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MINISTRY OF WATER DEVELOPMENT

WATER RESOURCES ASSESSMENT STUDY
KERIO VALLEY
(Elgeyo Marakwet & Baringo Districts)

MAIN REPORT

APRIL 1984

WATER RESOURCES DEPARTMENT
NAIROBI, KENYA

GROUNDWATER SURVEY TNO
DELFT, THE NETHERLANDS

SUMMARY

Background information

Project

The Water Resources Assessment Project (WRAP) is being carried out jointly by the Water Resources Branch of the Ministry of Water Development and the TNO Institute of Applied Geoscience, within the framework of the technical development co-operation between the Governments of Kenya and the Netherlands. The main objective of the project is the training of the Kenyan professionals and technicians in techniques of water investigations through the assessment of the quantity and quality of the available water resources in a number of selected areas. This report deals with the Kerio Valley, a semi-arid area in the Rift Valley Province, Western Kenya. The area of investigation includes the upper and central part of the Kerio River catchment, covering approximately 4000 km². The area lies for the greater part in the Elgeyo Marakwet and Baringo Districts. The present population is estimated to be 135 000.

Physiography

The physiography of the Kerio Valley reflects its complex geological history, which is closely related to the forming of the East African Rift System. On the western side, the Kerio Valley Basin is separated from the high Uasin Gishu Plateau by the steep Elgeyo Escarpment. To the east the valley is bordered by the Tugen Hills.

Geology

The geological base of the Kerio Valley is composed of Precambrian metamorphic rocks which are overlain by intermediate and basic Tertiary lavas interbedded with tuffs and sediments. A thick sedimentary cover of clayey floodplain sediments developed on the lavas during the Quaternary. The area is characterized by numerous faults of different magnitude and trend.

Soils

Most of the soils in the Kerio Valley are sufficiently rich for cultivation; however, because of the lack of water most land is still used for stock-rearing only.

Climate

The climate varies with altitude. Two distinct climatic zones can be distinguished. The climate on the floor of the Kerio Valley can be described as semi-arid, with high temperatures, high evaporation rates and relatively low rainfall. The climate of the higher areas (over 1500 m) can be described as highland sub-tropical, with lower temperatures, lower evaporation rates and higher rainfall.

Network of meteorological stations

The network of meteorological stations in the higher parts in and around the Kerio Valley required some rehabilitation. The sparse network on the valley floor was expanded with four new rain-gauge stations and five evaporation pans. Missing data on rainfall and evaporation and poor records were estimated by correlation analysis.

Rainfall

Long-term monthly averages and standard deviations were calculated for 11 rain-gauge stations, using records from 7 to 27 years. The high standard deviations indicate large fluctuations in monthly rainfall from year to year. Monthly or seasonal minimum average rainfall appears to be somewhat unpredictable. Most of the rainfall occurs from April to August, and in November, with less rainfall in June. The average annual rainfall varies between 1200-1600 mm in the elevated parts of the area. On the valley floor, average annual rainfall totals decline gradually from approximately 1200 mm at Kimwarer to 800 mm at Tot. Rainfall during 1982 was extremely heavy: for nine of the twelve rain-gauges the recorded rainfall surpassed totals that had a 90% probability of not being exceeded. The 1983 rainfall proved to be close to average.

Rainfall map

A map showing the long-term average rainfall was prepared.

The isohyets are based on the updated long-term (1958-1976) average annual rainfall data of 11 analysed rain-gauge stations, supplemented with data from less reliable or abandoned stations.

Evaporation

Long-term monthly average evaporation and standard deviations were calculated for six evaporation stations. The highest monthly

evaporation generally occurs during the period between December and April, peaking in March. There is a clear correlation between altitude and evaporation. At higher altitudes seasonal variation is much greater than at lower altitudes: annual evaporation is between 1200 - 1400 mm at Cherangani Forest and the higher parts of the area but in the valley the annual evaporation for 1982-1983 increases from 2300 mm at Kimwarer to approximately 2500 mm at Tot.

Surface water resources

Hydrology of the Kerio Valley

From its source in Metkei Forest the Kerio River flows some 500 km northwards before discharging into Lake Turkana. The total catchment area covers circa 17 800 km². The river course can be divided into three regions: the upper, middle and lower reaches. The project activities were mainly concentrated on the upper and middle reaches, as far as Tot, covering a catchment area of approximately 4000 km². The hydrological map prepared gives comprehensive information about the various catchment areas and the drainage pattern.

Little water is lost by sub-surface infiltration. Except for the mountainous forest area, surface water runoff is high, as indicated by the high drainage density. There are only four perennial tributaries: the Kimwarer, Mong, Torok and Arror rivers. The Kerio River itself is intermittent. High losses from evaporation cause the river to dry up between Chebloch and the confluence with the Arror towards the end of the dry season.

River gauging stations

To extend the existing hydrometric network, four automatic level recorders were installed and three staff gauge stations were rehabilitated. Flow measurements were intensified and during the rainy season a number of peak flow measurements were carried out. Alternative methods for peak flow measurements were introduced to overcome the lack of suitable equipment such as cableways. The monitoring of the present hydrometric network should be continued, to facilitate future analysis of the surface water potential.

Discharge rating curve

Discharges were measured regularly to establish rating curves for the four automatic water-level recorders. Three different methods were used simultaneously to measure discharge: current meter, float, and the so-called "slope-area" method.

New rating curves were prepared for three stations, and two rating curves were updated. In general the rating curves show a high correlation. However, to improve the accuracy, especially when the river is high, more peak flow measurements are required. The calculated outflows from the catchment areas between the two consecutive river gauging stations are not wholly consistent, indicating that the rating curves for the upstream and downstream stations are not completely in equilibrium. Unavoidable inaccuracies in the two rating curves accumulate in the outflow estimate for the intermediate catchment area.

River flow characteristics

During the rainy season the river discharges are characterized by flash floods. The river flow shows extreme fluctuations from hour to hour. There is very little time lag between rainfall and runoff. Peak flows at the established river gauging station generally occur at night. Runoff figures based on daily staff gauge readings are therefore considerably underestimated. The actual daily flow calculated from hydrographs is 2 - 20 times the estimated flow based on daily staff gauge readings. For annual flows the underestimation ranges between 30 to 40%.

The maximum instantaneous flow observed in the period 1982-1983 was 230 m^3/s at Tot. Zero flow was observed at Chebloch and Kinyach for a period of four weeks during March-April 1983. On the Arror River the maximum and minimum flows were 38 and 0.5 m^3/s respectively.

The ratios of annual runoff and rainfall decrease from approximately 0.28 at Chebloch to 0.13 at Tot. For the Arror River the ratio is 0.23.

Lake Kamnarok

Lake Kamnarok on the eastern bank of the Kerio River is a small lake that occassionally receives flood water during the wet season and empties for a great deal during dry periods. The lake has been the subject of some studies of the feasibility of enlarging its storage capacity, but no clear conclusions can be drawn from these.

Surface water balance

Calculation for the total groundwater outflow to the north indicate that the annual groundwater recharge from percolating rainfall is in the order of less than 1‰ of the total annual rainfall. The evapotranspiration in the valley is high, approximately 900 mm annually, which is about the same amount as the mean annual rainfall on the valley floor.

Surface water quality

The quality of the surface water was monitored at 21 sampling sites. The total content of dissolved solids (TDS) in the majority of samples did not exceed 100 mg/1. The water is of $Na\text{-}HCO_3$ or $Ca\text{-}HCO_3$ type. The TDS content of water in the Kerio River is inversely proportional to the total discharge.

No fluoride pollution from the Fluorspar Mines was observed in the Kerio River during the sampling dates between November 1982 and October 1983. At all sites, except one, the fluoride concentration did not exceed the WHO limit of 1.5 mg/1. Only in samples from a spring in the Tugen Hills was a high concentration (up to 9 mg/1) found.

Generally speaking, the anorganic quality of the surface water in the Kerio River, its major tributaries and Lake Kamnarok is good. The direct use of surface water for drinking purposes may be limited by the high suspended load content and possible organic pollution (no data are available on the latter).

Groundwater resources

Exploration for groundwater

Sites for test drilling were determined by geological methods and surface geophysical methods. The geological methods included aerial photo interpretation and ground reconnaissance surveying. The geophysical investigation mainly involved measuring the resistivity, with some additional seismic surveys. Thirteen boreholes were drilled with percussion rigs, to a maximum depth of 125 m. The transmissivity of aquifers and the yields of boreholes were tested either by a well test or a bailer test. Groundwater samples were collected for chemical analysis.

Occurrence of groundwater

Under the given hydrogeological conditions, the groundwater in the Kerio Valley occurs in four aquifer systems:

1. System comprising the fractured and weathered volcanics with interbedded sediments (1a) and the Kerio Valley sediments (1b).

2. System of torrent-wash deposits (scree fans) occurring along the Elgeyo Escarpment (2).

3. Alluvial system comprised of coarse, recent deposits which developed locally along the Kerio River (3a) and its tributaries (3b).

4. System of fractured and weathered Basement rocks (4).

System (1) can be considered as a regional one; the other three systems are of local importance only.

Regional aquifer system

The clayey character of the Kerio Valley floodplain sediments prevents vertical recharge. The groundwater in this system is mainly recharged through the fractures in volcanic rocks. The system is confined and the groundwater is interconnected via fractures and layers of coarse sediments. The transmissivity values vary between 1 and 36 m^2/day for the volcanics and between less than 1 and 15 m^2/day for the sediments. The boreholes situated in volcanic rock generally have higher yields than those in sediments. Seven of the ten boreholes drilled in this system had water rest levels within 30 m of the surface. This relatively shallow depth opens up the possibility of using hand pumps.

Local aquifer systems

Only a few hydrogeological data are available to describe the local aquifer systems.

The system of torrent-wash deposits (2) occurring along the Elgeyo Escarpment is recharged directly by rain or through surface water infiltration. One borehole was drilled in this system. The available data indicate an aquifer with a relatively high transmissivity (80 m^2/day) and shallow groundwater table (14 m below surface).

The shallow alluvial systems (3), which developed locally along the Kerio River and its tributaries, may have high transmissivity values, as indicated in the borehole near Tot. The Basement rocks contain isolated groundwater bodies (system 4) confined in the fractured and weathered zones. A transmissivity value of 9.0 m^2/day was obtained from one well test.

Groundwater balance

Groundwater outflow was estimated for 3 sections in the regional aquifer system. The groundwater outflow at Chebloch is circa 0.20 x $10^6 m^3$/year which indicates very low recharge (0.1%). The recharge between Chebloch and Kinyach and between Kinyach and Tot is even lower (less than 0.05%). At Tot the total groundwater outflow is circa 0.40 x $10^6 m^3$/year. Assuming that 50% of this amount is exploitable, the safe yield of the regional aquifer system amounts to only 0.2 x $10^6 m^3$/year. The exploitable amounts of groundwater in the local aquifer systems were roughly estimated from the geometry of these systems. The figures of 1.0 x $10^6 m^3$/year and 1.7 x $10^6 m^3$/year were obtained for the torrent wash system and the alluvial system respectively. However, these figures should be considered as an indication about the order of magnitude only.

Groundwater quality

Groundwater in the Kerio Valley is either of sodium-bicarbonate or magnesium-bicarbonate type. A high TDS content and high fluoride concentration are the factors limiting the potability of groundwater.

Two of the 13 newly drilled boreholes contain slightly saline water with a TDS content above the recommended WHO limit.

In four fresh-water wells the fluoride concentration exceeds the WHO limit of 1.5 mg/l. It means that water from 6 boreholes is not suitable for human consumption.

The high fluoride concentrations are not confined to volcanic rocks; they were also found in the Kerio Valley sediments and alluvial aquifers. Chemical and bacteriological analyses of groundwater are essential before hand pumps are installed.

Water resources assessment

Water supplies

The number of existing water supplies in the project area is limited. At present, surface water is the major source: it is abstracted from rivers and springs. The only groundwater supply is at Kabarnet. The Kabluk borehole is still not operational.

Water Demand

The water demand for the present (1984) human and livestock consumption, and for the demand in the year 2000, was calculated. At present domestic demand is 1.2 million m^3/year, increasing to 2 million m^3/year by 2000.

The existing water supplies satisfy approximately 15% of the present demand. Traditional supplies largely satisfy the remaining demand. However, safe water supplies should be constructed for the whole population, to reduce the risk to health inherent in using traditional sources.

Availability of water resources

Groundwater resources in the greater part of the valley are limited. Only circa 0.2 x $10^6 m^3$ can be recovered annually from the regional aquifer system. At the present rate of daily water demand, a maximum of 27 500 people can be supplied with drinking water of variable quality from this system. Larger amounts of groundwater can be recovered only along the Escarpment and in the narrow belt along the Kerio River. The safe yield at these parts is estimated at 2.7 x $10^6 m^3$/year.

As for the surface water, the total volume of outflow from the valley at Tot amounts to circa 300 - 500 x $10^6 m^3$. Similar to groundwater, the surface water is not evenly distributed over the area.

The use of surface water depends greatly on the minimum flows from permanent streams, on the duration of the dry spell between two consecutive periods of river flow for non-permanent streams, and on the availability of suitable sites for intake structures and for small or large reservoirs. If the surface water potential for domestic use and cattle watering and for irrigation and hydropower is to be assessed properly, these aspects still have to be studied in detail: different specific requirements have to be fulfilled for each purpose.

A water availability map was prepared to indicate the regional distribution of the water resources, using three categories of water availability: areas of high, medium or low potential.

Water development opportunities

The opportunities to develop groundwater are principally restricted to hand-pumped wells. Assuming an annual production of 2000 m^3, the available groundwater will be sufficient for circa 1450 hand pumps, unevenly distributed over the area. The best opportunities to develop groundwater are in the alluvial aquifers along the Kerio River where circa 850 shallow wells can be constructed. Each of these dug wells will cost approximately KShs.20 000/=. Additional investigations are required for each location. In the other parts of the valley, medium deep to deep boreholes are necessary to exploit the aquifers. In the scree fans along the Escarpment, the estimated amount of groundwater will be sufficient for circa 500 hand pumps. However,due to the limited area extent and unfavourable locations of some scree fans this number may be too optimistic.

Approximately 800 km^2 of the regional aquifer system has been identified as high to medium potential area for groundwater development. Sustained yield in this aquifer is sufficient for circa 100 hand pumps. This implies a maximum borehole intensity of one borehole per 8 km^2 or a borehole spacing of minimal 3 km. Each hand pump could supply approximately 300 people and would require an initial investment of about KShs.80 000/= including drilling costs. Detailed site investigations are required for each proposed location.

Ample opportunities are available for the development of surface water for domestic use and cattle watering, even for large-scale irrigated agriculture and hydro-electric power. However, the latter two were not considered by the WRAP study. Less costly development of surface water is possible, such as small reservoirs for cattle watering on the valley floor and sand dams with shallow wells in the river beds of intermittent streams. To bridge the dry spell between the main rainy seasons, the latter occuring in November and April, a total storage capacity of 0.3 x $10^6 m^3$ would be required for cattle-watering only, taking into account evaporation losses of 800 mm. Cattle watering could be guaranteed by 10 - 20 small reservoirs of approximately 8000 - 25 000 m^3 each, costing roughly between 100 000 and 200 000 Kenya Shillings. Properly dimensioned spillways are required to prevent overtopping of the embankment.

To guarantee domestic water supply and the supply for small-scale irrigation from surface water, detailed investigations of the various possibilities are required. In most of the area the surface water required is available, but a cost-benefit analysis is always necessary to identify the most feasible method of diverting water to a specific location.

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1. INTRODUCTION

1.1 Scope of the project

The Water Resources Assessment Project (WRAP) is jointly carried out by the Ministry of Water Development and the Institute of Applied Geoscience TNO (The Netherlands). The project is executed in the framework of the technical development co-operation between the governments of Kenya and The Netherlands.

Besides training of Kenyan professionals and technicians in the techniques of water investigations, the project aims to assess the available water resources in selected areas.

This report is dealing with the regional assessment of the quality and quantity of the water resources in the Kerio Valley, an area mainly located in Elgeyo Marakwet and Baringo Districts (Figure 1.1).

In June 1983 a Progress Report was issued for the investigations in Kerio Valley. The results were presented in two technical meetings in Nairobi and Eldoret.

Based on critical comments, many new data and a further analysis of data, this Main Report is a completely revised edition. The WRAP team involved in the related field and office work is listed in Annex 1.1.

1.2 Description of the project area

The area of investigation includes the upper and middle part of the Kerio River catchment. It is bounded approximately by the parallels 0°15'N and 1°30'N and the longitudes 35°30'E and 36°00'E (Figure 1.2). The total area amounts to about 4000 sq km.

Four physiographical units can be distinguished: the Elgeyo escarpment, the head of the Kerio Valley, the Kerio Valley proper and the Tugen Hills.

The east facing Elgeyo escarpment forms the western margin of this part of the Rift Valley and separates the Uasin Gishu Plateau from the Kerio Valley. The altitudes of the escarpment crest varies between 2300 and 2750 m above mean sea level (m.s.l.), while the elevations at the foot of the escarpment descends from 1370 m at Kimwarer in the south to 940 m above m.s.l. at Tot in the north. The total length of the escarpment is approximately 110 km.

The head of Kerio Valley is composed of numerous chains of low hills and ridges, divided by steep gorges. The gradient of the headwater of the tributaries, draining the Metkei Highlands is very steep. From Kimwarer northwards, the Kerio River meanders in a flat plain with an elevation close to 1000 m above m.s.l.

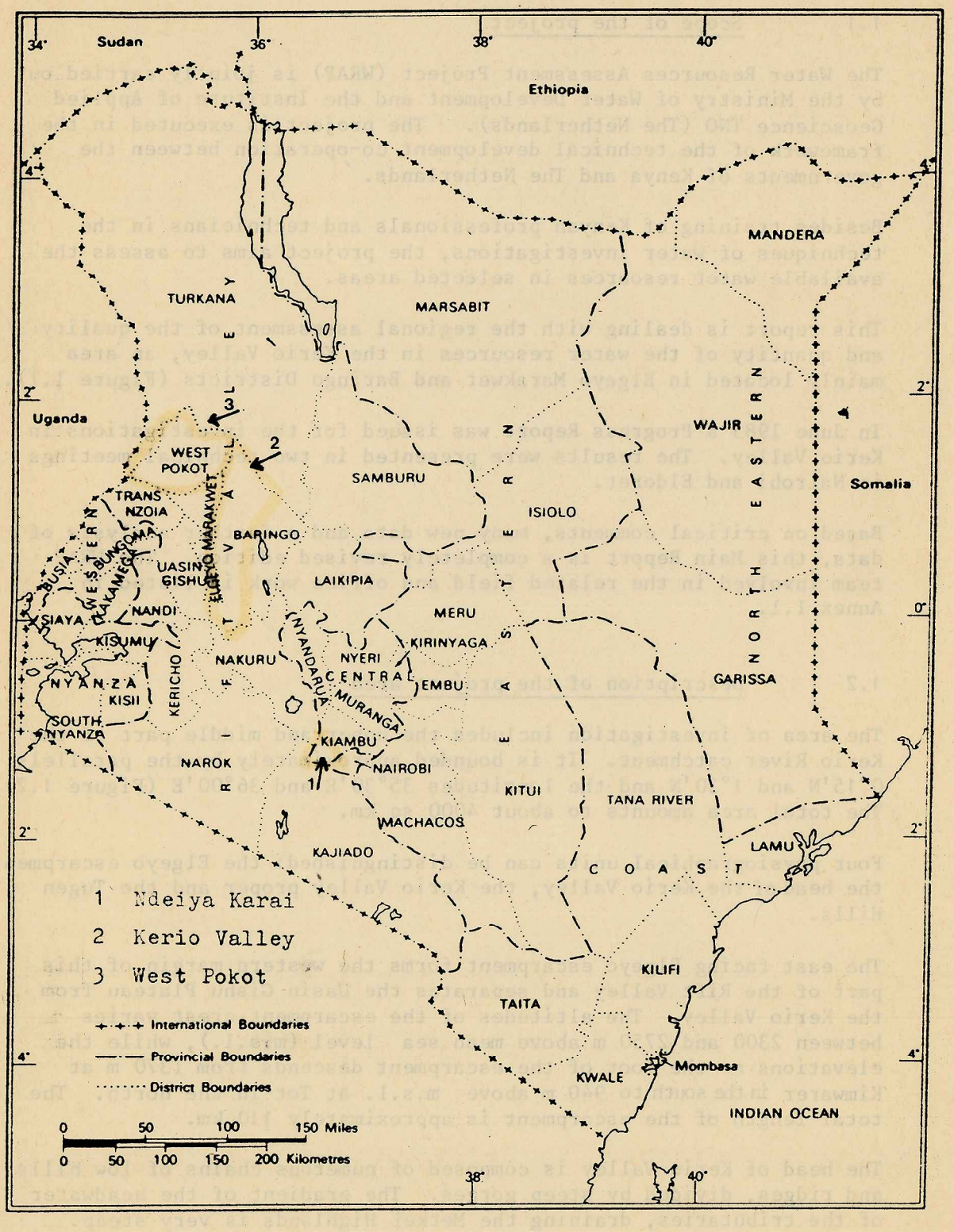


Figure 1.1 Location maps of the areas investigated by WRAP (map from Ojany and Ogendo, 1981).

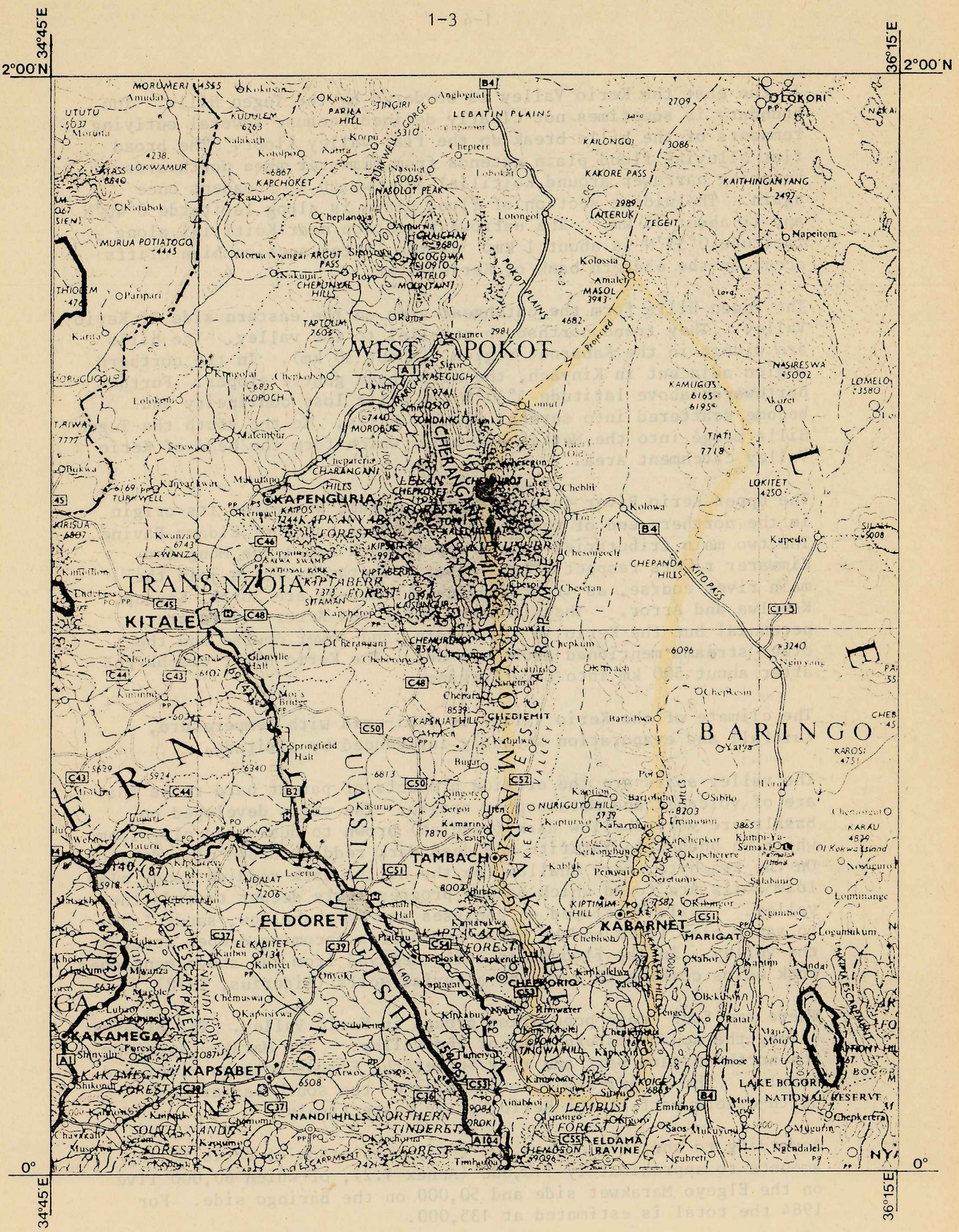


Figure 1.2 Kerio Valley project area
(from Kenya Route Map, Survey of Kenya; scale 1:1.000.000)

In the east the Kerio Valley is bordered by the Tugen Hills. The boundary is sometimes not clearly defined because several outlying remnants of the hills break up the flat valley floor. The broad flat alluvial flood plain extends from Kimwarer area northwards becoming narrower around Koitilial afterwhich it broadens once again. The widest section of flood plain is along latitutde 0°40'N and is about 15 km. The narrowest section near Koitilial along latitude 0°55'N is about 1 km. In the latter section high cliffs occur on the eastern bank of Kerio River.

