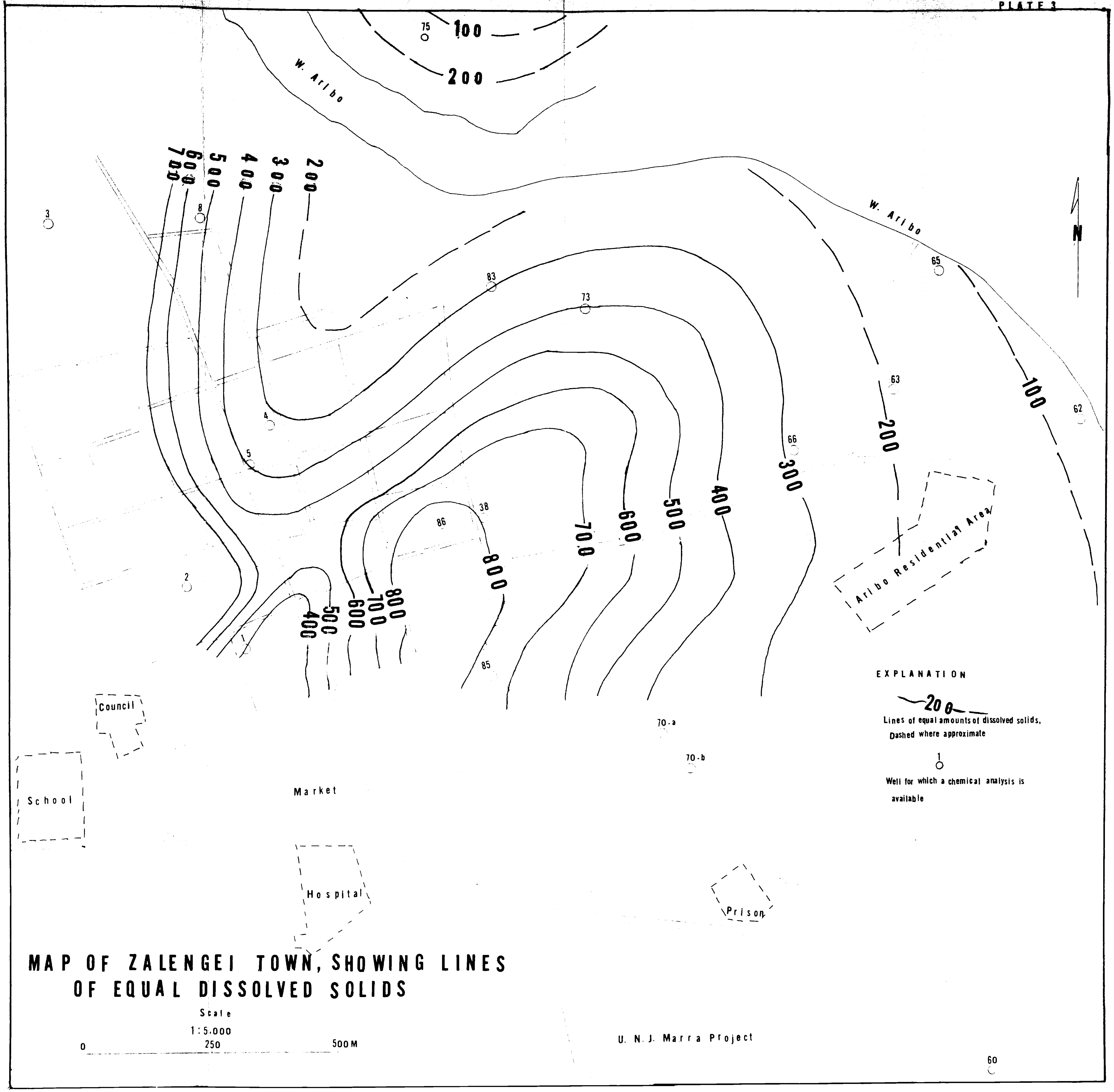
PLATE 3




# MAP OF ZALENGEI TOWN, SHOWING LINES OF EQUAL DISSOLVED SOLIDS