The Tugen Hills form the catchment area on the eastern side of Kerio Valley. They trend northsouth parallel to the valley. The hills are widest in the Kabarnet region, (about 30 km). In the northern region adjacent in Kinyach, the hills have gentle slopes. Further northwards above latitude 1°30'N the hills lose continuity and become scattered into several remnant hills. To the south the Tugen Hills merge into the Metkeí Highlands which form the head of Kerio Valley catchment area.

The Upper Kerio River is a perennial stream, which has its origin in the northern end of the Metkeí Highlands north of Eldama Ravine. The two main tributaries in the upper reach are : the Mong and Kimwarer rivers respectively. Other tributaries which join the main river course, as it progresses northwards are Torok, Kessup, Kabulwa and Arror. The Kimwarer, Torok and Arror Rivers are perennial but the Kerio in its middle and lower course and the other streams mentioned above are not. The Kerio River discharges after about 500 km into Lake Turkana.

The climate of the Kerio Valley is semi-arid with temperature, rainfall and evaporation strongly influenced by altitude.

The valley soils are the erosion products of parent hard rocks that are of volcanic and metamorphic origin. The soils developed on basalt are very shallow dark (reddish) brown to dusky red clay loam while on phonolite laterite and deep dark reddish brown clay develop. On the trachyte, very shallow (on the hills) dark reddish sandy clay loam soils are found which become progressively deeper towards the valley. Soils developed on gneisses are very shallow, sandy loams to sandy clay loams on the hills and scarps becoming deeper towards the valley. In the floodplain soils derived from the above mentioned rock units combine to form the alluvial soils (Siderius, 1978).

There are four main population groups in Kerio Valley. The Elgeyos occupy the south-western part of the valley. The Marakwets occupy the north-western part and they border the Elgeyos between Rimoi and Kabulwa. The Tugens and Pokots dominate the south-eastern and north-estern part of the Kerio Valley respectively.

According to the 1979 census the total population of Kerio Valley amounts to approximately 110,000 (Annex 1.2), of which 60,000 live on the Elgeyo Marakwet side and 50,000 on the Baringo side. For 1984 the total is estimated at 135,000.

In figure 1.3 the population density is presented. High densities are found along the northern part of the Elgeyo Escarpment and in the southeastern part of the Kerio Valley in the Tugen Hills. The lower part of Kerio Valley and the northeastern part are very sparsely populated.

Stockrearing is the main occupation for the people in the semi-arid lower areas of the Kerio Valley. The rearing of livestock provides cash, meat and milk. Large herds of goats and sheep are kept over the valley. Cultivation is mostly along the water courses where small patches of maize, cassava, beans, sorghum, millet, cotton, groundnuts and bananas grow. In the hilly sections of the Elgeyo Escarpment people keep fewer stock and concentrate on intensive cultivation by means of small scale irrigation.

Poor communication hinders development in the valley. The few existing roads are generally poor and impassable in rainy seasons. The schools are few and health facilities are most absent, except for some dispensaries.

The Fluorspare Mine at Kimwarer is the only major industrial enterprise in the Kerio Valley. It employs about 500 people in its mining activities. Fluorite deposits were discovered in Kerio Valley in 1968. Commercial production started in 1974. The mine is exploited by the Kenya Fluorspare Company.

The number of water supplies in the project area is very limited. All existing water supplies are gravity systems, using surface water. There are no production wells yet in operation in the valley.

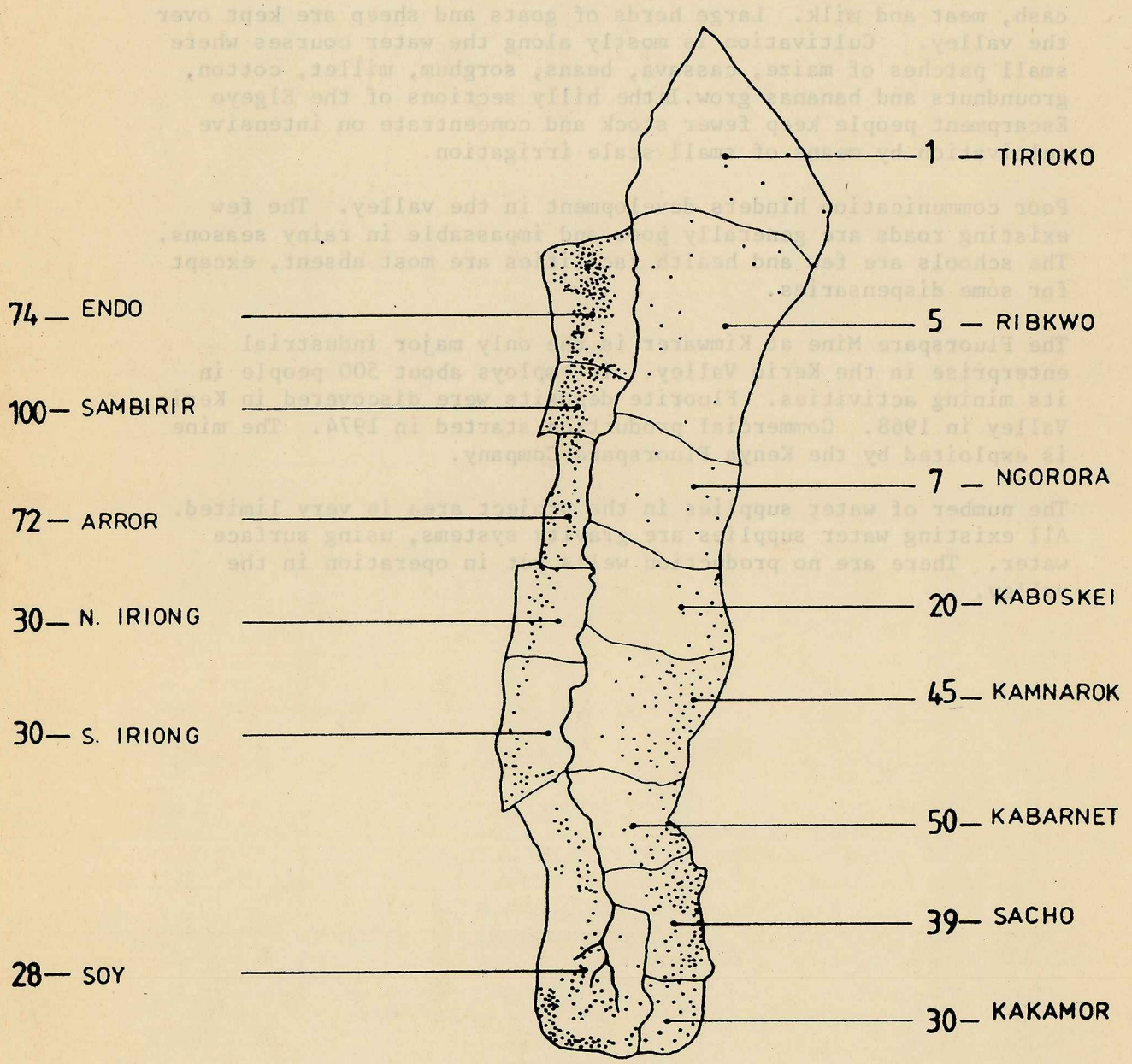


Figure 1.3 Population density in Kerio Valley (Census 1979)
Figures denote the population density per square km. Each dot represents 1000 inhabitants

2. GEOLOGY

2.1 Previous geological studies

In 1957, the Geological Survey of Kenya published a report which described the geology of Kalossia-Tiata area (Mason and Gibson,1957), in the northern most part of the project area. Another geological report by Walsh (1969) describes in detail the southern tip of the Kerio Valley. In the period 1965-70, the Kerio Valley has been geologically mapped by the East African Geological Research Unit (EAGRU), directed by Professor B.C. King. Several unpublished Ph.D. theses have been written in this research (Martyn, 1969; Chapman,1971; McClenahan, 1971; Webb, 1971 and Lippard, 1972). Based on the results of these works, three new geological maps on 1 : 250 000 scale have been issued (EAGRU, 1973; 1978 a,b). These maps cover the area between the Equator and latitude 1°30'N. As yet, no accompanying reports have been published for these maps. A detailed geological study; concerning the fluorite deposits in the Kerio Valley was carried out by Nyambok (1973) and Nyambok and Gaciri (1975). The most recent studies related to the geology of the Kerio Valley are the Landsat interpretation of the southern Kerio Valley by Rivereau (1981) and geophysical measurements carried out by Swain, et al (1981).

2.2 Geological history

The geological history of the Kerio Valley is closely related to the formation of the East African Rift System. The original shape of Kerio Valley basin followed the Sub-Miocene surface erosion (Lippard, 1972). In the successive geological periods, the Basement rocks were deformed by broad downwarping into a series of domes and depressions.

In some of these depressions sediments were laid down (e.g. Kimwarer formation and Tambach formation). The first large volcanic eruptions occured in Middle Miocene producing plateau lavas (e.g. Uasin Gishu phonolites). In Late Miocene the first movement along the Elgeyo Fault occured producing the scarp. After the formation of the Elgeyo Fault the basin was filled with layers of volcanic rocks, flowing from the east (Tiim and Ewalel phonolites). These rocks were strongly affected by the first "main" faulting period in Lower/Middle Pliocene, when renewed activity started on the Elgeyo Fault and which initiated the formation of the Tugen Hills (Lippard, 1972). During the Middle Pliocene several series of volcanic rocks (Eron basalts and Kabarnet trachytes) flowed into the basin from the east. The present form of the Kerio Valley basin was completed in the Quaternary, during the second "main" tectonic espisode, resulting in further movements on the Elgeyo and Tugen Faults and back tilting of the (western) Uasin Gishu block. From that time on no volcanic rocks have been laid down. but thick layers of sediments were deposited in the Kerio Valley. The present landform in the Kerio Valley basin reflects also the erosional processes in the area.

A schematic geological cross-section of Kerio Valley is shown in Figure 2.1.

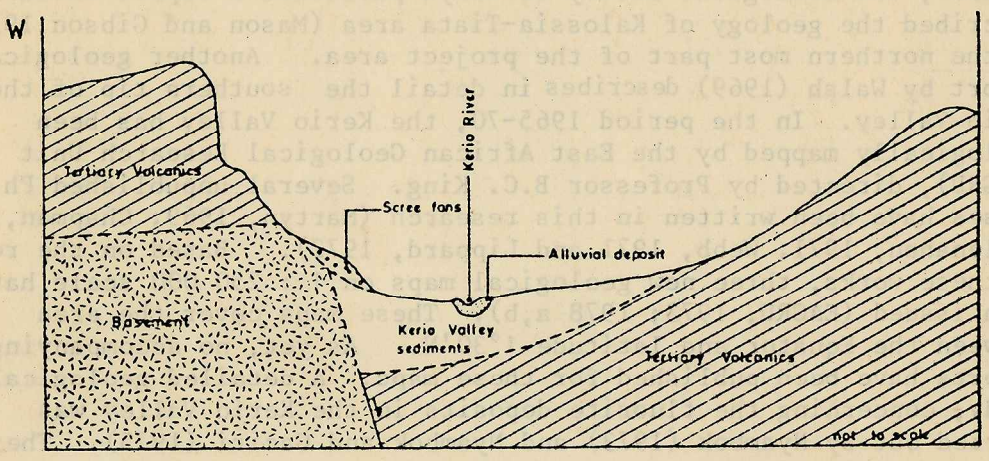


Figure 2.1 Schematic geological cross-section of Kerio Valley.

2.3 Stratigraphy

The stratigraphical description is mainly based on the new geological maps (EAGRU 1973 ; 1978 a,b), thesis by Lippard (1972) and geological reports Nrs.41 (Mason and Gibson, 1957) and 83 (Walsh, 1969). According to these references, the rock formations of the Kerio Valley can be divided into three groups:

- Precambrian rocks of Basement system
- Tertiary sediments and volcanics
- Quaternary deposits

The distribution of the rock formation in the project area is shown on the geological map (Plate 2.1). The summary on the lithostratigraphy and corresponding waterbearing properties is given in Table 2.1.

Table 2.1 Lithostratigraphic table and water bearing properties of the rocks.

PERIOD	EPOCH	FORMATION: Elgeyo Escarpment Sequence	FORMATION: Kerio Valley & Tugen Hills Sequence	THICKNESS (m)	LITHOLOGY	HYDROGEOLOGICAL CHARACTERISTICS
QUATERNARY	PLEISTOCENE - RECENT		Scree fans	50	boulders, gravel, sand clay	water bearing layers, separated with semi- permeable layers
			Kerio Valley Beds	600	silt, sand, gravel	
TERTIARY	MIDDLE PLIOCENE		Kabarnet Formation	650	trachytes; inter bedded with sand, gravel, silt	water bearing in weathered and faulted zones
			Eron Basalts	250	basalts	
	LOWER PLIOCENE		Ewalel Formation	450	phonolites, tuffs	
			Ngorora Formation	?	tuffs, shales, sandstones, conglomerates	?
	UPPER MIOCENE	Uasin Gishu Phonolites	Tiim Phonolites	950 350	phonolites	water-bearing in weathered and faulted zones
		Tambach Form / Chof Phonolites	Sidekh Phonolites	350 ? / 350	conglomerates, shales, sands, clays, tuffs (Tambach) phonolites	?
	MIDDLE MIOCENE	Elgeyo Formation	Kapchererat Basalts	550 ?	Basantites, basalts	
		Kimwarer Formation	Turkana Grits	50 ?	conglomerates, sand-stones, siltstones	waterbearing
PRE CAMBRIAN		Basement System		?	gneisses quartzites marbles	waterbearing in weathered zones and open faults

In the following sections a brief description of the major rock types is given. For a more detailed lithostratigraphical description see Annex 2.1.

2.3.1 Basement system

The Precambrian Basement rocks are the oldest rocks in the area. They comprise principaly of the various types of sediments which were transformed by a regional metamorphism into gneisses, schists, quartzites and marbles. The Basement rocks outcrop on the western side of the Kerio Valley along the Elgeyo Escarpment and on the eastern side on the slopes of Tiati Hills. In the Kerio Valley proper, the Basement rocks are covered by volcanics and sediments of variable thickness. The Basement rocks appear on the surface again in the northernmost part of the valley.

2.3.2 Tertiary sediments

The earliest Tertiary rocks in the Kerio Valley are represented by conglomerates, sandstones and siltstones which were laid down in a depression, south of Kimwarer during Middle Miocene. Comparable sediments occur also in the northern most part of the project area. Other Tertiary sediments are exposed along the Escarpment section near Tambach. They consist of conglomerates, shales, sandstones and clays. The outcrops of above sediments have only a limited extent.

The largest outcrops of Tertiary sediments, found in the area, are composed of shales, sandstones and conglomerates which were deposited during Upper Miocene and Lower Miocene. These sediments occur in the surroundings of Barwesa, Poi and Kinyach.

2.3.3 Tertiary volcanics

The volcanic rocks in the Kerio Valley are products of eruptions which took place from Middle Miocene till Middle Pliocene. The volcanic rocks are represented by basic lavas (basalts) and intermediate lavas (phonolites and trachytes). The lavas originated in several flows and are interbedded with tuffs and sediments.

In the south of the area, basalts occur along the head of Kerio Valley and in the surroundings of Cheplembus. In the north, stratigraphically younger basalts are found along the Ngoron River, north of Kolowa.

The phonolites, which cover the Uasin Gishu Plateau, form the top of the Elgeyo Escarpment up to 0°55'N. Outcrops of phonolites occur also at southernmost part of the valley and southeast of Kabarnet on Tugen Hills side. In the north, the phonolites outcrop along the eastern bank of the Kerio Valley between 0°05' and 0°25'N.

The trachytes are the youngest volcanic rocks in the areas. They cover a large area on the eastern side of the valley between 0°15' and 1°N.

The lithostratigraphical description of volcanic rocks is given in Annex 2.1.

2.3.4 Quaternary deposits

The fill of Kerio Valley comprises the flood-plain sediments (Kerio River Beds), which were laid down during late Pleistocene and Recent age. The deposits consist of silts and clays with coarse, poor-sorted lenses of torrent wash. They cover an area of about 1200 km², extending from Kimwarer to a location slightly north of Tot. Small patches of alluvial sands and gravels developed near all major rivers.

Several scree fans developed along the Elgeyo Escarpment between Kimwarer and Koitilial. They consist of massive wedge shaped fans of coarse landslip material, which includes big boulders. They are younger than the Kerio River Beds.

2.4 Mineral deposits

Except the fluorite, no mineral deposits of economic value are mentioned in the published geological reports.

The fluorite occurs as a vein mineral both in the Basement and volcanic rocks. The deposits,which are believed to be Tertiary in age, follow the structural pattern in the Basement rocks or fault zones in the Tertiary rocks. The fluorite occurs usually together with chert in cataclastic breccias. It shows considerable range in crystal form and colour. The most important deposits in the Kerio Valley are concentrated in the area round Kimwarer where they are mined.

2.5 Structure

The Kerio Valley is a part of the East African Rift System, with the Elgeyo Escarpment being the western boundary of this system.

The tectonic events during the rift forming produced several faults of different magnitude and trend. The position of major faults is indicated on Plate 2.1. The Elgeyo Fault is the most important structural feature in the area. The Elgeyo Fault belongs to a large structural system which extends from near the Equator to as far north as 2°45'N in Turkana. The presence of the fault is indicated by the Elgeyo Escarpment, which separates the Kerio Valley depression from Uasin Gishu Plateau. According to Lippard (1972), the total displacement on the fault varies between less than 500 m at Kimwarer

to more than 3000 m near Koitilial. The trend of the fault is between northnortheast and northnorthwest, which corresponds to the strike of the Basement rocks. The southern end of Elgeyo Fault is marked by a complex pattern of faults, trending between southwest and southeast. The displacements of these faults are probably less than 100 m.

In the deepest part of the Kerio Valley proper no faults could be traced on the aerial photographs, because of the thick sediment cover. On the satellite photos, however, several northeast and northwest trending lineaments have been observed (Rivereau, 1981), which may represent minor faults.

The structure of the eastern side of the Kerio Valley is controlled by a complex fault pattern in the Tugen Hills. There are numerous faults of different magnitude, with downthrow both to the west and east, respectively. Most of these faults occur at the higher altitudes on the slopes of the Tugen Hills. The area close to the valley is relatively fault-free. Only in the surroundings of Chebloch, a number of small northeast trending faults have been indicated.

3. GEOPHYSICS

3.1 Introduction

The geophysical investigation is described in this chapter in a summarized way. A detailed report giving all data and describing the methods applied, their restrictions, and a complete description of the results is soon to be published, (Geophysical Investigation of Kerio Valley, MOWD/WRAP 1984 a).

In this chapter of the Main Report only a short abstract of this report is given and the results described as far as relevant for the water assessment study.

Very little previous geophysical investigation have been undertaken in the Kerio Valley before the project started. A few resistivity soundings were made some years ago for the site investigation of Kabluk water supply scheme. The soundings could however not be traced back in the files of the Ministry of Water Development.

An interesting seismic and gravity survey (Swain et al., 1981) covered also part of Kerio Valley. Its purpose was, however, not water related but intended to establish the structural features of this part of the Rift Valley system. The authors conclude that a thickness of volcanic and alluvial fill of Kerio depression is at least 1000 to 2000 metres.

The survey of Kenya has published the Bouguer Gravity Anomaly map of Kenya (1982). Figure 3.1 shows a detail of this map, covering Kerio Valley. The greatest gravity anomaly in the whole of Kenya is in Kerio Valley with the centre of - 240 mgal near Lake Kamnarok. Quite evident is that the fill of the Kerio graben with relatively lighter material must be very impressive and with at least the afore-mentioned 1-2 km thickness.

3.2 Fieldwork

From the available geological information it was fairly obvious to choose the electrical resistivity sounding method for the investigation. Under similar conditions it provides generally the most useful results and is relatively cheap compared with other methods.

A few seismic lines were shot in January and February 1983. But this yielded not the required information and was therefore soon abandoned.

Fieldwork started in December 1981 and was finalised in December 1983. The crews usually went for a period of 3 to 4 weeks to Kerio Valley, after which some weeks were spent in Nairobi for a preliminary evaluation of the results and for repairs and maintenance of equipment and vehicles. A summary of the executed fieldwork is given in Table 3.1

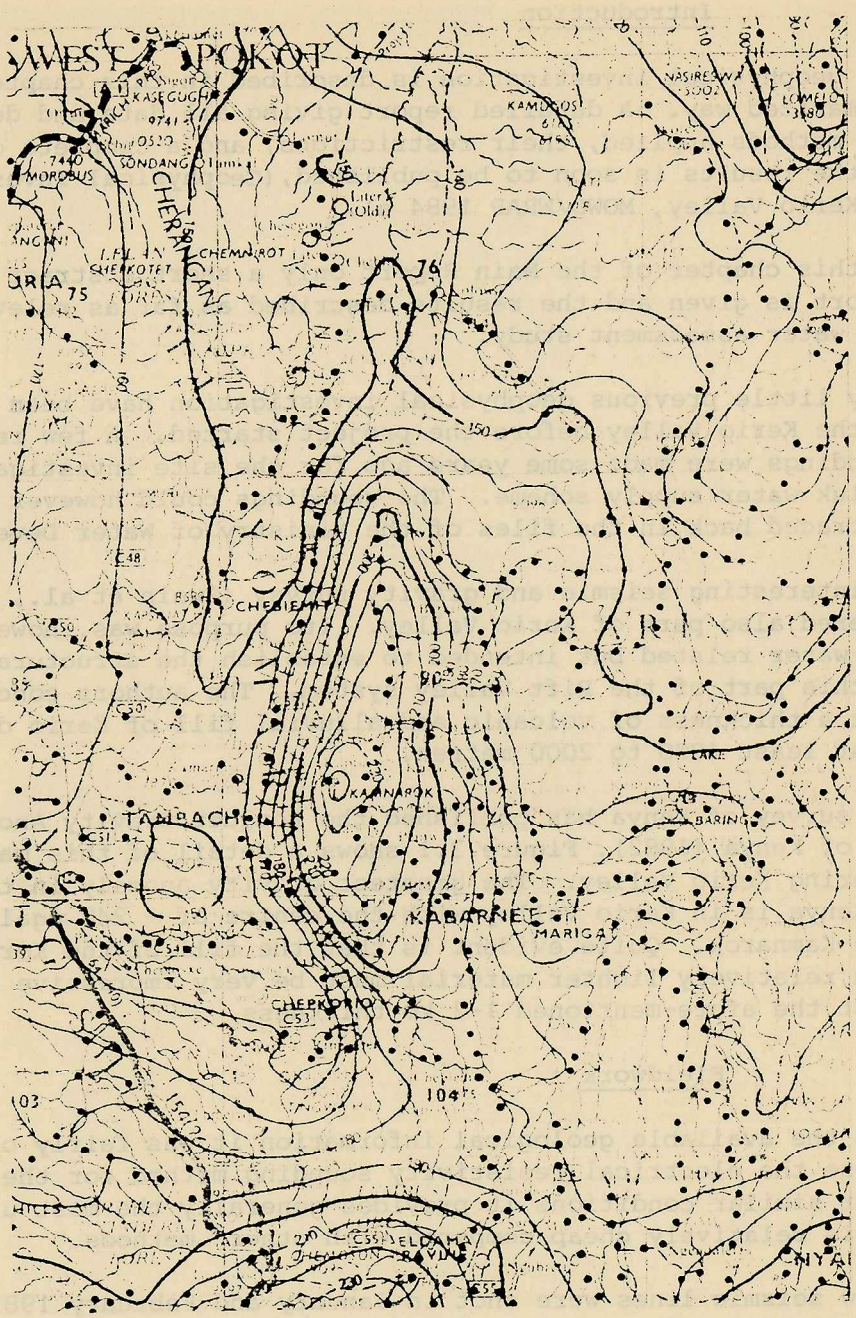


Figure 3.1 Detail of the Bouguer Gravity Anomaly map of Kenya (Survey of Kenya, 1982)

Table 3.1 Geophysical fieldwork in Kerio Valley

	Resistivity		Resistivity Profiling				Seismic Refraction			
Mapsheet	No. of Ves	AB/2 max (m)	No of Profiles	AB/2 (m)	Interval (m)	Total Length (km)	No.of Profiles	No. of Spreads	Geoph. Spacing (m)	Total Length (km)
76/2	5	500-1000	-	-	-					
76/3	24	160-1000	3	250/630	200/600	18.8				
76/4	4	1000	-	-						
90/1	31	320-1000	2	630	200	10.4				
90/3	33	250-1000	4	630	200/400	21.4				
104/1	56	200-1000	11	250/630	200	46.8	2	18	10/15	2.4
Total	153		20			97.4	2	18		2.4

3.2.1 Resistivity soundings

The locations of the resistivity soundings, the total number being 153, are shown on Plate 3.1. The soundings were carried out in the Schlumberger configuration. The maximum value of AB/2, which in most cases was applied amounted to 1000 m. The soundings were made with a GEA 51 resistivity equipment (Groundwater Survey TNO) and ABEM DC-Terrameter, provided by the Mines and Geology Department. The majority of the soundings are of good quality, only a few had to be repeated.

3.2.2 Resistivity profiling

After the execution of the first part of the resistivity fieldwork in the southern part of the Kerio Valley, it became clear that correlation between neighbouring soundings would not be easy. To map lateral changes (structural or others) it was decided to make ressistivity profiles along the same cross-sections.

Twenty profiles with a total length of 97 km were measured. The apparent resistivities were measured at a spacing of AB/2 = 630 m, and in the first two ones also with AB/2 = 250 m. Production amounted usually to 8 stations per day, with an interval of 200 m. This amounted to 1.5 km on the average per day. The ABEM DC-Terrameter was selected for the measurements because of its good portability.

3.2.3 Seismic refraction

Two seismic profiles were shot in the southern part of Kerio Valley. The equipment used was an OYO seismograph made available by Mines

& Geology Department. Shotholes were drilled by hand augers. Dynamite and a blasting expert was made available by the Kenya Fluorspar Company. Production amounted to two spreads per day on the average.

3.2.4 Well logging

Well logging was carried out routinely in all newly drilled boreholes (Table 3.2). Recorded were the natural gamma radiation (NG), the resistivity (RES) at two electrode spacings (20 and 100 cm), and the spontaneous potential (SP).

Unfortunately the gamma ray tool got stuck in the 10th borehole and during subsequent recovery efforts the cable broke. Delivery of new parts and repair took so much time that the last 4 boreholes could not be logged.

Resistivity and SP measurements were only possible in the uncased and water-filled parts of a borehole.

Table 3.2 Well logging

Borehole No.	Location	Total Depth	Casing (m)	Date of logging	Log recorded			Logged Interval (m)		
					NG	RES	SP	NG	RES	SP
C 5112	CHEBLOCH	120	0-44	28/10/82	X	X		3-120	28.3-120	
C 5170	KIBOINO	120	0-19	27/10/82	X	X	X	3.5-117.5	19-119	19.9-118.5
C 5211	KIMWARER	125	-	24/06/82	X	X		3-55.9	29.2-55.7	-
C 5333	KOLOWA	74.5	*0.4-12	24/03/83	X	X		3-72	10-72	-
C 5346	TOT (I)	96	*0.45-52.66	18/05/83	X	X	X	3-75.2	42.2-76	42.1-75.8
C 5334	RIMOI (I)	100.5	*0.4-83.4	15/04/83	X	X		3-85.2	70.5-85.2	-
C 5269	TOROK II	56.0	*0.4-48	26/01/83	X			3.4-37.5	-	-
C 5268	TOROK I	88.0	*0.4-22,5	18/02/83	X	X	X	3-67	22.5-66.5	22.5-66.5
C 5350	TOT (EAST)	69.0	*0.4-47.3	5/07/83	X	X	X	3-60	49-62	49-61

* indicates casing above groundlevel

NG = Natural gamma radiation
RES= Resistivity, long and short Normal (20/100 cm)
SP = Spontaneous potential

3.3 Data Evaluation

3.3.1 Resistivity soundings

The interpretation of resistivity soundings provides information on thicknesses and resistivities of underground, some of which might be water bearing. The interpretation of resistivity soundings is,

however, subject to equivalence. Several equivalent solutions are possible for one single sounding graph. Usually, the proper solution can be found from additional data (geology, borehole data, resistivity well logs). In the case of the Kerio Valley, these data were very scarce, and therefore the most simple and obvious solutions have been chosen.

The interpretation for a series of soundings along a section or situated in each others vicinity can be compared mutually and adjusted. This is based on the assumption that there is a certain degree of continuity in the geological layering of the subsurface. In several cases, however, it appears to be impossible to find comparable solutions for neighbouring soundings. In that case it must be assumed that there exists a geological discontinuity (fault, wedging out of layer).

The interpretation of the soundings was carried out by means of standard graphs and verified with a desk calculator (HP 9815 and HP 85) with plotter HP 9872 B).

3.3.2 Use of resistivity profiles

The traverses made with constant electrode separation yield apparent resistivity values, which are plotted along the distance covered (horizontal axis). These profiles can only be interpreted in a qualitative way. As long as the (hydro) geological composition of the underground does not change laterally, the resistivity reading remains the same. When the traverse crosses for instance a fault, the readings usually change. However, this can also happen when for example the thicknesses of the surface layer changes.

3.3.3 Use of seismic profiles

Seismic refraction profiles usually yield important information on depth to the water table and to the bedrock. The latter is in Kerio Valley beyond the reach of the equipment used. The depth to the water table could not be established successfully because in the very clayey sediments the difference in velocities is not visible. Near Chebloch the depth to the weathered trachyte could, however, be traced.

3.3.4 Use of resistivity logs

The resistivity recordings in boreholes can be a valuable aid in the interpretation of resistivity soundings, because the results obtained from the borehole are directly comparable to the resistivities obtained from the measurements at the surface.

In nine boreholes geophysical well logging has been carried out. The results are shown in the Report on the Geophysical Investigation in Kerio Valley (1984 a)

3.4 Results

3.4.1. General

The results of the geophysical investigations are presented in the report "Geophysical Groundwater investigation in Kerio Valley (1984a)" in 21 cross- sections and three maps. In this report we discuss only the major findings and give some examples.

3.4.2. Cross-sections

A total of 21 cross-sections have been drawn to present the interpretation of the resistivity soundings. All the sections run approximately in east-west direction, except two which are in north-south direction. the sections give together a comprehensive picture of the various geological formations in the area.

The sections are all extensively discussed in the Geophysical Report (1984a). This report gives all the field data and the interpretation of the data. A discussion on the accuracy of the findings of the investigation is included.

To give some examples three cross-sections are presented in this chapter (Fig.3.2, 3.3 and 3.4). These three sections show the major aspects of the geological structure and the hydrogeology of the project area.

Cross-section A-A' (Fig.3.2) from Tot to Kolowa shows on the western side relative shallow basement (50-90 m depth); in the central part of the valley mostly clayey sediments are found, whereas on the eastern side clayey wheathered volcanics are found. Groundwater prospects are in general poor, except in the hillwash material below the escarpment and in the alluvial deposits along the Kerio River.

Cross-section B-B' (Fig.3.3) runs from Arror to Kinyach. No significant alluvial deposits are found here along the Kerio. The high resistivity formations found on the eastern side represent fissured fresh trachytes (FT), the partly weathered trachytes (PWT), the weathered trachytes (WT), and the decomposed trachytes(mainly to clay minerals), underlain by clays from tuff, shales, sandstones and conglomerates of the Ngorora formation. Groundwater prospects in the trachytes with fairly high resistivity values (50-500 ohmm) are generally good. Elsewhere prospects are poor.

Cross-section C-C' (Fig.3.4.) across the valley at Chebloch bridge, shows the same layering as at cross-section B-B' on the eastern side of the main fault. The trachytic formations are here, however, overlain by sediments and boulders. On the western side, the hill wash material and the sand and gravel deposits are of considerable thickness. The groundwater prospects are good in the trachytes, but much poorer elsewhere.

Figure 3.2 CROSS-SECTION TOT-KOLOWA (A-A')

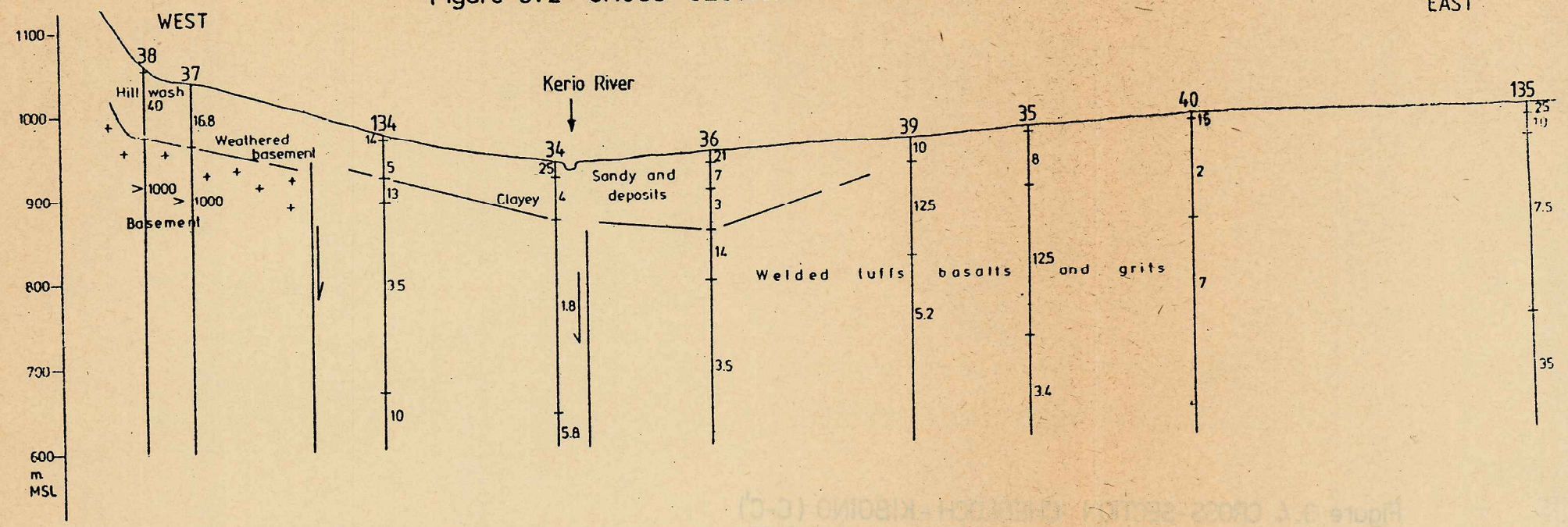


Figure 3.3 CROSS-SECTION ARROR – KINYACH (B - B')

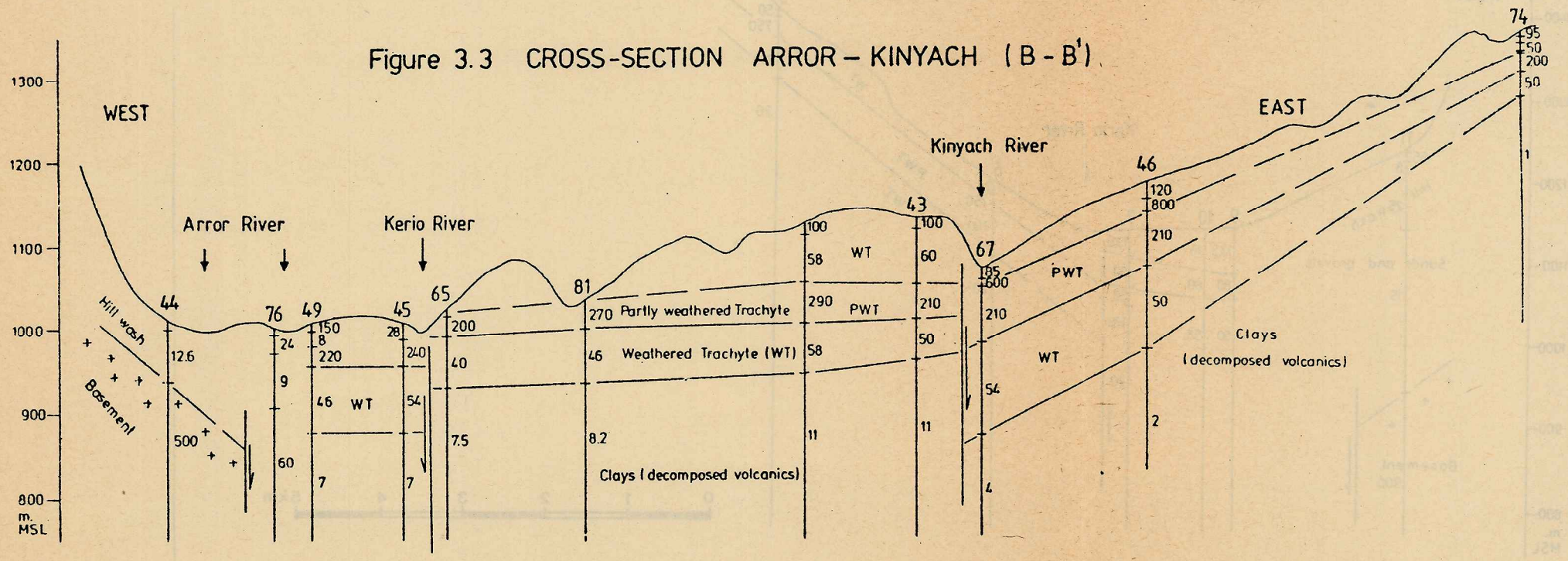
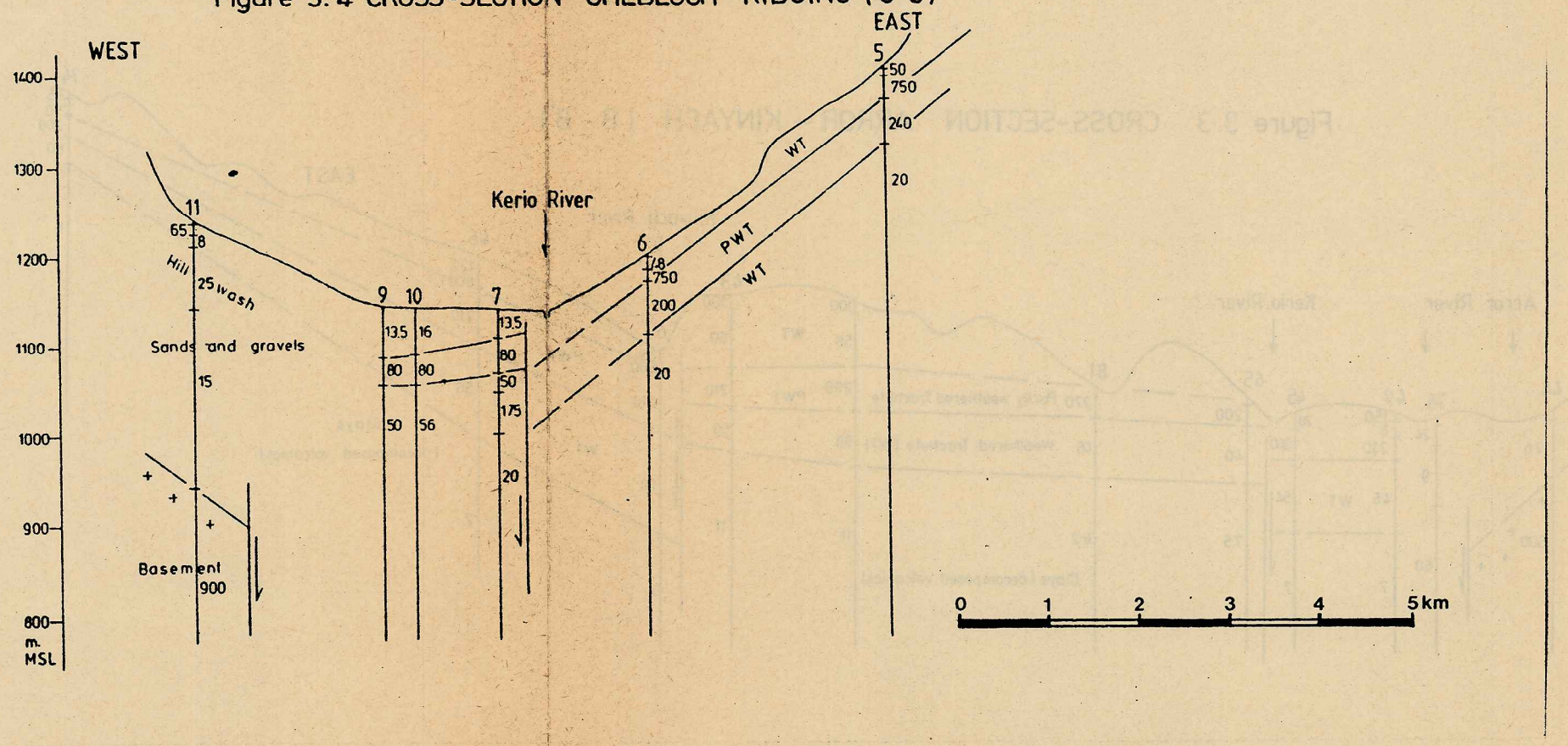


Figure 3.4 CROSS-SECTION CHEBLOCH - KIBOINO (C-C')



3.4.3 Resistivity map

Due to lack of roads or accessible foot paths to some of the selected sites in the area, it was not possible to have a well elaborated resistivity survey, which could have given a comprehensive iso-resistivity map with a dense grid pattern of easily comparable resistivity values. After a systematic review and evaluation of the resistivity data, however, it became clear that on the basis of the results the area can be divided into the following zones. These correspond to the various hydrogeological units in the area:

Zone I
- In this zone the basement outcrops or is found at shallow depth, especially near the edge of the main escarpment.
- The thickness of the sedimentary cover is usually less than 100 m.
- The boreholes struck water in the weathered basement.
- Groundwater prospects are poor to fair.

Zone II
- Depth to the basement is usually greater than 100 m.
- The overburden consists mainly of clayey sediments.
- Groundwater was struck in the sediments.
- Groundwater prospects are poor to fair.

Zone III
- This zone consists mainly of volcanic beds:
  . Trachytes, characterised by relatively high resistivity values;
  . Basalts, characterised by low to intermediate resistivity values;
  . Kabarimen-Tilingwo-Kolowa volcanics with very low resistivities.
- The overburden consists of a thin volcanic soil, if at all.
- Groundwater is mainly found in the weathered "old land surfaces" between the volcanic beds or in the fractured zones.
- Prospects for groundwater are fair for the basalts and the third group of volcanics, and good for the trachytes.

Zone IV
- This zone consists of the sediments on the rift floor. Three subzones are distinguished:
  . Scree fans along the foot of the escarpment;
  . Kimwarer sediments
  . Sediments of the central rift floor (Kerio Valley Sediments).
- The scree fans have a limited thickness of less than 50 m. Groundwater prospects are fair to good.
- The Kimwarer sediments and Kerio Valley sediments are for the greater part clays or clayey fine sands. Water was struck only in one borehole. Prospects are poor.

Plate 3.1. shows the extent of the four zones in the project area.

3.4.4. Hydrogeological interpretation of the results

From the hydrogeological information of all the boreholes drilled in the area and the results of the geophysical data interpretation, an attempt

Table 3.3 Relation between formation resistivity and hydrogeology

Geological formation	Resistivity (Ohmm)	Hydrogeology	Groundwater prospects	Tested Yield (m^3/h)
Sediments	1 - 10	Clay sandy clay	very poor	1
	5 - 15	clayey fine sand	poor	1
	10 - 20	fine sand medium sand	fair	1 - 3
		gravel scree fans	very good	20 - 40
Trachytes	5 - 20	completely weathered	poor	-
	20 - 100	weathered	poor - fair	1
	100 - 500	fissured partly weathered	good - very good	13 - 21
	500	fresh	very poor	-
Basalts and Phonolites	1 - 10	Very weathered	very poor	-
	10 - 50	partly weathered	fair	2
Turkana grits	15 - 35	conglomerates	fair (?)	-
Basement	10 - 20	decomposed very weathered	poor	
	20 - 50	weathered	poor - fair	1
	50 - 500	fissured - partly weathered	fair - good	3
	no value	fractured zones	good	5)*
	500	fresh	very poor	-

)* boreholes West Pokot District

was made to determine the relationship between the hydrogeology and the results of the geophysical interpretation. Table 3.3 gives a summary of this relationship, showing the main geological formations, their respective resistivity values, the hydrogeological conditions and the resulting groundwater prospects.

The table shows that values below 10 ohmm have very poor prospects. In the range of 10 to 20 ohmm the prospects are poor to fair, whereas the range of 20 to 50 is generally fair. The range 50 to 500 ohmm is fair to good, but higher than 500 ohmm is usually very poor.
It can be seen from the table that the resistivity values cannot be translated unequivocally to certain hydrogeological conditions. Each type of geological formation has its own range of resistivity values.

4. HYDROLOGY

4.1 Introduction

The hydrological study is aimed at obtaining a basis for the estimation (assessment) of the surface water potential and the groundwater recharge from percolating rainfall and infiltrating surface water. In the past the surface water potentials in the Kerio Valley have been investigated by different consultants (SOGREAH, 1982 and Pencol, 1984), however their studies were mainly concentrated on the availability of surface water for large scale irrigated agriculture and hydro power. The present study is concentrated in the first place on the assessment of groundwater availability, because this is a virtually unknown resource.

The project area is restricted to the catchment of the Kerio River and bounded by the Timboroa Forest and Metkei Forest to the south, the Tugen Hills up to the Chepanda Hills near Maron Mission to the east and the Elgeyo Escarpment and Cherangani Hills to the west. The surface water divide of the catchment is indicated on Plate 4.1. The northern boundary of the project area is formed by the Tot-Kolowa-Marigat Road.

The Kerio River is the main river passing through the centre of the valley. Other, predominantly intermittent, streams join the Kerio River from both sides of the valley.

The Kerio River has its source in Timboroa and Metkei forests through its perennial tributaries of Kimwarer and Mong respectively. The other tributaries carry water during the peak seasons of April/May and November and are dry for the rest of the year.

From Cherangani Hills rise the perennial tributaries of Arror and Embobut which increase the meagre flow of the Kerio River downstream of Koitilial and Tot respectively.

The climatogical conditions are considered to be a function of the altitude. Two distinct climatic zones can be distinguished:

- semi arid
- highland sub-tropical

The climate at the bottom of the Kerio Valley can be described as semi-arid, with high temperatures and evaporation rates, and relative low rainfall figures.

The annual maximum temperatures range from 26° to 35°C, and the evaporation rates exceed 2400 mm/year. Annual rainfall figures vary between 800 mm/year in the north to over 1000 mm/year in the south. The rainy seasons are between April and August and between November and December. Distinct peaks occur in May, August and November. There is a considerable variation in seasonal and annual rainfall, which makes rainfall prediction vary unreliable. The vegetation is scarce and soil cover is absent in most places.

The climate at the higher altitude areas (over 1500 m) can be described as a highland sub-tropical climate, with lower temperatures and evaporation rates, and higher rainfall figures compared to the climate in the lower part of the valley. The amount of rainfall received at different places depends very much on the position of the station in relation to the rainbearing winds.

The rainfall pattern on the eastern side of the valley is similar to the rainfall pattern inside the valley with three peaks in May, August and November, and an average annual rainfall of 1350 mm/year. The rainfall pattern at the Elgeyo-Marakwet side of the valley, however, exhibits distinct peaks in April, August and November, and a dry period during January and February. The average annual rainfall amounts to approximately 1200 mm/year. Due to less variation in seasonal rainfall, the vegetation cover on the western escarpment side is denser than on the Tugen Hills side of the valley.

4.2 Previous hydrological studies

Since the establishment of the Kerio Valley Development Authority (KVDA) in 1980, which covers the Kerio Basin up to Lake Turkana and including the Turkwell River Basin, the interest in the Kerio Valley has increased considerably. In December 1980, the KVDA commissioned ADEC and SOGREAH to draw up a general development plan for the Kerio Valley Basin.

As far as hydrology is concerned the SOGREAH studies are the most relevant:

(i) The SOGREAH study - Part one, (April, 1981), covers the Turkwell, the Kerio and Lake Baringo Basins. The important features for the hydrological study include:

- rainfall data analysis for a number of rain-gauge stations in the project area;
- run off data analysis for two river gauging stations one in the Arror River (2C5) and one in the Kerio River at Chebloch (2C7);
- analysis of meteorological data of some meteorological stations outside the project area.

(ii) Part two of the SOGREAH study (October, 1981), contains a similar rainfall and meteorological analysis as in part one, but the surface water runoff is analysed in more detail including flood estimates. The study is more specifically aimed at the evaluation of the water resources and examines their possible utilisation in such fields as hydropower, irrigation and domestic water supplies.

General conclusions from the SOGREAH study are as follows:

- Water resources are quite abdundat, but very unequally distributed over the study area. Resources appear to be plentiful in the zones which lie above the 800 mm isohyet.

Below this zone, losses due to evapotranspiration and direct evaporation predominate.

- Productive zones are situated directly above zones where there is a deficit. This is the case in the Kerio Valley between Chebloch and Tot, where the poor resources could be made up with flow from the Cherangani hills or by means of a diversion from the Nzoia River.

- Water resources are unequally distributed in time.

- While water resources appear to be quite abundant upstream on the main rivers, the scarcity of suitable dam sites and the heavy sediment transport may consitute major constraints in the regulation of resources.

- Present information on available surface water resources is not sufficiently precise.

- In order to gain a better idea of the water resources which could be mobilised by storage, water gauging installations should be set up urgently.

Other studies to be mentioned are:

(iii) Bell and Everard (1956) studied the behaviour of the Kerio River and of the entire catchment. This study was carried out between September 1955 and February 1956.

(iv) TAMS (1980), the National Master Water Plan, stage 1. This report deals with all aspects of water resources assessment, planning, developing and management.

(v) Pencol (1981, 1984), the Central Baringo Water Development Plan 1983-2003. This study includes the eastern bank of the Kerio River and covers the analysis of meteorological and hydrological data. Several dam sites are proposed for domestic water supplies and irrigated agriculture.

4.3 Hydro-meteorological network

At the start of the project the hydro-meteorological network inside the Kerio Valley was very limited. After consultation with the Hydrology Division of the Ministry of Water Development the project undertook the task to upgrade and to expand the sparse network.

Field work started with a reconnaissance survey of the project area in December 1981 and in February 1982. An inventory to the existing network was made and new sites for additional stations were identified. Actual rehabilitation of non-operational and poorly operating stations and installation of new equipment started in February and continued up to mid May 1982. Additional honorary observers were appointed and

and properly trained. Monthly each station was visited by the Assistant Hydrologist from Eldoret to check the procedures and to collect the record sheets from the previous months. The present hydro-meteorological network is shown on Plate 4.1.

4.4 Rainfall

4.4.1 General

Rainfall observations in the area have been made since 1903 at Eldama Ravine rain-gauge station (ref. no.89.35.007). However, the majority of rain-gauge stations used in this study have been operated for much shorter periods. Although in principle all monthly records were available considerable time has been spent to update and complete raw data. This included the conversion of data prior to 1965 from inches into millimeters. On the basis of quality and availability of data, the 1958-1976 period was selected as the representative common record period for 11 selected rain-gauge stations (Annex 4.1). The stations are shown on Plate 4.1. Only monthly and annual rainfall data will be discussed in this report. For more detail on data elaboration and filling in of missing data through correlation and double mass analysis reference is made to the Kerio Valley Hydrological Report (MoWD/WRAP, 1984).

4.2.2. Monthly rainfall

Longterm monthly averages for the 11 rain-gauge stations are presented in Table 4.1 together with the standard deviations and the average distribution of monthly rainfall as percentages of the longterm average annual rainfall. The distribution of monthly rainfall has been visualised in Figure 4.1. The rain-gauge stations have been grouped according to their position in relation to the Valley:

a. eastern mountain range, including the Tugen Hills
b. centre line of the Kerio Valley
c. western escarpment, including the Cherangani Hills.

Most rain-gauge stations exhibit more or less the same rainfall pattern with three consecutive peaks in April/May, July/August and in November. The heights of the peaks, however, vary from station to station. The rainfall distibution at Timboroa Forest station (reg.no.89.35.137) and Cherangani Forest station (reg.no.88.35.034) exhibits a somewhat different rainfall pattern, mainly due to topographic conditions. In general the rainfall distribution over the year is far better on the Elgeyo Escarpment than on the eastern side of the valley.

Table 4.1 Longterm average monthly rainfall (1958 - 1876)

Rain gauge station name and KMD.reg.no.	Elevation m.s.l.		Monthly rainfall data												Annual	
			Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	$\bar{x}$	s
Cherangani Forest 88.35.034	2,200	$\bar{x}$	35.2	42.2	68.8	114.5	151.0	112.9	167.9	190.7	112.1	92.7	82.5	40.3		
		s	36.1	45.8	50.9	50.9	54.8	29.3	52.3	56.1	62.5	26.4	76.3	41.7	1209	190
		%	2.9	3.5	5.7	9.5	12.5	9.3	13.9	15.8	9.3	7.7	6.8	3.3		
Marakwet D.C. 89.35.002	2,300	$\bar{x}$	38.2	54.3	88.8	171.7	173.1	78.0	110.2	94.3	73.2	115.6	143.0	64.9		
		s	65.7	52.6	59.2	74.0	83.6	44.5	67.1	28.2	43.1	60.7	102.9	61.9	1209	229
		%	3.2	4.5	7.4	14.2	14.4	6.4	9.1	7.8	6.1	9.6	11.9	5.4		
Eldama Ravine 89.35.007	2,200	$\bar{x}$	37.0	50.3	76.8	165.7	126.7	72.1	118.4	128.4	90.7	82.5	127.6	52.4		
		s	42.8	54.0	63.2	102.7	75.8	35.7	60.8	62.4	77.2	75.6	146.1	51.1	1129	347
		%	3.3	4.5	6.8	14.7	11.2	6.4	10.5	11.4	8.0	7.3	11.3	4.6		
Tambach 89.35.014	1,850	$\bar{x}$	32.1	50.2	104.5	167.4	174.8	88.8	127.7	138.9	83.6	101.9	149.9	66.5		
		s	32.3	64.5	75.0	68.2	113.3	55.5	48.2	63.8	50.3	52.9	115.9	70.5	1281	299
		%	2.5	3.9	8.2	13.1	13.6	6.9	9.6	10.8	6.5	8.0	11.7	5.2		
Kabarnet 89.35.020	2,050	$\bar{x}$	39.2	34.6	96.3	166.0	163.0	116.3	202.1	214.8	78.1	70.9	110.5	64.0		
		s	48.1	37.3	78.8	101.4	103.7	93.1	70.0	116.6	52.2	49.3	132.6	79.1	1355	365
		%	2.9	2.6	7.1	12.3	12.0	8.6	14.9	15.9	5.8	5.2	8.2	4.7		
Karbartonjo 89.35.051	2,250	$\bar{x}$	57.5	59.9	94.7	164.6	201.2	92.5	174.3	194.9	70.6	75.8	134.6	75.3		
		s	76.4	61.2	89.4	114.2	139.4	59.2	70.2	87.6	58.0	71.6	163.4	96.8	1425	400
		%	4.0	4.2	6.6	11.6	14.1	6.5	12.2	13.7	5.0	5.3	9.4	5.3		
Tenges 89.35.091	1,900	$\bar{x}$	31.0	38.0	69.0	148.5	149.6	93.8	144.0	173.2	61.8	64.3	98.5	64.6		
		s	41.4	47.5	61.1	100.9	75.9	67.5	71.6	79.2	36.4	50.1	117.8	95.0	1142	297
		%	2.7	3.4	6.1	13.1	13.2	8.3	12.7	15.3	5.4	5.7	8.7	5.7		
Chebloch* 89.35.093	1,200	$\bar{x}$	29.8	42.5	74.9	176.2	134.6	79.3	142.6	135.7	55.1	56.6	124.7	33.5		
		s	39.3	60.6	52.6	253.3	96.1	89.1	56.3	86.3	49.0	47.7	164.7	49.7	1094	371
		%	2.7	3.9	6.9	16.2	12.4	7.3	13.1	12.5	5.1	5.2	11.5	3.1		
Chepkoria 89.35.131	2,600	$\bar{x}$	54.3	58.4	102.6	216.1	205.5	108.0	148.0	173.2	101.8	119.5	173.8	89.5		
		s	66.9	56.8	70.2	103.1	169.7	100.7	51.4	79.9	56.4	77.0	138.6	92.6	1444	299
		%	3.5	3.8	6.6	13.9	13.3	7.0	9.5	11.2	6.6	7.7	11.2	5.8		
Timboroa 89.35.137	2,750	$\bar{x}$	48.4	51.7	100.1	160.0	142.7	95.6	184.3	247.7	95.2	61.7	93.2	52.2		
		s	52.5	54.2	123.3	96.0	52.7	40.6	80.1	165.7	50.7	38.0	88.7	60.0	1333	295
		%	3.6	3.9	7.5	12.0	10.7	7.2	13.8	18.6	6.9	4.6	6.9	3.9		
Barwesa 89.35.146	1,200	$\bar{x}$	28.3	34.7	47.1	126.5	133.0	66.1	95.6	81.9	54.3	29.4	75.2	47.7		
		s	49.3	54.6	44.5	110.4	97.9	55.3	83.5	55.0	54.4	23.9	101.2	61.1	993	281
		%	3.5	4.3	5.8	15.6	16.4	8.1	11.8	10.1	6.7	3.6	9.3	5.9		

* 1958 - 1972

From the longterm monthly averages and the standard deviations presented in Table 4.1, it becomes obvious that the monthly rainfall in general fluctuates heavily from year to year. The standard deviations for the drier months are of the same magnitude as the monthly averages, indicating that a monthly rainfall fluctuation interval can be expected varying between two up to even three times the longterm average monthly rainfall. Altogether monthly or seasonale minma of average rainfall appears unpredictable, which is a great drawback for agricultural planning.

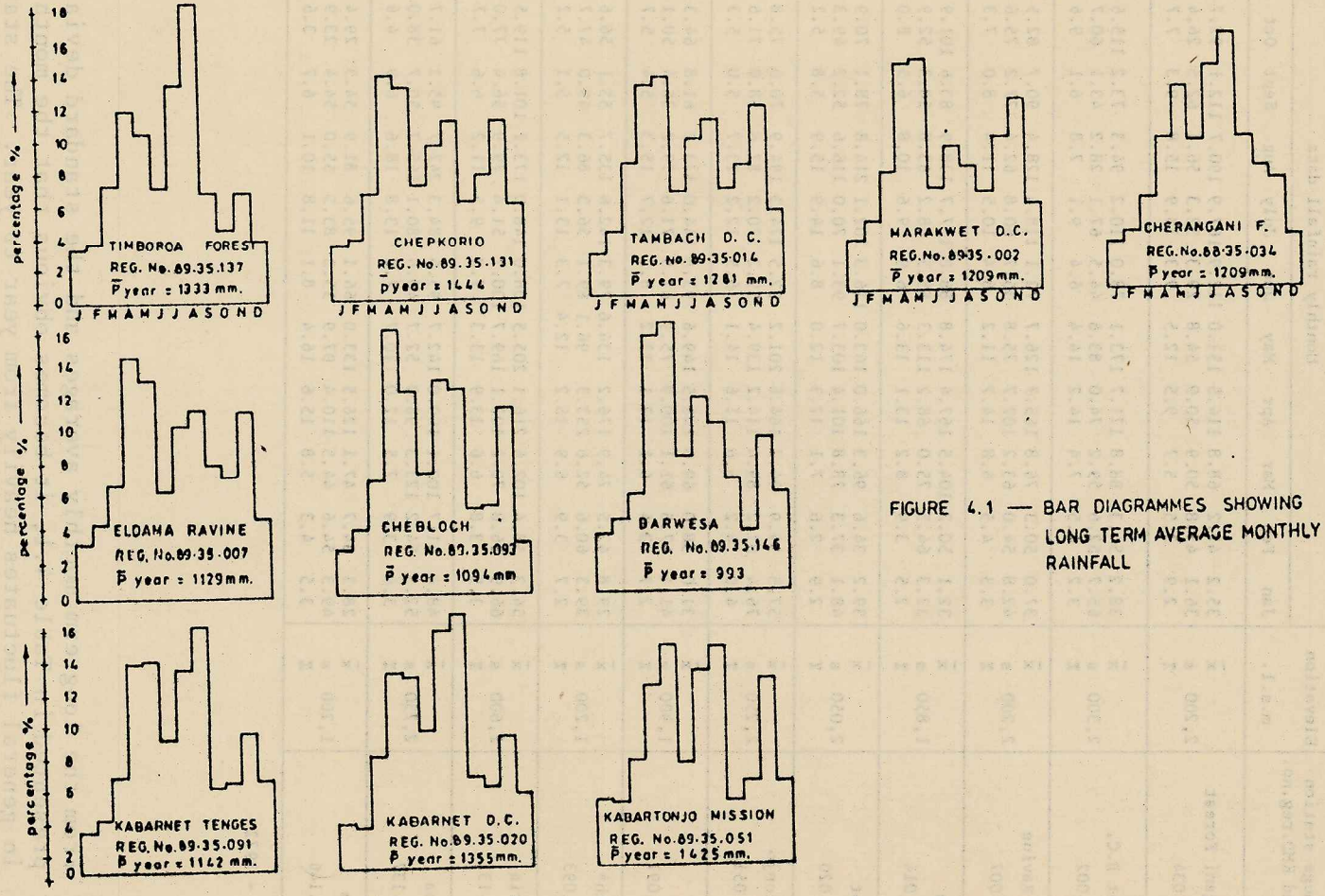


FIGURE 4.1 — BAR DIAGRAMMES SHOWING LONG TERM AVERAGE MONTHLY RAINFALL

The monthly rainfall figures for the period 1982-1983, i.e. after rehabilitation and extension of the rain-gauge network by the project, are presented in Annex 4.2. These figures have not been included in the longterm monthly rainfall, they were used however to calculate the monthly runoff rainfall ratio (Section 4.6.4).

4.4.3 Annual rainfall

Annual rainfall data for the period 1958-1976 for the 11 rain-gauge stations are presented in Table 4.2, including longterm average annual rainfall and standard deviations for each station. Data which were obtained or revised through double mass analysis and/or linear regression are indicated. The standard deviation of the longterm average annual rainfall varies between 16-34% of the average annual rainfall. The ratio between maximum and minimum annual rainfall ranges from 1.7 to 4.0.

An isohyetal map for the longterm average annual rainfall 1958-1976 has been prepared (Plate 4.2). This map is based on the up-dated longterm average annual rainfall data of the 11 analysed rain-gauge stations and completed with data from less reliable or abandoned stations. Inside the valley rainfall decreases from 1000 mm in the upstream part of the valley to 700 mm around Tot. High rainfall, i.e. rainfall exceeding 1300 mm, occurs in the upper parts of the catchment area, in the Tugen Hills, Metkei Forest and the Elgeyo Escarpment including the Cherangani Hills.

Analysis of the annual rainfall frequency distribution for 14 rain-gauge stations have been carried out. The results, together with the probability curves, are presented in the Kerio Valley Hydrological Report (MoWD, 1984). For nine out of 14 rain gauges the recorded rainfall in 1982 exceeded the 90% probability of non-exceedence. The 1983 rainfall proved to be close to average.

4.5 Evaporation

4.5.1 General

Except for a water balance study to assess the groundwater recharge, evaporation data are very important for agricultural planning. Especially when irrigated agriculture is foreseen in the near future, as is the case in the Kerio Valley. Evaporation data records of stations near to the project area go back till 1946, Eldoret Met. Station (MoWD reg. no.2). However, this station was abandoned in 1960, evaporation measurements continued thereafter at a new station. Woodhead (1968) develeoped a regression equation to relate the annual potential evaporation Eo(mm) to altitude h(m):

Table 4.2 Longterm average annual rainfall

Station Name	Cherangani	Marakwet	Eldama-Ravine	Tambach	Kabarnet	Kabartonjo	Tenges	Chebloch	Chepkorio	Timboroa	Barwesa
KMD reg. No.	88.35.034	89.35.002	89.35.007	89.35.014	89.35.020	89.35.051	89.35.091	89.35.093	89.35.131	89.35.137	89.35.146
Elevation in msl	2,200	2,300	2,200	1,850	2,050	2,250	1,900	1,200	2,600	2,750	1,200
Year 1958	1,197	1,380	1,308	1,614	1,651	1,770	1,436	1,296	1,672	1,402	1,036
9	1,058	1,032	913	1,163	1,131	1,223	929	870	1,072	1,141	889
60	1,161	1,066	958	1,124	1,007	1,040	895	709	1,510	1,281	677
1	1,599	1,699	1,321	1,816	2,030	1,984	1,829	1,557	2,048	1,605	1,269
2	1,361	1,158	1,080	995	1,318	1,227	1,174	811	1,412	1,508	808
3	1,255	1,636	1,446	1,479	2,016	1,790	1,498	1,797 2)	1,750	1,703	1,515
4	1,392	1,033	1,210	1,067	1,623	1,958	902	697	1,471	1,366	934
5	930	788	473	793	679	862	641	689	1,157	922	774
6	1,476	1,208	774	1,344	1,350	1,528	1,054	1,075	1,433	1,303	1,126
7	1,146	1,261	1,897	1,578	1,535	2,254	1,399	1,567	1,665	1,341	1,301
8	1,238	1,030	1,854	1,335	1,183	1,416	1,173	1,189	1,458	1,407	986
9	947	1,461	1,014	1,068	971	1,229	813	756	1,295	941	688
70	1,309	1,150	1,213	1,239	1,508	1,680	1,479	1,255	1,746	1,617	1,237 1)
1	978	1,399	1,029	1,263	1,431	1,520	1,180	1,272 2)	1,594	1,309	1,129 1)
2	1,078	1,228	813	1,931	1,443	1,125	1,114	925	1,285	1,191	534 1)
3	1,166	995	832	975	879	813	741	575 2)	923	1,240	617 1)
4	1,324	1,262	1,128	1,289	1,049	1,096	1,212	1,571 2)	853	1,450	1,349 1)
5	1,395	1,163	1,189	1,315	1,721	1,457	1,221	1,409 2)	1,339	1,942	1,230 1)
6	958	1,017	993	959	1,225	1,102	1,001	771 2)	1,125	654	761 1)
n	19	19	19	19	19	19	19	19	19	19	19
$\bar{x}$	1,209	1,209	1,129	1,281	1,355	1,425	1,142	1,094	1,444	1,333	993
s	190	229	347	299	365	400	297	371	299	295	281

1) from double mass analysis
2) from regression equation

$$Eo = 2422 - 0.358\ h \qquad (r^2 = 0.66, \quad n = 78).$$

The above formula can only be applied to obtain approximate figures. From six evaporation stations around the Kerio Valley the available data have been updated, data from before 1965 have been transferred from inches into millimeters. Inside the Kerio Valley evaporation measurements were initiated by the project in April 1982 at five different locations. The evaporation stationsused in this report (Annex 4.1) are shown on Plate 4.1. Only monthly and annual evaporation data will be discussed in this report.

4.5.2 Monthly evaporation

Longterm monthly averages for six operation stations are presented in Table 4.3 together with the standard deviation and average distribution of monthly evaporation as percentage of the longterm average annual evaporation. In general it can be observed that in all stations the highest monthly evaporation occurs during the period between December and April with a more or less pronounced extreme evaporation in March. There is a clear relationship between altitude and evaporation. Seasonal variation at higher altitude is considerably greater compared to the variation at lower altitude. The standard deviations are relatively small and varies between 10-25% of the monthly average evaporation.

The monthly evaporation figures for the period 1982-1983, i.e. after rehabilitation and extension of the network by the project, are presented in Annex 4.3. Although evaporation inside the valley increases in northward direction, the monthly figures for 1982 and 1983 indicate that the evaporation measured in the valley is comparable with the evaporation at Marigat, Perkerra Expt.station (reg.no.77).

4.5.3 Annual evaporation

Annual evaporation data are presented in Table 4.4, including longterm average annual evaporation and standard deviations for each station. The standard deviations, being in the order of 10% of the average annual evaporation, indicate relative small variations in annual evaporation. Considering the longterm evaporation data, annual evaporation ranges from1200 mm Cherangani Forest (reg.no.60) in the higher part of the area to 2300 mm at Sigor (reg.no.114) in the northern part of the valley. Inside the valley the annual evaporation in 1982-1983 (Annex 4.4) increases from 2300 mm at the Fluorspar mine to approximately 2500 mm at Tot.

Table 4.3 Longterm average monthly evaporation

Evaporation station name and M.O.W.D. reg. no.	Elevation m.s.l.		Monthly evaporation data Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual data Period	$\bar{x}$	s
Eldoret L.S.F.T.C. no. 49	2,150	$\bar{x}$	187	176	200	165	141	117	97	103	123	152	143	167			
		s	30	25	34	28	19	22	9	11	19	22	35	23	1955-1982	1778	168
		%	10.5	9.9	11.2	9.3	7.9	6.6	5.5	5.8	6.9	8.5	8.0	9.4			
Cherangani Forest no. 60	2,200	$\bar{x}$	131	122	131	100	90	80	67	69	94	107	99	120			
		s	28	31	37	29	26	24	24	25	30	29	24	41	1957-1982	1220	218
		%	10.7	10	10.8	8.8	7.4	6.4	5.5	5.7	8.0	8.7	8.1	10			
Kabarnet M.O.W.D. yard no. 63	1,900	$\bar{x}$	202	195	218	166	138	121	110	121	149	174	150	178			
		s	37	32	43	33	17	15	14	21	30	33	26	33	1959-1982	1923	168
		%	10.5	10.1	11.3	8.6	7.2	6.3	8.7	6.3	7.8	7.6	7.8	9.3			
Perkerra Expt. station no. 77 (Marigat)	1,050	$\bar{x}$	245	239	262	205	207	199	184	189	215	229	201	222			
		s	24	27	36	29	36	25	26	28	26	33	33	33	1959-1982	2598	186
		%	9.4	9.2	10.1	7.9	8.0	7.7	7.1	7.3	8.3	8.8	7.7	8.5			
Sigor no. 114	1,050	$\bar{x}$	235	216	236	180	165	165	150	160	190	200	171	215			
		s	27	37	47	30	16	21	20	23	20	18	24	33	1966-1982	2285	124
		%	10.3	9.5	10.3	7.9	7.2	7.2	6.6	7.0	8.3	8.8	7.5	9.4			
Eldama Ravine M.O.W.D. yard no. 130	2,050	$\bar{x}$	190	196	213	166	166	134	123	130	151	157	134	157			
		s	20	23	36	39	33	16	16	22	26	30	15	24	1975-1982	1912	194
		%	9.9	10.2	11.1	8.7	8.7	7.0	6.4	6.8	7.9	8.2	7.0	8.2			

Table 4.4 Annual Evaporation data 1955-1982

Station Name	Eldoret	Cherangani	Kabarnet	Marigat	Sigor	Eldama-Ravine
MoWD reg.no.	49	60	63	77	114	130
Elevation in msl	2,150	2,200	1,900	1,050	1,050	2,050
Year 1955	1,748					
56	1,567					
57	1,620	956				
58	1,693	982				
59	1,688	938	1,722	2,612		
60	1,350	1,069	2,018	3,086		
61	2,054	1,147	1,889	2,801		
62	1,921	913	1,785	2,586		
63	1,867	864	1,711	2,550		
64	1,772	948	1,637	2,408		
65	2,003	1,076	2,037	2,764		
66	1,996	1,129	1,928	2,629	2,290	
67	1,912	1,287	1,721	2,522	2,102	
68	1,738	1,334	1,691	2,454	2,110	
69	2,001	1,298	1,976	2,736	2,278	
70	1,897	1,136	1,868	2,665	2,241	
71	1,842	1,451	1,944	2,530	2,392	
72	1,999	1,321	1,991	2,554	2,382	
73	1,886	1,447	2,009	2,774	2,450	
74	1,859	1,521	1,929	2,513	2,390	
75	1,707	1,474	1,974	2,405	2,276	1,834
76	1,772	1,519	2,268	2,551	2,382	2,049
77	1,518	1,269	1,917	2,348	2,184	1,915
78	1,422	1,010	1,893	2,403	2,175	1,629
79	1,614	1,449	1,950	2,654	2,146	1,941
80	1,659	1,576	2,375	2,974	2,541	2,287
81	1,604	1,256	1,961	2,438	2,279	1,836
82	1,578	1,344	1,954	2,396	2,224	1,797
n	28	26	24	24	17	8
$\bar{x}$	1,778	1,220	1,923	2,598	2,285	1,912
s	168	218	168	186	124	194

Table 4.5 River gauging stations (RGS)

MoWD reg.no.	River	Location	Co-ordinates Sheet no. NA 36-12/16 37-9 Scale 1:250.000 X	Y	Type W=Wier S=Staff/gauge R=Recorder	Record opened	Period closed	Rated Q-h curve	Catchment area sq. km.	Remarks
2C1	Spring	Tambach	780	065	W.S	08.1946	04.1960	Yes		
2	Spring	Tambach	780	064	W.S	08 48	06. 60	Yes		
3	Spring	Tambach	780	064	W.S	08. 48	06. 63	Yes		
4	Embata dam	Kabarnet	805	055	S	09. 65	-	No		
5	Arror		785	111	S	02. 61	-	Yes 1)	185	
6	Kessup	Kessup Forest	778	067	S	07. 60	11. 61	No	11.5	3)
7	Kerio	Chebloch	795	050	S.R	09. 62	-	Yes 1)	893	6)
8	Kerio	Lokori	167	212	S.R	01 69	-	Yes 2)	6467	4) March 1983
9	Kamarin				W.S	08. 75	04. 77	No		
10	Kessup	Kessup Forest	-		W.S	01 73	03. 75	No	-	
11	Kessup	Kessup Forest	777	064	S	04. 74	-	No		
12	Embobut	Tot	796	137	S	12. 74	-	No	133	
13	Torok	Biretwo	782	061	S	02. 77	-	No	20	
14	Kimwarer	Fluorspar Mine	794	035	S	02. 77	-	No	190	4)
15	Mong	Fluorspar Mine	796	035	S	02. 77	-	No	142	4)
16	Kerio	Tot	800	135	S.R	02. 82	-	Yes	3710	5)6)
17	Kerio	Kinyach	793	106	S.R.	02. 82	-	Yes	2471	5)6)
18	Arror	Arror	792	107	S.R	02. 82	-	Yes	278	5)6)

1) Updated
2) Not yet updated
3) Station re-opened in March 1978
4) Project rehabilitated stations
5) Project installed staff gauge
6) Project installed automatic water level recorder (AWLR)

4.6 Surface water runoff

4.6.1 General

At the start of the project only a limited number of river gauging stations (RGS) were operational in the project area (Table 4.5). On the Kerio River one staff gauge existed at Chebloch - RGS 2C7, and an automatic water level recorder at Lokori - RGS 2C12, which was not functioning. Other staff gauges existed on the main tributaries of the Kerio River, i.e. the Kimwarer, Torok, Arror and Embobut rivers. Except for the recorder at Lokori, automatic water level recorders (AWLR) were non-existent in the project area. River stages are only read once per day by local observers, in most cases no readings are taken on Sundays, public holidays and during leave periods. Flow measurements by wading are being carried out at irregular time intervals. Depending on the availability of funds and transport, the accessibility and the importance of the gauging stations the number of flow measurements range from zero to 12 measurements annually. Peak flows have not been monitored in the past and consequently the rating curves can be extrapolated up to limited stage height only, i.e. the maximum wading depth.

The existing hydrometric network and the available river stage and discharge data were insufficient to carry out a water balance study. Therefore the project installed four automatic water level recorders and rehabilitated a number of staff gauges (Table 4.5). More details are given in the Kerio River Hydrological Report. Especially the water level records supplied very useful information on the flow regime of the river and peak stages. It has been the policy of the project not to duplicate the considerable amount of analysis of past data carried out by SOGREAH (1981) and other consultants in relation to the surface water availability for irrigated agriculture and hydropower. On the other hand the data from the four water level recorders will be very useful for planning and evaluation of future surface water development proposals in the Kerio Valley. The data that became available, however, have not been analysed for this purpose. The project highly recommends continuous monitoring of the present hydrometric network to facilitate future analysis of the surface water potential when longer time series and more peak flow measurements have become available.

4.6.2 The catchment area (MoWD drainage area 2C)

The Kerio River originates in the Metkei and Timboroa Forest area north-west of Eldama Ravine. This mountainous forest area at an approximate elevation of 2500m above m.s.l. receives abundant rainfall of over 1400 mm annually (Plate 4.2). The Kerio River flows some 500 km to the north-north-east before discharing into Lake Turkana. The total catchment area covers about 17,800 km^2. The river course can conveniently be divided into three regions:

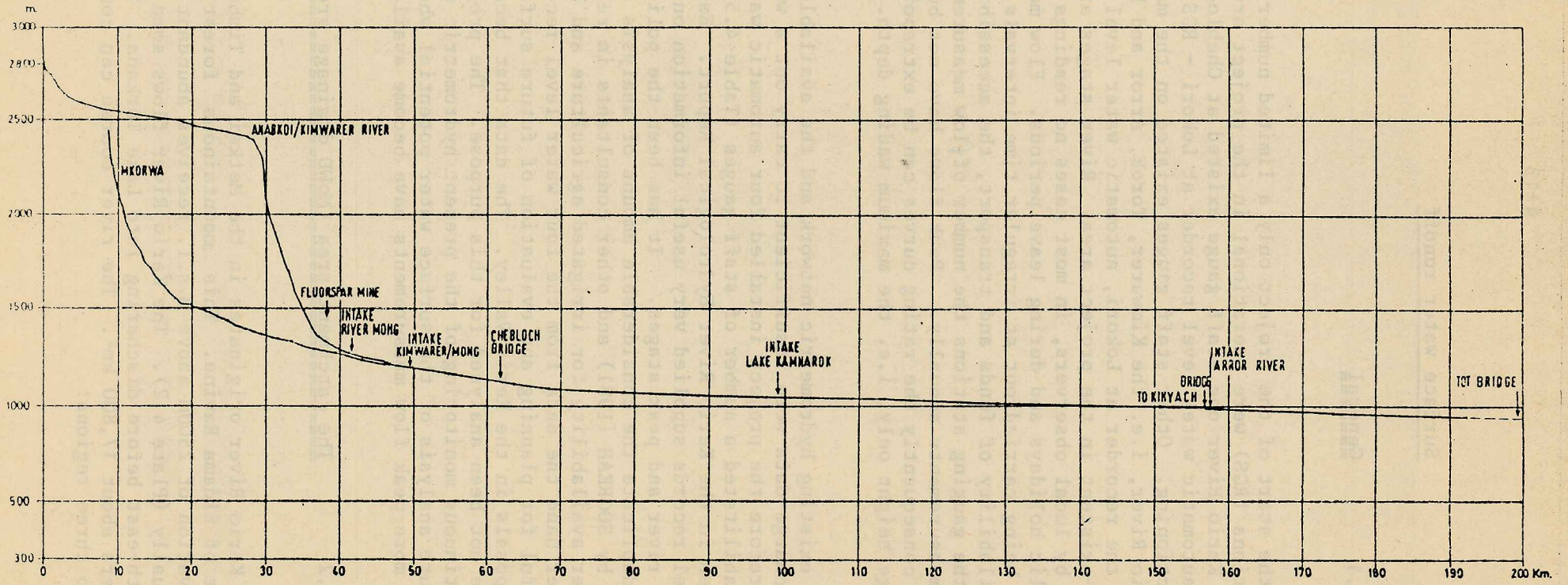


Figure 4.2 Longitudinal river profile

- The upper river course is approximately 60 km long, extending from its source to Chebloch and covering a drainage area of 893 km². Rainfall decreases from 1400 mm in the upper parts to 950 mm annually at Chebloch. There are five major headwater tributaries: the Ainabkoi-Kimwarer, Mong, Endo, Mogorwa and Kiptanoi Rivers. The Ainabkoi is the largest, it drains a substantial area of the highlands north of Timboroa before falling over the southern end of the Elgeyo Escarpment with a single drop of 200 m (Figure 4.2). Beyond the falls, as the Kimwarer River, the slope gradually decreases before emerging into the plains near Kimwarer where it is joined by the Mong and Endo Rivers. At Chebloch the river flows through a deep gorge. Staff gauges exist on the Kimwarer and Mong Rivers - RGS 2C 14/15 respectively, and on the Kerio River some 400 m downstream of the Chebloch bridge - RGS 2C7 (Plate 4.1). An automatic water level recorder monitors here the total outlow of the catchment of the upper river course.

- The middle river course extends over a length of 140 km, from Chebloch to the confluence with the Embobut River, approximately five km downstream of Tot and drains an area of 3000 km² including the catchment of the Embobut River. The Elgeyo Excarpment and the Cherangani Hills further north receive at higher altitudes abundant rainfall of over 1200 mm annually (Plate 4.2) and are densely forested. At the valley floor rainfall is fairly constant at 800-900 mm per yer. Many of the smaller tributaries originating from the Elgeyo Escarpment lose their water before reaching the main river due to evaporation and to some extent because the flows are tapped for traditional irrigation in the immediate vicinity. The only perennial tributaries are the Torok, Arror and Embobut Rivers. The Kerio River itself falls dry at the end of the dry season. The slope of the river reduces from 0.027 at Chebloch to 0.011 at Tot (Figure 4.2).

  The mountain range on the east bank is less steeply sloping, lower and receives considerably less rainfall, approximately 800 - 900 mm annually (Plate 4.2). The most important streams are the Yeptos, Kinyach and Tilingwa Rivers, however none of these rivers are permanent streams. The Yeptos River also supplies water for local irrigation. Some of the rivers feed underground flows which appear downstream as small springs. The yields, however, are limited to 1-5 l/s, most of these springs fall dry at the end of the dry period (Pencol, 1981/1984).

  Lake Kamnarok has been the subject of several studies to enlarge the storage capacity of the lake for irrigation purposes. At present the lake fills up during the wet season and partially empties again during dry periods.

  Staff gauges exist on the Torok River -RGS 2C13, the Arror River - RGS 2C5 in the upper catchment upstream of Kapsowar and - RGS 2C18 near the confluence of the Arror with the Kerio River near Kinyach, and at the Embobut River - RGS 2C12 (Table 4.5). Automatic water level recorders monitor the outflow from the catchments upstream of Kinyach - RGS 2C17 and Tot - RGS 2C16.

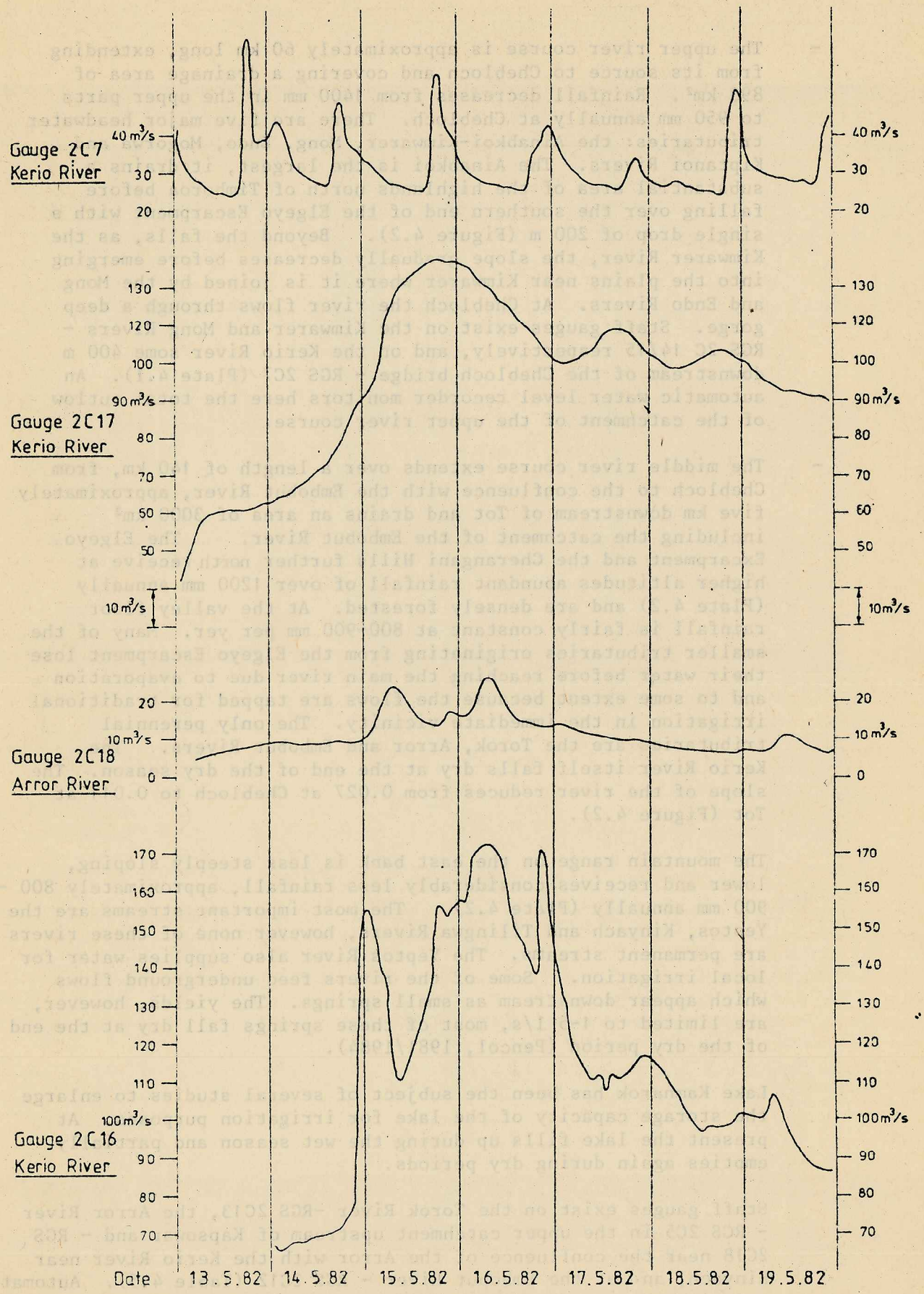


Figure 4.3 Discharge hydrographs

The lower river course extends from Tot to Lake Turkana in the north. Over a distance of some 300 km the river flows through a wide delta, draining approximately 14,000 km². Rainfall decreases rapidly from 800 mm at Tot to less than 200 mm annually near Lake Turkana. High evaporation rates result in semi arid climatic conditions. Rainfall contribution to the Kerio River flow is very little, most of the rainfall evaporates before reaching the river. There is only one gauging station at Lokori - RGS 2C8 equipped with an automatic water level recorder. Unfortunately this station has not been monitored during the project period.

The project activities have been concentrated only on the upper and middle river catchments. Figure 4.3 gives discharge hydrographs to illustrate the different flow regimes of the Kerio River at three sites along the river and of the Arror before joining the Kerio River at Kinyach. Note that most peak flows occur at night time. The travel time between Chebloch - RGS 2C7 and Kinyach - RGS 2C17, total distance 100 km, varies between 20 to 24 hours and between Kinyach and Tot - RGS 2C16, total distance 45 km between 8 to 12 hours.

4.6.3 Discharge rating curves

The stage-discharge relation is defined by the comples interaction of the river channel characteristics, including cross-sectional area, shape, slope and roughness of the river bed. Through a permanent control structure in the river channel, i.e. a weir or a natural control formed by a non-erodable river bed, the relation between river stage and discharge becomes a straight line function when plotted on double logarithmic paper. In case no control structure is present different relations exist during the rising and falling limb of a flood. Most river gauging stations in the project are uncontrolled.

Rating curves are only valid for limited time periods and have to be adopted continuously, especially when the river bed is unstable as a result of scouring and silting. One of the constraints to establish reliable discharge-rating curves is the limited number of peak flow measurements. This certainly is the case with the Kerio River where most peak flows occur around midnight (Figure 4.3). During the rainy season of April/May 1983, an attempt was made to monitor peak flows simultaneously at Chebloch -RGS 2C7, Kinyach RGS 2C17, Tot - RGS 2C16 and at the Arror River - RGS 2C18.

Unfortunately, the early 1983 rainy season appeared to be relatively dry and no extreme floods could be measured. In August 1983 peak flow measurements were repeated at Tot Bridge, and this time some high floods could be measured. The maximum measured flow at Tot was 160 m^3/sec.

The following methods for discharge measurements have been applied by the project:

- by current meter:

  (a) through wading, this method can be applied up to a maximum water depth of one meter (Ott, Braystoke current meter equipment)

  (b) by bridge crane if a suitable bridge is present at an appropriate channel section - RGS 2C16 (Braystoke equipment)

- by float, in case the water depth exceeds one meter and no bridge or cable way is present. This appropriate method gives a rough estimate of the surface velocity. To use this method effectively, the ratio between surface water velocity and average velocity has to be established from regular discharge measurements.

- by the so-called "slope-area" mothod (Chow, 1964). This method is based on the Manning equation (4-1) and requires accurate cross-sections to establish the relationship between the stage (h) and the area (A), and between the stage (h) and the hydraulic radius (R). Both can be plotted in graphs. The Manning roughness coefficient (n) has to be calculated from regular discharge measurements combined with slope measurements.

In order to get a proper insight into the interrelationship between the different parameters, i.e. between surface water velocity and average water velocity and between the slope and the Manning coefficient, the three methods have to be carried out simultaneously. This way peak flows can be fairly accurately estimated in case appropriate equipment for peak flow measurements is lacking.

To extrapolate rating curves beyond the highest measured discharge, high flows are estimated by use of the Manning formula:

$$Q = 1/n \quad A.R.^{2/3}.S^{\frac{1}{2}} \qquad (4\text{-}1)$$

in which
Q = discharge in m^3/s
A = cross-sectional area in m^2
R = hydraulic radius in m
S = surface water slope
n = Manning's roughness coefficient

Under favourable conditions an error of 10-20% may be expected in a slope-area estimate of flow which more or less is double the measuring error in current meter measurements.

The hydrology section of the MoWD has published curves for rvier gauging stations RGS 2C5, 2C7 and 2C12 in the Kerio River catchment. These rating curves, however, needed to be updated. The project tentatively updated and established rating curves for the following stations:

- Kerio River at Chebloch - RGS 2C7 (Annex 4.4.1). Unfortunately no discharge measurements could be made above the 1.47 m stage level. The second part of the curve for stage height above 1.47 m, was established by means of the slope area method in combination with a previously extrapolated curve based on past measurements below 1.47 m as well.

- Kerio River at Kinyach - RGS 2C17 (Annex 4.4.2). The rating curve consists of three sections with different slopes. The first and second sections are based on seven discharge measurements. Because there is no flow at a stage of 0.35 m, the first section is the relationship between measured discharge and observed stage minus 0.35 m. The second section is given by the relationship between measured discharge and stage. No peak flows could be measured and consequently the third section was established by means of the slope-area method.

- Kerio River at Tot - RGS 2C16
  After the dry season of early 1983 the lower inlet pipe had to be lowered by 24 cm, which resulted in different rating curves:

  (a) for the period April 1982 - March 1983 (Annex 4.4.3)
  (b) for the period April 1983 - todate (Annex 4.4.4).

  Both rating curves are based on actual discharge measurement and show a high correlation. The discharge measurements include several peak flow measurements. It appears that this station is fairly stable.

- Arror River at Kapsowar - RGS 2C5 (Annex 4.4.5)
  The published rating curve has been updated provisionally. Except for the period 14/5 - 7/12 1982, for which period a higher coefficient was found, the rating curve is still valid. The data of this station have not been further analysed nor used in this study.

- Arror River at Arror -RGS 2C18 (Annex 4.4.6)
  The rating curve consists of two parts. Both sections are based on discharge measurements and show a high correlation indicating a stable relation between discharge and stage, of a natural control.

4.6.4. Runoff

Daily flows

Runoff figures from previous hydrological studies have been based on daily staff gauge reading at Chebloch - RGS 2C7. As the instanteous peaks occur mostly around midnight, these flow data represent the flows six to ten hours after the recession of flow started. From Figure 4.2 it can be seen that during the rainy season calculated daily flows are considerably under-estimated. Applying the rating curves for each station, the stage hydrographs from the four automatic water level have been elaborated into daily flows.

During floods and peak flows, discharges were calculated at a two hours interval from which the actual daily outflow and the average daily flow could be calculated:

$$\text{total daily outflow} = \sum_{n=1}^{12} (Q_n \times \Delta t) \text{ in } m^3$$

The calculated actual daily flow amounts to 2-20 times the estimated flow based on daily staff gauge readings. Under extreme conditions this figure can be as high as 40 times the estimated flow.

Due to mechanical problems with the operation of the water level recorders, the hydrograph records sometimes show an interruption. In those cases daily flows were estimated from the daily staff gauge readings. Daily flow data for the four river gauge stations are presented in Annex 4.5.

During the observation period the following maximum (instanteous) and minimum flows have been recorded.

Table 4.6 Maximum and minimum flows

	max m^3/s	date	min m^3/s	date or period
Chebloch 2C 7	224.36	27.08.83	0	24.03 - 24.04.83
Kinyach 2C17	201.17	03.12.82	0	24.03 - 24.04.83
Arror 2C18	37.95	05.11.82	0.52	March - April 1983
Tot 2C16	231.88	24.08.83	0.11	04.04.83

Monthly flows

From the daily flows the monthly total outflow and monthly average flows have been calculated (Annex 4.5) and have been summarised in Table 4.7. The only station with a long term record 1964 - 1983 is RGS - 2C7 at Chebloch. The longterm average monthly flows for 2C7 for the period 1965 - 1976, were calculated by SOGREAH, 1981.

In Table 4.8 these figures are compared with the monthly figures from 1982 and 1983.

Table 4.7 Monthly flow data 1982

Catchment			JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
RGS 2017	2471 km²	Total $\times 10^6 m^3$				15.468	63.823	28.169	57.230	45.389	8.857	7.199	54.864	81.199
		Monthly mean				6.54	23.83	10.87	21.37	17.32	3.42	2.69	21.16	30.32
		Daily max.				92.04	113.72	30.17	107.26	79.43	16.46	38.14	86.30	177.22
		Daily min.				0.02	0.68	1.72	1.24	2.55	1.24	1.14	1.35	9.86
		Runoff in mm.				18.5	71.5	31.5	64.0	52.0	10.0	8.0	61.5	91.0
		Rainfall in mm.				350	260	60	90	160	80	130	310	90
		Runoff/Rainfall				0.05	0.28	0.53	0.71	0.33	0.13	0.06	0.20	1.01
		Evap. in mm.	220	210	270	150	140	130	150	130	170	140	150	130
Between 2017-17	1378 km²	Total $\times 10^6 m^3$				+ 87.03	+ 98.39	+ 27.19	- 44.48	- 10.58	+ 2.05	+ 2.19	+ 35.64	+ 61.63
		Monthly mean				+ 83.58	+ 36.73	+ 10.49	- 16.61	- 3.95	+ 0.79	+ 0.82	+ 13.75	+ 23.01
		Daily max.												
		Daily min.												
		Runoff in mm.				+ 55.0	+ 62.5	+ 17.0	- 28.0	- 6.5	+ 1.5	+ 1.5	+ 22.5	+ 39.0
		Rainfall in mm.				330	210	30	50	100	50	110	210	60
		Runoff/Rainfall				0.17	0.30	0.57	-	-	0.03	0.01	0.11	0.65
		Evap. in mm.	270	260	320	190	200	170	180	160	180	180	150	190
RGS 2017	2471 km²	Total $\times 10^6 m^3$				103.5	162.213	55.363	12.750	35.805	10.909	9.390	90.487	142.825
		Monthly mean				39.90	60.56	21.36	4.76	13.37	4.21	3.51	34.91	53.32
		Daily max.				124.92	125.45	110.80	26.74	41.60	10.95	20.23	112.98	201.17
		Daily min.				0.09	11.86	4.79	2.38	2.19	2.10	1.11	2.99	9.54
		Runoff in mm.				42.0	65.5	22.5	5.0	14.5	4.5	4.0	36.5	58.0
		Rainfall in mm.				340	230	40	70	120	60	120	250	70
		Runoff/Rainfall				0.12	0.28	0.56	0.07	0.12	0.08	0.03	0.15	0.83
		Evap. in mm.	250	240	300	180	180	160	170	150	180	160	160	170
2018	976 km²	Total $\times 10^6 m^3$				8.988	15.021	3.704	2.136	8.222	1.738	7.876	20.962	10.805
		Monthly mean				3.47	5.58	1.43	0.80	3.07	0.67	2.94	8.09	4.03
		Daily max.				22.16	25.97	6.03	8.70	16.90	1.33	29.32	37.95	23.63
		Daily min.				0.74	2.04	0.52	0.17	0.71	0.49	0.42	2.04	1.31
		Runoff in mm.				32.5	54.0	13.5	7.5	29.5	6.0	28.5	75.5	39.0
		Rainfall in mm.				300	220	40	90	160	80	140	180	60
		Runoff/Rainfall				0.11	0.25	0.34	0.08	0.18	0.08	0.20	0.42	0.65
		Evap. in mm.	150	140	200	90	100	80	120	90	150	120	100	170
Between 20.-19	1494 km²	Total $\times 10^6 m^3$				+ 7.51	- 2.23	+ 2.93	- 1.89	+ 1.53	- 0.17	- 4.24	- 31.45	- 28.63
		Monthly mean				+ 2.90	- 0.83	+ 1.13	- 0.71	+ 0.57	- 0.07	- 1.57	- 12.13	- 10.69
		Daily min.												
		Runoff in mm.				+ 8.0	- 2.5	+ 3.0	- 2.0	+ 1.5	- 0.0	- 4.5	- 32.5	- 30.0
		Rainfall in mm.				230	180	40	60	120	70	100	180	50
		Runoff/Rainfall				0.03	-	0.08	-	0.01	-	-	-	-
		Evap. in mm.	260	260	320	180	200	170	180	190	190	190	170	160
RGS 2019	3710 km²	Total $\times 10^6 m^3$				120.0	175.0	62.0	13.0	45.553	12.480	13.028	80.0	125.0
		Monthly mean				52.34	70.79	28.78	5.22	17.01	4.82	4.81	26.10	75.10
		Daily max.				210.00	161.37	147.93	10.58	38.02	22.77	23.98	133.11	181.89
		Daily min.				4.19	24.88	7.37	2.30	3.15	2.05	1.67	5.83	8.0
		Runoff in mm.				32.5	47.0	16.5	3.5	12.5	3.5	3.5	21.5	33.5
		Rainfall in mm.				310.	210	40	70	130	60	120	220	70
		Runoff/Rainfall				0.10	0.22	0.41	0.05	0.10	0.06	0.03	0.10	0.48
		Evap. in mm.	260	260	320	180	200	170	190	190	190	190	160	160

Table 4.7.2 Monthly flow data 1983

		JANUARY	FEBRUARY	MARCH	TOTAL APRIL - MARCH	APRIL	MAY	TOTAL JUNE - MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
961 km²	Total $\times 10^6 m^3$	5.939	0.964	0.5	371.58	3.810	26.498	321.60	9.724	40.769	102.259				
	Monthly mean	2.22	0.40	0.2	11.78	1.58	9.89	10.20	3.75	15.22	38.18				
	Daily max.	9.86	0.74	0.36	177.22	63.02	92.77	177.22	11.27	108.06	224.36	113.72			
	Daily min.	0.32	0.22	0.00	0.00	2.02	1.72	0.00	1.87	10.53	10.53	27.49			
	Runoff in mm.	6.5	1.0	0.5	420	4.5	29.5	360	11.0	45.5	114.5				
	Rainfall in mm.	10	50	20	1620	125	160	1290	11.0	170					
	Runoff/Rainfall	0.65	0.02	0.03	0.26	0.04	0.18	0.28	0.10	0.27					
	Evap. in mm.	180	170.	240	1880	190	150	1930	150	130	130	140	170	140	150
1578 km²	Total $\times 10^6 m^3$	+ 5.773	+ 3.143	+ 0.01	+ 267.99	- 2.393	- 8.219	+ 72.0	+ 0.718	+ 0.604	+ 24.479				
	Monthly mean	+ 2.15	+ 1.30	0.0	+ 8.50	- 1.03	- 3.06	+ 2.28	+ 0.28	+ 0.19	+ 9.14				
	Daily max.														
	Daily min.														
	Runoff in mm.	+ 3.5	+ 2.0	-	170	- 1.5	- 5.0	+ 50	+ 0.5	+ 0.5	+ 15.5				
	Rainfall in mm	10	40	10	1210	110.	120	900	70	100					
	Runoff/Rainfall	0.35	0.05	-	0.14	-	-	0.05	0.01	0.01					
	Evap. in mm	190	180	250	2230	180	170	2190	150	140	130	150	180	160	170
2371 km²	Total $\times 10^6 m^3$	11.712	4.107	0.510	639.57	1.417	18.279	393.55	10.442	41.373	126.738	134.964	79.681	28.920	
	Monthly mean	4.37	1.70	0.19	20.28	0.55	6.83	12.48	4.03	15.41	47.32	52.07	29.75	11.16	
	Daily max.	9.54	3.86	1.03	201.17	6.89	25.0	201.17	17.60	47.88	138.95	105.78	62.37	29.59	
	Daily min.	2.01	1.03	0.00	0.00	0.00	2.60	0.00	1.92	2.50	5.00	13.84	10.37	5.52	
	Runoff in mm.	4.5	1.5	0.5	260	0.5	7.5	160	4.0	16.5	51.5	54.5	32.0	11.5	
	Rainfall in mm.	10	40	10	1360	120	130	1040	90	120					
	Runoff/Rainfall	0.45	0.04	0.05	0.19	0.01	0.06	0.15	0.04	0.14					
	Evap. in mm.	190	170	250	2120	180	160	2100	150	140	130	140	180	150	160
2764 km²	Total $\times 10^6 m^3$	2.428	1.704	1.515	85.10	2.291	7.658	71.04	2.604	4.323	10.167	3.249	10.363	8.993	
	Monthly mean	0.91	0.70	0.57	2.7	0.88	2.86	2.25	1.00	1.61	3.80	1.25	3.87	3.47	
	Daily max.	1.33	1.65	1.07	37.95	6.63	20.75	37.95	3.77	6.03	18.12	6.95	14.63	23.63	
	Daily min.	0.62	0.56	0.52	0.52	0.52	0.88	0.52	0.56	0.60	0.60	0.75	0.75	0.79	
	Runoff in mm.	8.5	6.0	5.5	310	8.0	27.5	260	9.5	15.5	36.5	11.5	27.5	32.5	
	Rainfall in mm.	30	30	20	1370	150	140	1140	90	80					
	Runoff/Rainfall	0.28	0.2	0.28	0.23	0.05	0.20	0.23	0.11	0.19					
	Evap. in mm	140	130	140	1430	130	130	1500	110	90	110	100	130	110	110
961 km²	Total $\times 10^6 m^3$	- 6.64	- 3.81	- 1.13	- 68.21	- 0.57	- 0.02	- 74.1	- 0.57	- 5.12	+ 23.83	- 3.86	+ 0.70	- 2.23	
	Monthly mean	- 2.48	- 1.58	- 0.42	- 2.16	- 0.22	- 0.01	- 2.35	- 0.22	- 1.91	+ 8.90	- 1.49	+ 0.26	- 0.86	
	Daily max.														
	Daily min.														
	Runoff in mm.	- 7.0	- 4.0	- 1.0	-	- 0.5	- 0.0	-	- 0.5	5.5	+ 25.0	- 4.0	+ 0.5	- 2.5	
	Rainfall in mm.	10	20	10	1070	110	90	860	100	100					
	Runoff/Rainfall	-													
	Evap. in mm.	190	180	260	2260	180	180	2240	170	140	160	160	180	160	170
3710 km²	Total $\times 10^6 m^3$	7.500	2.000	0.900	656.46	3.140	25.921	390.5	12.480	40.57	160.733	134.349	90.743	35.685	
	Monthly mean	3.96	0.84	0.36	20.82	1.21	9.68	12.38	4.81	15.15	60.01	51.80	33.88	13.77	
	Daily max.	8.09	1.04	0.59	210.00	15.15	33.56	210.00	25.80	39.74	231.88	124.33	170.76	32.01	
	Daily min.	0.94	0.61	0.13	0.13	0.11	4.28	0.13	1.77	2.10	5.15	16.50	12.39	4.85	
	Runoff in mm.	2.0	0.5	0.5	180	1.0	7.0	110	3.5	11.0	43.5	36.0	24.5	9.5	
	Rainfall in mm.	10	40	10	1290	120	130	1010	90	110					
	Runoff/Rainfall	0.20	0.01	0.05	0.14	0.01	0.05	0.13	0.04	0.10					
	Evap. in mm.	190	170	240		180	160	2090	150	140	140	140	180	150	160

Table 4.8 Monthly flow data at Chebloch - RGS 2C7

	1965 - 1976*)		1982	1983
	average m^3/s	standard deviation	m^3/s	m^3/s
January	0.62	0.60		2.22
February	1.06	1.05		0.40
March	1.38	1.76		0.20
April	6.69	6.93	6.54	1.58
May	13.57	17.3	23.83	9.89
June	3.76	2.62	10.87	3.75
July	5.33	4.48	21.37	15.22
August	6.97	5.36	17.32	38.18
September	5.06	4.09	3.42	
October	1.24	0.72	2.69	
November	3.21	4.36	21.16	
December	3.04	4.36	30.32	
Annual mean	4.36	2.49		
April '82 - March '83 mean value			11.70	
September '82 - August '83 mean value			10.75	

*) SOGREAH, 1981 data based on daily staff gauge readings

The considerable differences are not only due to under-estimated flows from daily staff gauge readings but as well due to the above average rainfall. Also the monthly rainfall distribution over 1982 and 1983 is not representative for an average year. The monthly flows from the other stations could not be compared with previous records.

Monthly rainfall and evaporation figures have been estimated for each catchment area, and are presented in Table 4.7 together with the monthly runoff depth and the runoff rainfall ratio. The runoff rainfall relationship depends on numerous factors and requires among other proper hydrograph analysis and continous monitoring of rainfall with automatic rainfall recorders. The presented runoff rainfall ratios were calculated in an attempt to compare the runoff rainfall ratios for different catchment areas. However, on a monthly basis no definitve conclusions could be drawn.

In Table 4.7 the monthly flow data for the catchment areas between two river gauging stations have been calculated as well. These data are not consistent, indicating that the rating curves for the upstream and downstream stations are not completely in balance. Unavoidable inaccuracies in the two rating curves accumulate in the monthly flow data for the catchment area in between, therefore not too much value should be given to these figures.

Annual flows

The Hydrology Section of the MoWD normally presents annual flow data as per calendar year. However, the present period of record for the automatic water level recorder April 1982 - August/November 1983 does not cover a calendar year. Therefore annual flows are presented as per hydrological year. The hydrological year was taken from April, i.e. start of the early rains, to March, i.e. end of dry season. However, 1982 appeared to be an extremely wet year, particularly the months April, May and November. To eliminate the effect of the heavy rainfall during April and May 1982, the annual runoff for the period April 1982 - March 1983 has been compared with the rainfall for the period June 1982 - May 1983 for each station (Table 4.9). The annual runoff rainfall ratios for the two periods were averaged. To estimate the "average year" annual outflow the height of the longterm average rainfall was calculated for each catchment area on the basis of the isohyetal map (Plate 4.2).

It appears that the annual figures for the period June 1982 - May 1983 are fairly well comparable to the "average year" figures.

Table 4.9 Annual flows

		1982 April-March	1983 June-May	Average Year
RGS-2C7, Kerio River at Chebloch				
1) Total outflow	$m^3 \times 10^6$	371.58	321.60	310
2) Mean annual flow	m^3/s	11.78	10.20	10
3) Runoff depth	mm	420	360	350
4) Rainfall depth	mm	1620	1290	1300
5) Runoff-rainfall ratio		0.26	0.28	0.27
RGS -2X17, Kerio at Kinyach				
1) Total outflow	$m^3 \times 10^6$	639.57	393.55	460
2) Mean annual flow	m^3/s	20.28	12.48	14.5
3) Runoff depth	mm	260	160	190
4) Rainfall depth	mm	1360	1040	1100
5) Runoff-rainfall ration		0.19	0.15	0.17
RGS - 2C18, Arror River at Arror				
1) Total outflow	$m^3 \times 10^6$	85.10	71.04	80
2) Mean annual flow	m^3/s	2.70	2.25	2.5
3) Runoff depth	mm	310	260	300
4) Rainfall depth	mm	1370	1140	1300
5) Runoff-rainfall ratio		0.23	0.23	0.23
RGS- 2C16, Kerio River at Tot				
1) Total outflow	$m^3 \times 10^6$	656.46	390.52	480
2) Mean annual flow	m^3/s	20.82	12.38	15
3) Runoff depth	mm	180	110	130
4) Rainfall depth	mm	1290	1010	1000
5) Runoff-rainfall ratio		0.14	0.11	0.13

By comparing the SOGREAH (1981) figures for Chebloch - RGS 2C7 with the figures from Table 4.9 the rate of under estimation of the annual outflow based on daily staff gauge readings can roughly be established. In Table 4.10 the SOGREAH (1981) figures have been summarised.

Table 4.10 Summarised data from SOGREAH for RGS - 2C7

1) Total outflow	$m^3 \times 10^6$	137.50	160.75
2) Mean annual flow	m^3/s	4.36	5.10
3) Runoff depth	mm	150	180
4) Rainfall depth	mm	1180	1180
5) Runoff/rainfall ratio		0.13	0.15

The first column gives figures based on the longterm (1965 - 1976) average annual flow (Table 4.8), the figures from the second column are based on estimates. These figures indicate that for the catchment area monitored by RGS - 2C7 the annual outflow estimated from daily staff gauge readings is approximately 30 to 40% lower than the actual calculated outflow from the hydrograph.

4.7 Water balance

The components of the water balance generally taken into account are given by the following equations:-

Precipitation = Evaporation + Runoff + Percolation + Change in soil moisture content + Change in surface water retention.

If the water balance is calculated over a one-year period it can be assumed by first approximation that the soil moisture content and the surface water retention at the beginning of the year are equal to the values at the end of the one-year calculation period. Thus both terms become zero, and the equation simplifies to:-

$$P = E_a + R + G$$

where P = average rainfall in mm

E_a = actual evapotranspiration

R = surface water runoff

G = groundwater recharge or percolation

From the annual water balance the percolation can be assessed;

the percolation equals the rainfall minus the surface water runoff and the actual evaporation:

$$G = P - E_a - R$$

However, in practise it becomes very difficult to give a relatively accurate figure for the actual evapotranspiration. This would require additional studies on the vegetation pattern, cover and the consumptive use for each type of vegetation, trees, bushes and crops. Therefore the water balance study has been approached from the other end. Under the topographical and hydrogeological conditions of the Kerio Valley the law of continuity results in the equation, that the groundwater outflow Q at a certain point equals the total groundwater recharge G from the catchment area upstream of that point.

In section 5.5.3 the groundwater outflow to the north has been calculated at Chebloch, Kinyach and Tot. From these calculations it appears that the expected average groundwater outflow and thus the annual groundwater recharge is very limited. The groundwater recharge is in the order of less than 1‰ of the annual rainfall, which is in fact negligible in comparison to the other water blanace components.

The water balance data for each catchment for the period June 1982 - May 1983 are summarised in Table 4.11

Table 4.11 Water balance data

Catchment areas		2C7	Between 2C7/17	2C17	2C18	Between 2C17/16	2C16
Total outflow	$m^3 \times 10^6$	321.6	72.0	393.6	71.0	(-) 74.1	390.5
Runoff depth	mm/yr	360	50	160	260	-	110
Rainfall depth	mm/yr	1290	900	1040	1140	860	1010
Runoff/Rainfall ratio		0.28	0.05	0.15	0.23	-	0.13
Evaporation	mm/yr	1930	2180	2100	1500	2260	2090
Evapotranspiration	mm/yr	930	850	880	880	> 860	900

The observed loss in annual flow between Kinyach - RGS 2C17 and Tot - RGS 2C16 is the difference in annual flow between the total flow from the Kerio River at Kinyach plus the flow from the Arror - RGS 2C18 and the flow measured at Tot. As explained before, the hydrogeological conditions are such that it is very questionable that this amount of water could be considered as a contribution to the sub-surface flow. Neither is it probable that these losses can be explained by evapotranspiration.

This would indicate that the observed losses are the result of accumulated errors in the flow figures from the upstream and downstream station. This question can only be solved if more reliable rating curves have become available. Another possibility is that the flow from the Arror into the Kerio River is considerably smaller, due to local irrigation practices between the gauging station and the confluence. However, this has not been checked.

4.8 Surface water quality

4.8.1 General characteristics

Twentyfour partial analyses of surface water from the Kerio River and some of its tributaries could be traced in the files of the MoWD. More than half of the analyses were carried out in 1975, the five most recent analyses dated from 1981. The available surface water quality data are presented in Annex 4.6.1. During the present study the surface water quality was monitored at 21 sites. The sampling sites are shown on Plate 4.1. In total, 98 surface water samples have been collected between November 1982 and October 1983. The number of samples per site vary between one and seven.

The majority of samples were analysed in the laboratory of the Ministry of Water Development. Part of the samples from the first and the last sampling campaign were analysed by the Government Chemist's Department. The results of the analyses are listed in Annex 4.6.2. The most complete data are available for November 1982. The samples were collected at all sites, except one, and the analyses of 11 samples include all major ions. In the other 10 samples only potassium analysis is lacking. Despite the fact that not all analyses can be considered as accurate (because of an unbalanced anion-catian sum), the November results provide the best means for comparing the analyses with each other. The analyses are summarised in Table 4.12 and graphically represented in Figure 4.4.

The total dissolved solid content (TDS) vary from 32 to 300 mg/l. In the majority of samples (16), the TDS content does not exceed 100 mg/l and the water can therefore be classified as low mineralised water. The bicarbonate is the major anion in all samples. As for the catians either sodium or calcium predominate. Some of the samples show a relatively high Fe-content. The samples collected in the Kerio River at various sections show only slight differences in the TDS-content.

Generally speaking, the TDS content of water in Kerio River increases towards the north and the water type changes from Na-HCO_3, at Kimwarer to Ca-HCO_3 at Tot . The increase of calcium concentration can probably be attributed to the solution of marble which occur in the Basement rocks. The calcium rich water is supplied to the Kerio River through the tributaries on the Escarpment side of the valley, as indicated in the Ca-HCO_3 water type found at sampling sites 15 (Embamachutkwa River), 12 (Arror River) and 21 (Embobut River).

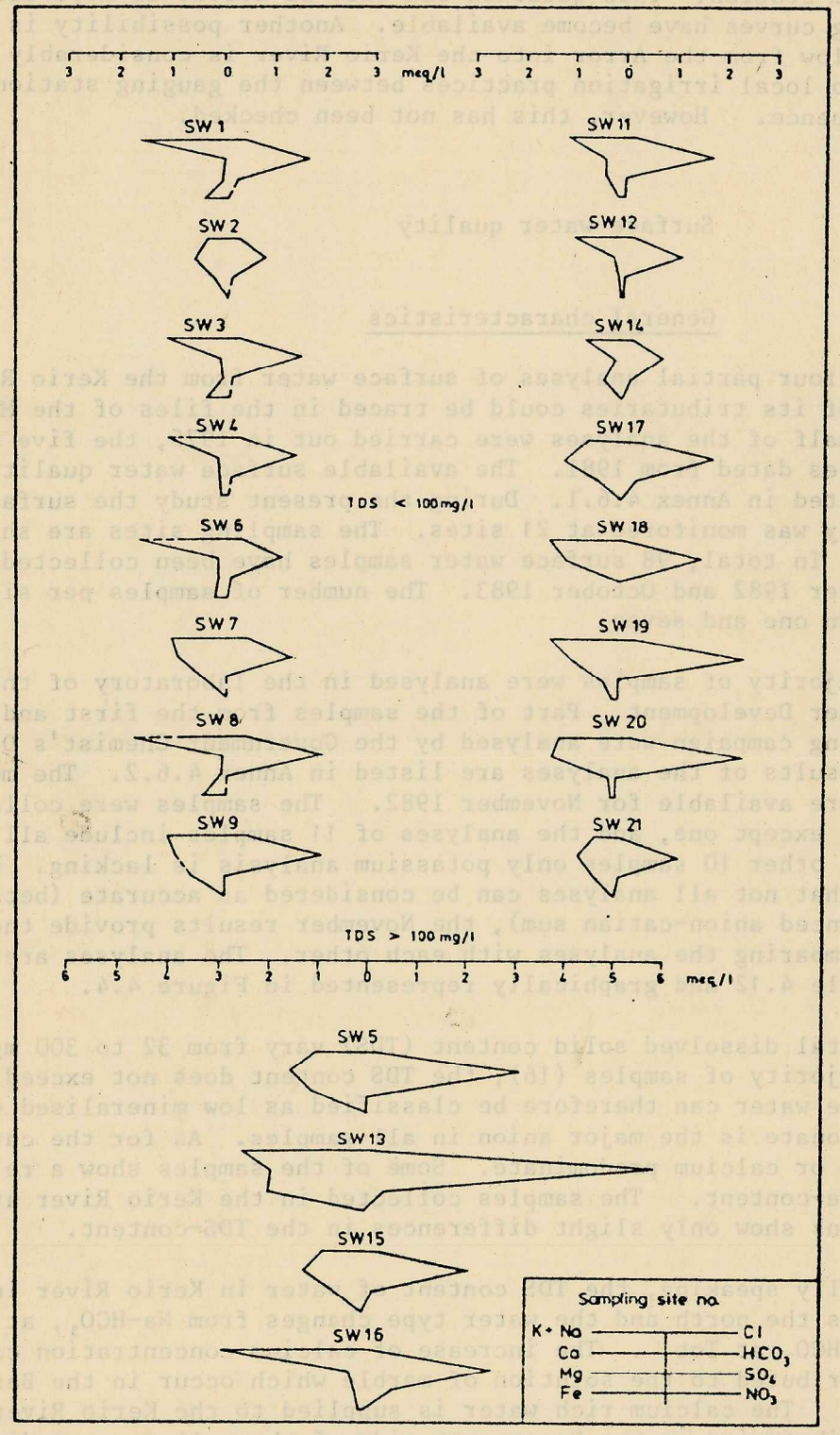


Figure 4.4 Stiff diagrams of surface water

Table 4.12 Surface water quality, November 1982

Sample Site No.	Source*	pH	EC µS	mg/l Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2	Hard. **	TDS (mg/l)
SW 1	Mong River	6.8	76	14	-	0.5	0.4	6.4	0.1	6	49	5	-	0.2	-	14	46
SW 2	Kimwarer River	6.5	54	5.0	-	5.8	1.4	0.2	0.1	5	24	0.5	-	0.1	-	21	32
SW 3	Kerio River	7.0	76	12	-	1.2	0.6	6.0	0.1	6	44	2	-	0.3		16	46
SW 4	Kimwarer/Mong	6.8	62	9.0	-	1.9	1.0	2.2	0.0	5	39	2	-	0.3		13	37
SW 5	Mokorwa River	8.0	280	24	-	30	13	1.5	0.0	7	195	2	-	0.4		130	168
SW 6	Kailel Stream	7.3	80	11	-	2.0	1.0	4.1	0.1	4	63	1	-	0.3		17	48
SW 7	Kerio River	6.4	80	12	-	9.2	3.3	0.7	0.2	7	39	0	-	0.3		38	48
SW 8	Lake Kamnarok	6.9	80	11	-	0.6	0.4	7.1	0.1	7	59	0	-	0.6		16	48
SW 9	Kabluk Spring	6.1	92	13	-	9.7	2.1	0.1	0.0	8	59	0		0.3		33	55
SW 11	Erron River	7.6	86	11	3.6	4	1.9	1.6	-	2	54	0	0.0	0.4	20	18	51
SW 12	Kirumb. River	7.6	59	8.5	3.5	2.4	0.5	0.8		2	34	0	0.0	0.3	28	8	35
SW 13	Musgut Supply	7.7	500	53	7.8	38	24	0.0	-	8	354	20	0.0	1.4	32	196	300
SW 14	Torok River	8.1	49	6.6	1.5	1.6	1.9	0.0	0.0	4	24	3	0.0	0.3	0	12	29
SW 15	Embamach River	8.7	240	15	6.2	24	7.6	0.0	0.0	10	136	10	0.0	0.4	0	92	144
SW 16	Kinai Spring	7.6	270	62	9.1	4.8	1.4	1.8	0.0	2	165	28	1.5	4.4	0	18	162
SW 17	Arror River	8.8	93	5.3	2.2	11.2	2.9	0.0	0.0	2	58	7	0.0	0.3	0	40	56
SW 18	Kinyach River	7.7	97	14	4.3	5.6	0.0	0.3	-	1	53	1	0.0	1.0	16	14	58
SW 19	Kerio River	7.9	117	12	4.6	9.6	1.9	1.3	-	2	73	0	0.0	1.1	12	32	70
SW 20	Kerio River	7.7	126	11	4.0	13	1.0	0.9	-	2	78	0	0.0	0.8	12	36	75
SW 21	Embobut River	6.9	65	3.3	0.9	7.2	1.9	0.0	-	1	39	2	0.0	0.2	12	26	39

*for location see Plate 4.1 ** Tot. hardness in $mgCaCo_3/l$ - not determined

Lake Kamnarok and the streams which drains the volcanic rocks on the eastern side of the valley contains low mineralised water of Na-HCO_3 type. An exception is found in the sample from Mokorwa River (Site 5) which contain moderately mineralised Ca-HCO_3 water, with a relatively high Mg concentration. The sample from the Kipnai Spring, (Site 16) contain water of a similar type as the groundwater found in nearby borehole C 5470 (see section 5.5.4). The highest TDS content was found in a smple of tap water from the Muskut Dispensary (Site 13). This water, which has its source in a small stream north of the village, contains a high concentration of sodium and bicarbonate. Also the Ca^{2+}, Mg^{2+} and SO_4^{2-} concentrations are relatively high.

4.8.2 Fluoride content of surface water

The effluent from Fluorspare Mine at Kimwarer, the fluorite deposits in Basement rocks from the fluoride rich spring water from volcanics rocks of Tugen Hills are potential sources of fluoride in surface water.

The samples from Kimwarer River, taken in May 1975 upstream of the confluence with the Mong River, (Annex 4.6.1), showed a clear pollution from the Fluorspar Mine. The high EC and pH-values and the extremely high iron (60 mg/l) and fluoride concentration (165 (?) mg/l) must be attributed to the effluent from the mine. Relative high Fe and F concentration in the Kerio River were found at the Chebloch bridge.

In samples from November 1983, the fluoride concentration in the Kerio River up to Arror does not exceed 0.5 mg/l. The increase of fluoride at Arror (to 1.1 mg/l) can probably be attributed to the natural sources from the tributaries, which drains volcanics rocks of Tugen Hills. The springs which feed streams may contain a high fluoride concentration as showed at Kipnai spring (site no.16), where a concentration of 4.4 mg/l was found.

A fluoride concentration of 1.4 mg/l found in sampling site no.13 at Muskut may have its source in the fluoride deposits, which occur in this area.

The analyses of November 1983 samples showed, that with one exception (site no.16), all sampling sites contained water with a fluoride content within the WHO-limit.

4.8.2 Water quality variations

Composition of surface water is subject to rapid changes in time. A single sample can therefore never be considered as a representative one for a long period. A frequent sample collection is necessary to monitor the eventual changes in the water quality. As already mentioned, the number of samples per site vary between one and seven. (see Annex 4.6.2).

In Table 4.13, the ranges of total dissolved solid (TDS) content and the fluoride concentration are listed per site. As for the TDS content, considerable differences occurs between the maximum and minimum values. However, water in all samples can still be classified as low to moderately mineralised. The comparison of TDS contents of water in Kerio River with the discharges measurements (Section 4.6.4) indicates that the TDS content is inversely proportional to the total discharge rate. A low TDS content during a high discharge can be attributed to a dilution effect by the rain water.

The fluoride concentrations show also large variation, but the absolute values at the majority of samples remain low. As for the rivers, a concentration exceeding 1.5 mg/l has been found only in one sample from the Kerio River and one sample from the Muskut River. The four samples from the Kipnai Spring showed high F concentration, ranging from 4 to 9 mg/l.

Table 4.13 Ranges of TDS-content and fluoride concentration in surface water.

Sampling Site	Number of sample's	TDS-range (mg/l)	F-range (mg/l)
SW 1	6	43- 60	0.1-0.4
2	7	18- 90	0.0-0.3
3	5	46-108	0.3-0.7
4	6	36- 90	0.3-0.5
5	5	60-180	0.5-0.8
6	3	48-114	0.3-0.8
7	7	48-126	0.1-0.6
8	5	48-120	0.6-1.5
9	5	50- 63	0.2-0.6
10	5	48- 82	0.1-0.6
11	1	51	0.4

Sampling Site	Number of sample's	TDS-range (mg/l)	F-range (mg/l)
SW 12	1	34	0.3
13	6	300- 480	1.0-1.6
14	7	18- 62	0.1-0.3
15	2	144- 240	0.4-0.6
16	4	162- 480	4.4-9.0
17	4	42- 150	0.1-0.5
18	2	58	1.0
19	5	42- 258	0.5-2.5
20	5	60- 180	0.1-0.8
21	7	39- 66	0.1-0.2

Generally speaking, the surface water in the Kerio River, its major tributaries and Lake Kamnarok is of good anorganic quality. High suspended load content and possibly organic pollution (no data available) may limit the direct use of surface water for the drinking purposes.

5. HYDROGEOLOGY

5.1 Previous hydrogeological studies

A first general approach for the assessment of groundwater resources in the Kerio Valley is found in the National Master Water Plan (TAMS, 1980). Referring to the geological conditions, this study assumes that rock formations in the Kerio Valley could be among the most productive in Kenya's semi-arid zones.

A Water Resources study for the Kerio Valley Basin by SOGREAH (1981) concluded that from geological point of view, sufficient groundwater resources for domestic use could exist in the upper valley of the Kerio River (present project area). An estimated value of 2.0% of annual rainfall was used to approximate the available groundwater resources, yielding an order of magnitude of 0.5 $l/s/km^2$. However, the authors stressed that this value cannot be considered as anything more than a guess, since very few hydrogeological data were available.

The Central Baringo Development Plan (PENCOL, 1981) deals, among other things with the groundwater conditions of the eastern side of the Kerio Valley. The weathered land surfaces and fractures in volcanic rocks are assumed to be the most common aquifer type. Also the sedimentary deposits in the Kerio Valley are assumed to have favourable groundwater potential. However no quantitative aspects of groundwater resources could be given because of very limited amount of information available from boreholes.

All above studies stressed a need for additional hydrogeological data.

5.2 Available data

5.2.1 Aerial photographs

The project area is covered by seventy photographs, distributed over three flight lines. The photographs are printed on 1:62,000 scale. The interpretation of aerial photographs yielded information on the accessibility of the area, drainage pattern, lithological boundaries and structure (see Annex 5.1).

5.2.2 Boreholes

During the inventory phase of the study, four boreholes could be traced in the files of the Ministry of Water Development. However, only two boreholes were located in the field - C 4838 near Kabluk and C 1167 in the surroundings of Rimoi. The project has selected 13 additional borehole sites. Four criteria have been considered to determine new sites:

Table 5.1 Borehole data

Borehole Number	Location	Coordinates X	Coordinates Y	Sheet No.	Surface Elevation (m + msl)	Total depth (m)	Completion data	Water struck level depth (m)	Water struck level elevation (m + msl)	Water rest level depth (m)	Water rest level elevation (m + msl)	Geol.log	Geoph.log	Well test	W. sample	Aq. syst.*
C 1167	Rimoi	7858	0795	90/3	1220	160	23-10-50	76	1144	76	1144	X	-	X	-	4
C 4838	Kabluk	7958	0642	90/3	1110	143	9-01-81	5 & 84	1105	4 & 14	1106	X	-	X	-	1b/a
C 5112	Chebloch	7935	0501	104/1	1150	120	5-07-82	32 & 47	1118 1103	28.2 & 27.7	1122 1122	X	X	X	X	1b/a
C 5170	Kiboino	7988	0514	104/1	1420	120	21-09-82	28 & 58	1392 1362	18.7 & 18.4	1401 1401	X	X	X	X	1a
C 5211	Kimwarer	7975	0347	104/1	1340	125	20-10-83	38 & 115	1302 1225	28.0 & 22.0	1312 1318	X	X	X	X	1a
C 5212	Kimwarer Farm	7942	0397	104/1	1310	97	8-11-82	85	1225	69.3	1241	X	X	-	X	1b
C 5268	Torok	7851	0610	90/3	1200	88	24-02-83	13 & 42	1187 1118	10.3 & 13.8	1190 1186	X	X	X	X	2
C 5269	Torok East	7885	0616	90/3	1090	56	26-02-83	28 & 51	1062 1039	19.5 18.8	1070 1071	X	X	X	X	1b
C 5333	Kolowa	8067	1354	76/4	960	75	4-08-83	10	950	9.7	950	X	X	X	X	3b
C 5334	Rimoi Farm	7855	0670	90/3	1130	100	13-06-83	75	1055	70.2	1060	X	X	X	X	1b
C 5346	Tot Centre	7964	1333	76/3	1020	96	14-07-83	60	960	41.4	979	X	X	X	X	4
C 5349	Tot Bridge	8003	1343	76/3	940	23	27-07-83	8	932	7.0	933	X	-	X	X	3a
C 5350	Tot East	7978	1337	76/3	985	69	27-06-83	58	927	40.8	944	X	X	-	X	1b
C 5370	Mokorwa	8023	0345	104/1	1400	55	30-08-83	37 & 42	1363 1358	30.1 & 29.7	1370 1370	X	-	X	X	1a
C 5487	Kinyach	7977	1035	90/1	1070	55	23-11-83	8 & 26	1062 1044	10.1 & 10.0	1060 1060	X	-	X	X	1a

* see section 5.4

- hydrogeological reconnaissance
- geophysical correlation
- monitoring network
- water demand.

The location of boreholes is shown on Plate 5.1. The boreholes have been drilled with percussion rigs to a maximum depth of 125 m. Data on the boreholes are summarized in Table 5.1 and 12 geological logs are presented in Annex 5.2. The logs are based on the samples, collected during drilling at one or two meter intervals.

5.2.3 Auger holes

From September till November 1983, the shallow water table has been investigated in the surroundings of Lake Kamnarok. Twenty-six holes were drilled by means of Edelman hand auger to a maximum depth of 13 m. The location of the auger holes and the drilling data are given in Annex 5.3.

5.2.4 Well-test data

The data obtained from a well test in borehole C 4838 in March 1981 are not suitable for a reliable analysis. Eleven well tests and two bailer tests have been carried out during the present study. Data obtained from well tests have been analysed using Jacob's method for the pumping phase and Theis's method for the recovery data (Kruseman and de Ridder, 1970). The analyses are shown in Annex 5.4 and the results are summarized in Table 5.2. The transmissivity value (T=hydraulic conductivity times thickness of the aquifer) obtained from the recovery phase are considered more reliable than the values obtained from the pumping phase, since the former is not directly influenced by the discharge variation.

The specific capacity is another parameter derived from the well test. The specific capacity of a well is the yield produced per meter drawdown (Q/s in m^2/day). The specific capacity can be used to estimate the well yield corresponding to a given drawdown. In the last column of Table 5.2, the well yield for a drawdown of 10 m is calculated for each borehole.

5.2.5 Groundwater levels

The data on water struck level and water rest level are listed in Table 5.1. The water struck level corresponds with the depth below the surface at which groundwater is encountered during the drilling. The water rest

Table 5.2 Well test data

Borehole Number	Location	Depth (m)	Aquifer system*	Test date	Disch, Q (m^3/day)	Drawdown s (m)	Q/s (m^2/day)	T-Pump. (m^2/day)	T-Recovery (m^2/day)	Init.rest level (m)	Yield** (m^3/h)
C 1167	Rimoi	160	4	23-01-50	24	-	-	-	-	76	1
C 4838	Kabluk	143	1b/a	07-03-81	Data not reliable						?
C 5112	Chebloch	120	1b/a	29-06-82	120	48.95	2.5	2.3	2.6	28.2	1
C 5170	Kiboino	120	1a	07-09-82	238	8.45	28.2	29.0	36.3	19.7	12
C 5211	Kimwarer	125	1a	14-10-83	86	31.73	2.7	0.7	0.9	24.7	1
C 5212	Kimwarer F.	97	1b	09-11-82	Bailer test; borehole empty after 2 hours					68.6	< 1
C 5268	Torok	88	2	22-02-83	158	2.83	56.0	72	83	13.8	23
C 5269	Torok East	56	1b	02-03-83	127	14.40	9.0	3.2	8.9	18.9	3
C 5333	Kolowa	75	3b	11-08-83	172	Borehole empty after 1 hour				9.7	1
C 5334	Rimoi Farm	100	1b	09-06-83	95	13.23	7.2	10.9	15.8	70.3	3
C 5346	Tot Centre	96	4	22-07-83	158	18.29	8.7	9.6	9.0	41.4	3
C 5349	Tot Bridge	28	3a	28-07-83	133	1.26	105	110	81	7.0	44
C 5350	Tot East	69	1b	28-06-83	Bailer test; borehole empty after 1 hour					40.8	< 0.5
C 5370	Mokorwa	55	1a	06-09-83	85	16.07	5.2	1.5	3.4	27.7	2
C 5487	Kinyach	55	1a	24-11-83	144	2.80	51.0	9.4	13.9	10.6	20***

* see section 5.4 ** yield per s = 10 m *** uncertain

level represents the final level to which groundwater rose or fell. The groundwater level elevations above mean sea level have been estimated from the 1:50 000 topographical map and are therefore rather inaccurate. To establish the relation between the surface water-and groundwater-levels more accurate level measurements were necessary. Levelling of the boreholes in relation to the nearby rivers has been carried out by a survey team of the Ministry of Water Development. The results of this survey are given in Table 5.3.

The regular monitoring of groundwater levels in completed boreholes started in November 1982. The readings have been taken once or twice monthly, depending on accessibility of the sites. The obtained data and the corresponding well hydrographs are shown in Annex 5.5. Five boreholes have a more or less complete one-year record period. The other boreholes have been monitored over a shorter period.

Table 5.3 Elevations of groundwater related to nearby surface water levels on 7.11.83

Borehole Number	Location	Name of rel. river	Distance (m)	Elevation *(m)	
				Bh-surface	g. water
C 5346	Tot Cent.	Kerio	4027	96.08	+ 55.25
C 5350	Tot East	Kerio	2527	46.22	+ 7.26
C 5349	Tot Bridge	Kerio	217	4.64	- 1.92
C 5333	Kolowa	Kerio	7993	42.16	+ 34.16
C 5333	Kolowa	Tuga	160	4.99	- 3.01
C 5487	Kinyach	Kinyach	240	9.69	- 0.86
C 5334	Rimoi F.	Kerio	3225	58.83	- 11.37
C 5268	Torok	Kerio	5855	120.74	+106.92
C 5269	Torok East	Kerio	1156	6.71	- 11.29
C 5112	Chebloch	Kerio	1239	29.30	+ 1.64
C 5170	Kiboino	Kerio	4226	287.37	+269.68
C 5370	Mokorwa	Mokorwa	432	36.01	+ 11.06

* above or below surface water level

5.2.6 Chemical data

Twentyfour groundwater samples have been collected from 13 boreholes between August 1982 and November 1983. Most of the samples have been collected during well tests, other samples have been obtained by means of a sampler.

Table 5.4 Chemical data

Borehole no.	Date of sampling	pH	EC (µS/cm)	mg/l										Hard. ($CaCO_3$)	TDS (mg/l)	Aquif. system
				Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2			
C 5112	28-08-82	7.5	630	-	-	37	11	0.1	-	20	412	4	-	0.4	-	139	380	1b/a
C 5112	24-06-83	8.2	300	-	-	0	16	-	-	0	412	3	-	0.4	-	94	180	
C 5170	7-09-82	7.7	170	-	-	4.0	2.0	3.5	0.7	8	122	1	-	0.6	-	48	102	1a
C 5170	24-06-83	7.4	120	-	-	8.8	4.0	-	-	3	63	2	-	0.3	-	36	70	
C 5211	27-06-83	7.8	500	-	-	10	6.5	-	-	5	302	5	-	0.9	-	48	300	1a
C 5211	6-10-83	6.9	300	68	8.4	7.2	2.9	-	0.6	2	217	0	0	0.8	16	30	180	
C 5211+	14-10-83*	8.1	2800	600	27	34	20	0.0	0.0	12	1780	0	21	1.4	4	166	1670	
C 5211	15-10-83**	7.0	2400	452	23	52	17	0.0	0.1	8	1524	0	0	1.4	4		1450	
C 5212	27-06-83	8.2	650	-	-	15	55	-	-	30	295	0	-	2.0	-	232	390	1b
C 5268	21-06-83	6.8	250	-	-	6.8	1.4	-	-	5	117	0	-	0.2	-	224	150	2
C 5269	21-06-83	8.5	500	-	-	21	22	-	-	0	327	0	-	0.7	-	144	300	1b
C 5333	11-08-83	7.6	460	-	-	18	23	-	-	9	329	7	-	3.4	-	128	275	3b
C 5334	19-06-83	8.4	900	-	-	21	75	-	-	26	529	89	-	0.4	-	370	540	1b
C 5334	27-06-83	8.2	650	-	-	24	64	-	-	35	417	65	-	0.4	-	286	390	
C 5346	22-07-83*	8.5	915	-	-	24	86	-	-	54	470	20	-	0.6	-	364	550	
C 5346	23-07-83**	8.5	900	-	-	24	85	-	-	53	412	18	-	0.6	-	360	540	4
C 5349	28-07-83*	8.1	500	-	-	15	2.3	-	-	7	259	14	-	4.8	-	48	300	3a
C 5349	28-07-83**	8.3	485	-	-	12	4.6	-	0.0	4	232	5	-	4.8	-	46	290	
C 5350	11-07-83*	8.4	1940	-	-	2.4	5.1	-	0.0	166	900	27	-	1.7	-	22	1165	1b
C 5350	11-07-83**	8.5	2000	-	-	0.8	9.7	-	-	171	959	30	-	1.8	-	20	1200	
C 5370	4-09-83	8.0	750	-	-	72	50	-	-	6	641	17	-	0.9	-	360	450	
C 5370	6-09-83*	8.3	520	-	-	31	40	-	-	11	284	3	-	1.3	-	220	310	1a
C 5370	7-09-83**	7.9	620	-	-	22	87	-	-	10	566	2	-	0.9	-	360	370	
C 5487	25-01-84	7.9	570	-	-	8.8	2.9	5.0	0.0	16	455	19	-	7.4	-	34	340	1a

+ Borehole deepened * start of well test ** end of well test - not determined

The samples from borehole C 5211 were analysed by the Government Chemist's Department. All other samples were analysed in the laboratory of the Ministry of Water Development. The results of the analyses are listed in Table 5.4. The complete analyses of major constituents (Na^+, Ca^{2+}, HCO_3^-, Cl^-, SO_4^{2-} and SiO_4) as well as some minor ions, (K^+, Fe, Mn, NO_3^-, and F) are available only for the samples analysed by the Government Chemist. The absence of K^+ and Na^+ concentrations in the analyses from MoWD laboratory is due to malfunctioning of the flamephotometer. Consequently no accuracy check (by calculating the cation -anion balance) can be made for the majority of the samples.

In October 1983, samples for isotope analyses have been collected in the boreholes C 5333 and C 5346. The analyses of tritium, carbon 14 and oxygen 18 were carried out in the Netherlands. The results are as follows:

	^3H(TU)	^{14}C(%)	$\delta^{18}O$ (‰)
C 5333	5.7 ± 1.4	115.8 ± 1.0	-2.66
C 5346	< 4.2	95.6 ± 0.9	-4.16

5.3 Groundwater occurrence

The groundwater occurrence is controlled by climatological and geological conditions of the area. From hydrogeological point of view, fresh metamorphic and volcanic rocks can be considered as impervious and have no storage capacity. The nonindurated sediments on the other hand, store and transmit water. Under the given geological conditions, the groundwater found in Kerio Valley occurs in:

- weathered and/or fractured zones in metamorphic and volcanic rocks
- sediments interbedded between volcanic rocks
- flood plain and torrent wash deposits.

5.4 Aquifer conditions and systems

The analyses of the aquifer conditions is based on geological information (Chapter 2), geophysical investigations (Chapter 3) and data from 15 boreholes (Section 5.1).

The Kerio Valley is a tectonic depression filled up with volcanics and sediments which overly the metamorphic Basement rocks. The latter, apart from the uppermost weathered and fractured zones, do not transmit water and are considered as the impermeable base. The depth to the Basement surface differs considerably on both sides of the Elgeyo Fault. On the western side, the Basement rocks either outcrop on the foot of the

Escarpment or are found at relative shallow depths under the sedimentary cover. On the eastern side of the fault, the geophysical measurements indicate that depth to the impermeable base exceeds 1000 m.

The Basement rocks appear on the surface again in the northernmost part of the project area (Plate 2.1). Theoretically, the Tertiary and Quaternary sequence, overlying the Basement may be considered as waterbearing. The volcanic rocks transmit water in fractured and weathered zones, while sediments do the same through the pore space between the grains. Fresh volcanic rocks and clay layers separate the waterbearing strata and create the confined conditions in the aquifers as indicated by the differences between water struck-and rest levels (Table 5.1).

The total depth of boreholes, in most cases, does not exceed 100 m. The information on the possible presence of waterbearing zones in deeper layers is obtained from the geophysical measurements. The analysis of resistivity data, combined with surface geology and drilling data, resulted in 20 cross-sections showing the distribution of different layers and their hydrogeological characteristics. Three cross-sections are presented in Chapter 3.

Based on the available hydrogeological data, four aquifer systems can be distinguished in the Kerio Valley (Figure 5.1):

1. System comprising the fractured and weathered volcanics with interbedded sediments (1a) and the Kerio Valley sediments (1b)

2. System of torrent wash deposits (scree fans) occurring along the Elgeyo Escarpment

3. Alluvial system composed of coarse, recent deposits which locally developed along the Kerio River (3a) and its tributaries (3b)

4. System of fractured weathered Basement rocks.

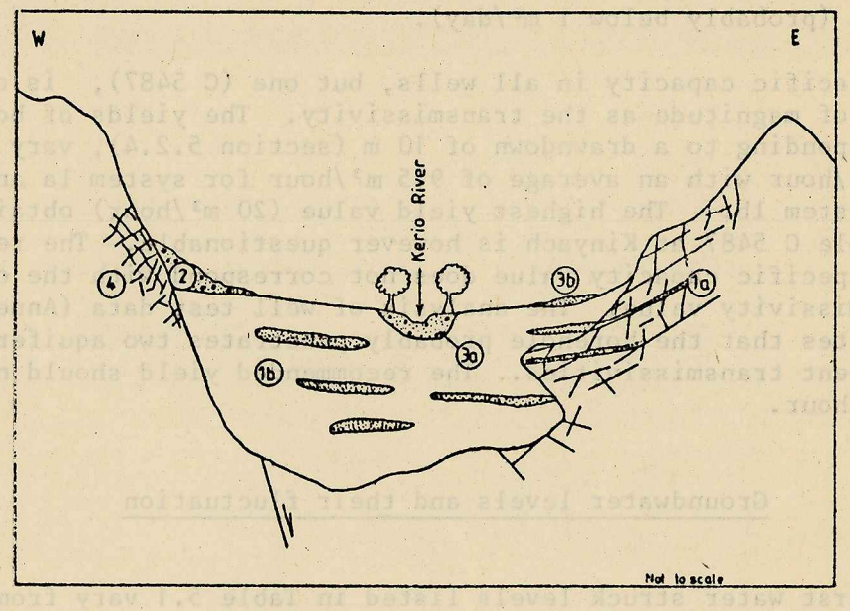


Figure 5.1 Schematic cross-section showing the aquifer systems.
1a = volcanic rocks; 1b = Kerio Valley sediments;
2 = scree fan; 3a,b = recent alluvial deposits:
4 = Basement rocks.

The system 1 can be considered as a regional one, the other three systems are of local importance only. The characteristics of the aquifer systems are described in the following sections.

5.5 Regional aquifer system (1)

Ten out of 15 boreholes in the project area have been drilled in this system. The difference between the water struck-and water rest-levels (Table 5.1) indicate that this aquifer system is confined. The groundwater is interconnected through fractures and coarse-sediment layers respectively. The system is mainly recharged through the fractures in volcanic rocks which outcrop on the eastern side of the valley. Part of the infiltrated water may discharge in small springs which are located in the Tugen Hills uplands (PENCOL,1981). The infiltration capacity of the Kerio Valley sediments is low as suggested by the presence of swamps, the Lake Kamnarok and numerous erosion gullies.

5.5.1 Transmissivity, specific capacity and yield

The transmissivity values obtained from 8 well tests (Table 5.2) vary from 1 to 36 m^2/day. The lowest calculated transmissivity values are found in the boreholes C 5211 and C 5112, situated in clayey sediments and decomposed volcanics (?), respectively. The highest value is

calculated for borehole C 5170 which penetrates fractured volcanic rocks at Kiboino. The bailer tests in boreholes C 5212 and C 5350, located in clayey Kerio River sediments, indicate very low transmissivity values (probably below 1 m^2/day).

The specific capacity in all wells, but one (C 5487), is of the same order of magnitude as the transmissivity. The yields of boreholes, corresponding to a drawndown of 10 m (section 5.2.4), vary from 0.5 to 20 m^3/hour with an average of 9.5 m^3/hour for system 1a and 1.5 m^3/hour for system 1b. The highest yield value (20 m^3/hour) obtained for borehole C 5487 at Kinyach is however questionable. The relatively high specific capacity value does not correspond with the calculated transmissivity value. The analysis of well test data (Annex 5.4) indicates that the borehole probably penetrates two aquifers of different transmissivities. The recommended yield should not exceed 10 m^3/hour.

5.5.2 Groundwater levels and their fluctuation

The first water struck levels listed in Table 5.1 vary from 5 to 85 m below surface. In several boreholes, water has been struck at two different depths as indicated by different rest levels. The rest levels vary from 10 m (C 5487) to 70 m (C 5334) below surface. Seven of the ten boreholes have water rest levels within 30 m below surface. In borehole C 4383 and C 5487 the final rest levels are lower than struck levels indicating that shallow perched aquifers are present. Shallow groundwater was not encountered on the eastern, southern and northern side of Lake Kamnarok as appears from the auger hole data (Annex 5.3).

According to Table 5.3 (Section 5.2.5), the elevation of groundwater in the boreholes C 5112, C 5170 and C 5370 in the southern part of the area is higher than nearby surface water levels. In the central part of the area (boreholes C 5269, C 5334 and C 5487), the groundwater level is below the surface water levels in Kerio and Kinyach River respectively.

Five boreholes in system 1 have a more or less complete one-year record period of groundwater level fluctuations (Annex 5.5). The one-year hydrographs of boreholes C 4838, C 5112, C 5170 and C 5211 show similar behaviour, although the absolute variations are different. An example of a well hydrograph is shown on Figure 5.2.

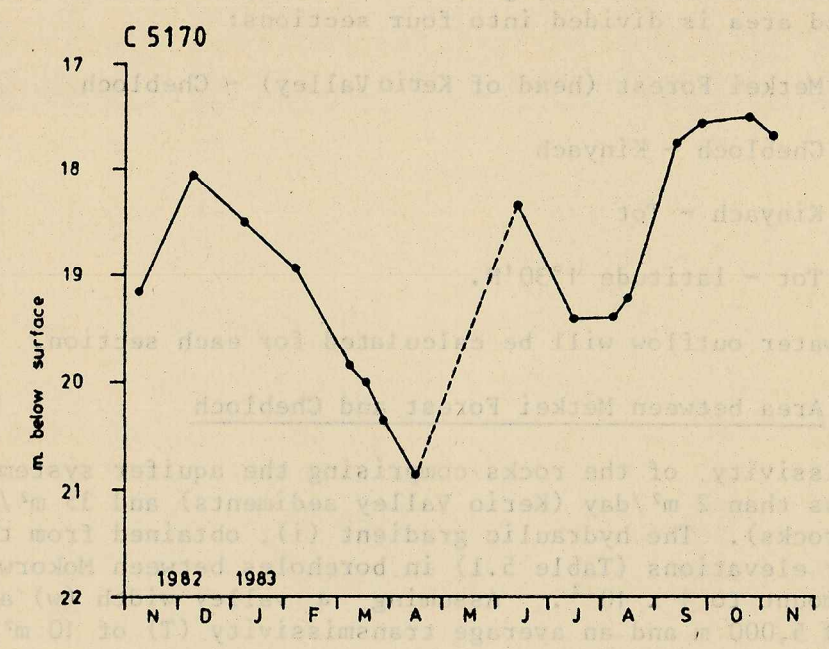


Figure 5.2 Well hydrographs of borehole C 5170 (Kiboino).

There are three peaks in respectively December/January, June and September/October. The minimum levels have been recorded in April and August. The first peak reflects the November rains, while the dry months December, January and February will be responsible for a sharp drop of groundwater level in April. The other two peaks can be correlated with the rains in March-May and July-August periods. The hydrograph of C 5212 has a different behaviour in the first half of the recorded period, showing a continuous rise of level from February till July. The data from other boreholes are not suitable for further analyses.

It has been pointed out that next to the variations in recharge, the groundwater level fluctuations in a confined aquifer may also be influenced by changes in barometric pressure.

5.5.3 Groundwater flow and balance

The movement of groundwater from a recharge area to a discharge area depends on the amount of available recharge, the aquifer characteristics and the mode of discharge. In the Kerio Valley, these conditions are not uniform, due to great variation in rainfall distribution, morphology and geological composition of the underground (Plate 2.1).

For the quantification of the groundwater flow, in system 1, the investigated area is divided into four sections:

i. Metkei Forest (head of Kerio Valley) - Chebloch

ii. Chebloch - Kinyach

iii. Kinyach - Tot

iv. Tot - latitude 1°30'N.

The groundwater outflow will be calculated for each section.

i. Area between Metkei Forest and Chebloch

The transmissivity of the rocks comprising the aquifer system 1 range between less than 2 m^2/day (Kerio Valley sediments) and 35 m^2/day (volcanic rocks). The hydraulic gradient (i), obtained from the groundwater elevations (Table 5.1) in boreholes between Mokorwa and Chebloch amount to 1×10^{-2}. Assuming a valley width (w) at Chebloch of 5,000 m and an average transmissivity (T) of 10 m^2/day, the application of Darcy's law yields a flow rate (Q) :

$$Q = Tiw = 10 \times 1 \times 10^{-2} \times 5 \times 10^{3} = 500 \text{ m}^3\text{/day}$$

or 0.18×10^6 m^3/year.

This low flow rate indicates a low recharge, which equals to only 0.1% of total rainfall (1000 mm/year) over the estimated recharge area of 200 km^2 (volcanic rocks).

ii. Area between Chebloch and Kinyach

The average transmissivity in this section is assumed to be 25 m^2/day. The hydraulic gradient in this section is 4×10^{-3} and width of the valley at Kinyach is about 8,000 m. Hence:

$$Q = 25 \times 4 \times 10^{-3} \times 8 \times 10^{3} = 800 \text{ m}^3\text{/day}$$

or 0.29×10^6 m^3/year.

An increase of flow rate of 0.11×10^6 m^3/year between Chebloch and Kinyach represents the total recharge over the area. This value corresponds to 0.04% of the total rainfall (900 mm/year), assuming that the only recharge takes place on the volcanic rocks (total area of 300 km^2).

iii. Area between Kinyach and Tot

The groundwater flow rate is calculated for this section, using the following parameters:

$$T = 20 \text{ m}^3\text{/day}; \quad i = 4 \times 10^{-3}; \quad w = 12.5 \times 10^3 \text{ m hence}$$

$$Q = 1000 \text{ m}^3\text{/day or } 0.36 \times 10^6 \text{ m}^3\text{/year.}$$

It means that the increase in recharge between Kinyach and Tot amounts to 0.07 x 10 m^3/year. This corresponds with 0.03% of total annual rainfall (850 mm) over a recharge area of 240 km^2.

It must be stressed, however, that all calculated groundwater outflows are based on approximated values. Consequently they give an indication about the order of magnitude only.

iv. Area between Tot and latitude 1°30'N

Little is known about the hydrogrological conditions in the area north of Tot. There are no boreholes and the geophysical data are scarce because of the poor accessibility of the sites. It can be assumed however that the groundwater continues its flow through system 1 towards the north. Near the latitude 1°30'N, the outcropping Basement rocks may form a barrier to the groundwater flow. Unfortunately, the lack of data allows only the guess, that the Kerio Valley is a closed basin. If this assumption is correct, the groundwater in this part should either appear on the surface as spring flow or will discharge entirely in the Kerio Valley. However, no springs were observed and the baseflow of the Kerio River is too low. Another possibility is that groundwater comes close to the surface and evaporates or that it slowly moves through clayey sediments along the line Lomut-Sigor into the Wei Wei Basin.

Additional data are necessary to find out which groundwater mechanism exists in this part of the Kerio Valley.

5.5.4 Chemical composition of groundwater

The results of chemical analyses of samples, collected from 9 boreholes in system 1, are listed in Table 5.4. A rough estimate of the total dissolved solids (TDS) in water can be obtained from the electrical conductivity (EC) measurements. According to Table 5.4, the EC - values range from 120 µS/cm (BH C 5170) to 2800 µS/cm (BH C 5211). Using a conversion factor 0.6 (Hem, 1975) it yields a TDS content between 70 and 1670 mg/l. The boundary between fresh and saline water is usually taken at 1000 mg/l. Samples from boreholes C 5211 (after deepening) and C 5350 exceed this limit and can be classified as slighly saline.

Low mineralized fresh water (TDS less than 200 mg/l) is found in boreholes C 5112 and C 5170. The samples from the other five boreholes contain moderately to highly mineralized fresh water.

Figure 5.3 shows the stiff diagrams in which the ion concentrations are expressed in milliequivalents per liter.

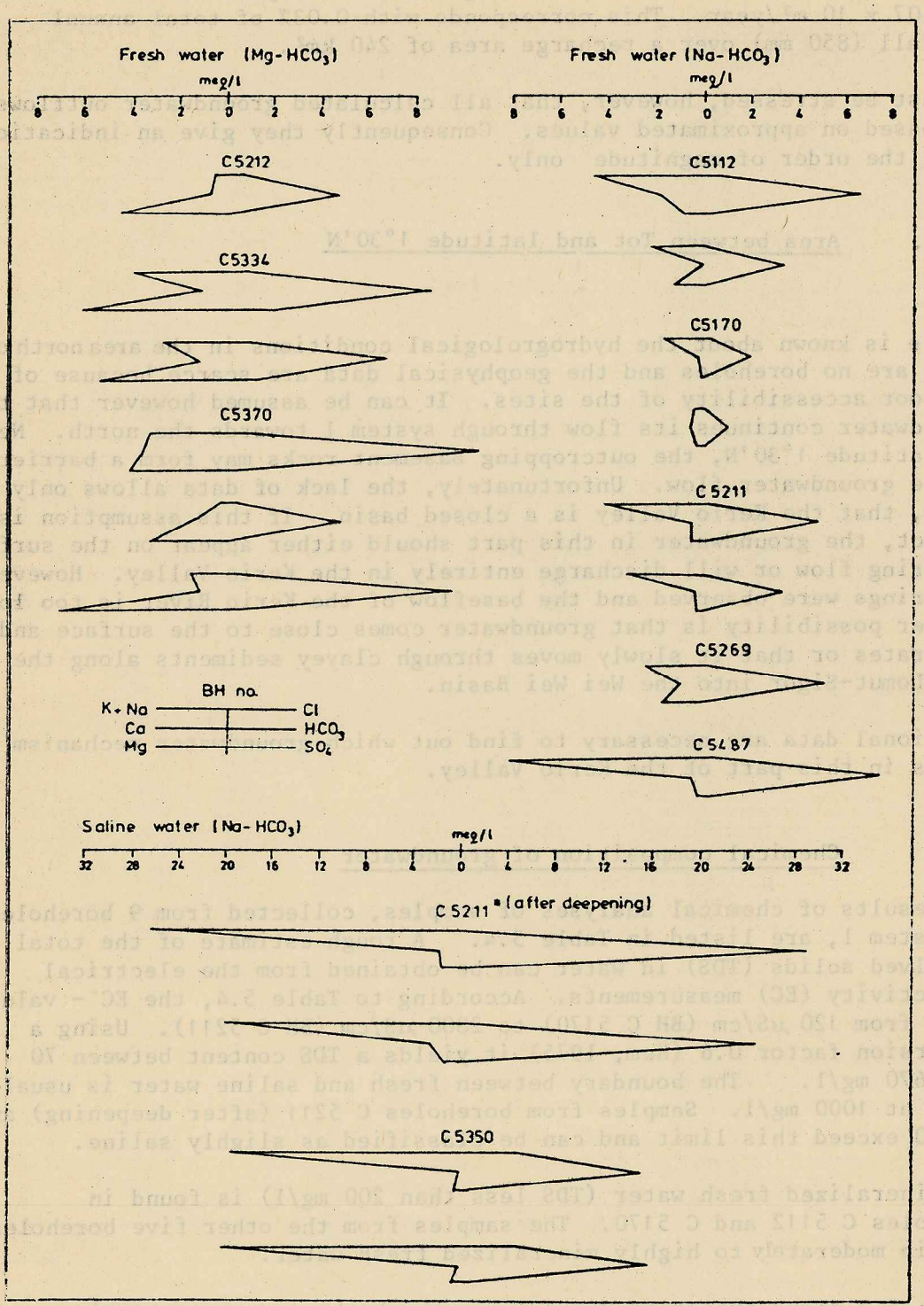


Figure 5.3 Stiff diagrams of groundwater samples from system 1.

As already mentioned, the Na and K - analyses are not available for the majority of the samples. The concentrations of these ions have been therefore calculated as the difference between the sum of the determined anions and determined cations. However, the calculated values may be erroneous, because the accuracy of the determined ions cannot be checked.

The bicarbonate is the major anion in all samples. The concentrations range from 63 mg/l to 641 mg/l in fresh water samples and between 900 and 1780 mg/l in four slightly saline water samples. The chloride concentration in almost all samples does not exceed 35 mg/l. A relative high Cl-concentration (171 mg/l) is found only in saline water from borehole C 5350. The sulphate concentrations are significantly only in samples from boreholes C 5334 (89 mg/l) and C 5350 (30 mg/l). The fluoride concentrations, higher than 1.5 mg/l are found in borehole C 5212, C 5350 and C 5489. In the latter, a concentration of 7.4 mg/l has been found.

As for the cations either sodium + potassium (calculated value) or magnesium ions predominate. The Na - concentrations are assumed to be considerably higher than those of K. No value range of these ions can be given, however, because the determined concentrations are available only for one borehole. The concentrations of magnesium range from 2 to 76 mg/l. The calcium concentrations vary between 0 and 72 mg/l.

The results of the chemical analyses show considerable differences in groundwater composition of system 1. The composition of groundwater reflects the composition of infiltrating water and the biological and chemical processes in unsaturated and saturated zones.

As assumed in previous section, the system 1 is mainly recharged in the areas of outcropping volcanic rocks. The volcanic sequence of Kerio Valley comprises basalts, phonolites and trachytes (see Chapter 2). The mineral compositions of these rocks are different and consequently, different groundwater composition may be expected in these formations.

The basalts usually contain olivine (Mg, Fe - silicate) and the weathering of this mineral may give rise to magnesium rich water. The borehole C 5370 (Mokorwa) obtains its water from basalts. The groundwater is of Mg - HCO_3 type. The Mg - HCO_3 water types are also found in boreholes C 5212 and C 5334. The aquifer of the former is recharged either through the basalts on the eastern side of the valley or through the basanites in the Kerio Valley Head. The source of high Mg - content in water from borehole C 5334 is not known.

The phonolites and trachytes contain sodium-rich minerals, nepheline (Na-feldspatoid) and sanidine (K, Na-feldspar) respectively. These rocks usually give rise to a sodium-bicarbonate water-type, which is found in the majority of samples from system 1.

The samples from borehole C 5211 (Kimwarer) indicate that great differences in water quality may occur in the vertical section of the aquifer system 1. Initially this borehole was drilled to a depth of 55 m. The samples from this part of aquifer show fresh water with low to moderate TDS contents. The borehole has been deepened to 125 m and at 115 m another water-bearing layer has been encountered, containing saline water.

The horizontal distribution of the saline water is not known. The saline water in borehole C 5350 in the north of the area has a much higher Cl-content and lower Ca-concentration than the saline water from borehole C 5211.

Referring to the drinking water quality standards (e.g. in Freeze and Cherry, 1979), it is concluded that in 4 of the 9 boreholes, the groundwater is not suitable for drinking purposes. Two boreholes contain slightly saline water and two boreholes contain fresh groundwater with a fluoride concentration exceeding the permissible limit of 1.5 mg/l.

5.6 Local aquifer systems

Only few hydrogeological data are available for the description of local aquifer systems. Consequently, only general characteristics can be given.

5.6.1 System of torrent wash deposit (System 2)

This system comprises the torrent wash deposits (scree fans) occuring along the Elgeyo Escarpment. The system is recharged directly by rain or through surface water infiltration from the streams which orginate at the higher elevations of the Escarpment. The relation between this system and the system 1 (see 5.5) is not clear. The impermeable character of the underlying upper part of the Kerio River Beds may indicate that there is no hydraulic connection between these two systems. On the other hand no springs have been observed along the margins of the scree fans. It means that if the groundwater from system 2 is not entering system 1, it either evaporates or discharges as seepage.

The borehole C 5269 near Biretwo is the only one located in this system. The drilling data (Table 5.1) indicate that a perched water aquifer overlays the main water bearing strata. The well test yielded a tranmissivity value of 80 m^2/day. The specific capacity, which is of the same order of magnitude, indicate a relatively high yield: 23 m^3/hour for a drawdown of 10 m. The chemical analysis (Table 5.4 and Figure 5.4) indicate a low mineralized water of Na-HCO_3 type with a fluoride concentration within the WHO limit.

The amount of groundwater stored in the scree fans between Kimwarer and Koitilial can be only roughly estimated.

Approximately 10 km^2 from a total scree fans-area of 30 km^2 is considered to be waterbearing. Assuming a saturated thickness of 10 m and an effective porosity of at least 10% a total storage of 10 x $10^6 m^3$ is calculated. Assuming further that at least 10% of this amount can be annually recovered without risk of aquifer depletion, a total of at least 1 x $10^6 m^3$ water is expected to be abstractable from these scree fans.

It must be stressed, however, that this figure is a guess only. Additional hydrogeological data are necessary to make a more reliable estimate.

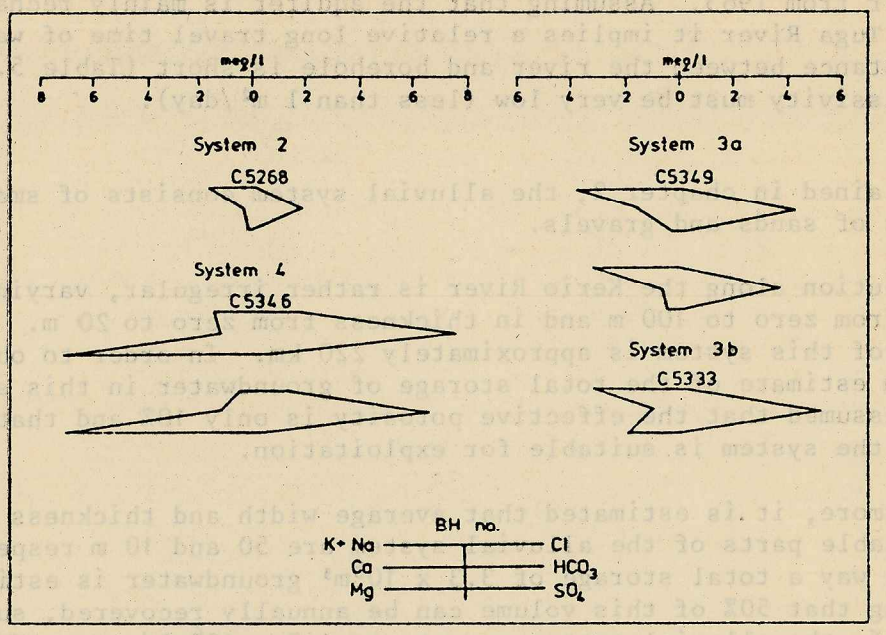


Figure 5.4 Stiff diagrams of groundwater samples from local aquifer systems.

5.6.2 Alluvial system (System 3)

The alluvial system comprises the relative coarse, recent deposits which locally developed along the Kerio River (3a) and its tributaries (3b). Two boreholes have been drilled in this system; borehole C 5349 (Tot bridge) near Kerio River and borehole C 5333 (Kolowa) near Tuga River. According to Table 5.3, the groundwater levels in both boreholes are lower than the water level in nearby rivers. It means that the system 3 is mainly recharged with the river water. The drilling data (Table 5.1) indicate that the system is unconfined or semi-confined.

The alluvial system supplies soil moisture to the vegetation zone along the river. Shallow groundwater within 5 m below surface, has been encountered in auger holes along the eastern bank of the Kerio Valley near Lake Kamnarok (see Annex 5.4).

A relatively high transmissivity value (70 m^2/day) has been obtained from a well test in borehole C 5349. The well test data from borehole C 5333 (Kolowa) were not suitable for analysis. The transmissivity of the aquifer is probably low as seems from the rapid drop of groundwater level in this borehole during the pumping phase.

The Na-HCO_3 water types are characterised by a moderate TDS content. However, the high fluoride concentrations found in both boreholes (3.4 and 4.8 mg/l respectively), limits the potability of the groundwater.

Isotope analyses of a sample from borehole C 5333 are given in Section 5.2.6. According to the laboratory at which the analyses were carried

out, the age of groundwater is estimated at 50 years with an admixture of water from 1963. Assuming that the aquifer is mainly recharged from the nearby Tuga River it implies a relative long travel time of water. Since the distance between the river and borehole is short (Table 5.3), the transmissivity must be very low (less than 1 m^2/day).

As explained in chapter 2, the alluvial system consists of small patches of sands and gravels.

Distribution along the Kerio River is rather irregular, varying in width from zero to 100 m and in thickness from zero to 20 m. Total length of this system is approximately 220 km. In order to obtain a minimum estimate of the total storage of groundwater in this system it is assumed that the effective porosity is only 10% and that only 30% of the system is suitable for exploitation.

Furthermore, it is estimated that average width and thickness of the exploitable parts of the alluvial system are 50 and 10 m respectively. In this way a total storage of $3.3 \times 10^6 m^3$ groundwater is estimated. Assuming that 50% of this volume can be annually recovered, sustained yield of the alluvial system amounts to $1.7 \times 10^6 m^3$/year. This figure should be considered as an indication of the order of magnitude only. Updated estimates can be made after a large part of the aquifer system is being exploited.

5.6.3 System of fractured and weathered Basement rocks (System 4)

The fractured and weathered metamorphic rocks may contain isolated groundwater bodies. The recharge takes place either by percolation through the superficial deposits in the southern part of the Kerio Valley or directly through the cracks in the outcropping rocks in the north. Two boreholes were drilled in Basement rocks.

For borehole C 1167 (Rimoi) only water level data are available. The borehole completion form indicates an unconfined aquifer. Recent groundwater level monitoring, however, showed that the water rest level is considerably higher than the reported value from 1950.

The data from borehole C 5346 near Tot indicates confined groundwater condition (see Table 5.1). The Basement rocks are covered with clayey sediments. The transmissivity value of 10 m^2/day and the yield of 3 m^3/hour suggest that the Basement rocks may locally supply sufficient amount of groundwater for hand pumps.

The analyses of groundwater from C 5346 indicate a magnesium - bicarbonate water type with a very high Mg^{2+} - concentration of 86 mg/1. Some magnesium may go in solution during the weathering of biotite and bornblende, but high Mg^{2+} - concentrations are generally unusual in the groundwater from Basement rocks. An erroneous analaysis is possible, because no accuracy check can be made (see Section 5.2.6.)

The TDS content of 550 mg/l slightly exceeds the recommended limit (500 mg/l) for drinking water purposes. The fluoride content on the other hand is low. An interpretation of isotope data from borehole C 5346 resulted in an estimated age of the groundwater of 100 years. This indicates a rather slow circulation of groundwater in this aquifer system.

5.7 Hydrogeological map

The available hydrogeological data, which have been discussed in the previous sections, are summarised on the hydrogeological map (Plate 5.1). This map shows the major aquifer systems, their hydraulic properties and groundwater quality.

6. WATER RESOURCES ASSESSMENT

6.1 General

The previous chapters of this report deal specifically with the hydrogeological investigation aimed at the assessment of water resources in the Kerio Valley. This chapter summarizes the results in the context of water availability for planning purposes at district level and local developments. Other studies directed by the Ministry of Water Development and the Kerio Valley Development Authority through SOGREAH (1981) and PENCOL (1981, 1984), studied the possibilities for surface water development in the valley with emphasis on large scale irrigated agriculture and reservoirs for domestic use and hydropower. These developments being beyond the scope of this project have not been studied in details. Therefore the project's recommendations are mainly dealing with small scale developments, such as hand pumped wells and the use of surface water for cattle watering.

A preliminary inventory on the present water use in the valley has been carried out. The present and future total water demand has been established on basis of the 1979 population data.

6.2 Water supplies

6.2.1 Domestic water supplies

The number of existing water supplies in the Kerio Valley is limited (Plate 6.1). Surface water is the major source, being abstracted from rivers and springs. The only water supply utilizing groundwater at present is the Kabarnet water supply. Groundwater is also obtained from hand-dug shallow wells in the river beds during the dry seasons.

The water supplies in the valley fall into two categories:

- water supplies operated by the Ministry of Water Development
- water supplies operated through the self-help programmes with assistance from donor agencies.

The existing water supplies and the water supplies presently under construction or in the design phase are listed in Table 6.1

Table 6.1 Water supplies in the Kerio Valley

Name	Source River-Borehole	Yield m³/day	Population served	Remarks
Elgeyo Marakwet District				
1. Existing				
Arror	Arror			
Chegilet				
Chepsigot/ Cheptebo	Torok			Gravity supply
Chesetan	Emboman & Embokutel	57	2,000	Gravity supply
Chesongoch	Chesongoch	15		Gravity supply
Fluorspar Mine	Mong			Pumped supply
Muskut	Muskut	22	1,200	Gravity supply
Tambach	Kessup	45	1,500	Gravity supply
Tot	Embobut	35	2,000	Gravity supply
2. Under construction				
Kiptoro	BH C-1167			Borehole supply
3. Under design (Proposed)				
Kapsicha				
Resim/Kibiobo				
Koimur				
Baringo District				
1. Existing				
Bartolimo	Emboini			
Kabarnet	BH C 4722 C 4780	14		Borehole supply
Kabartonjo	Kukumbani	45	2,600	Gravity supply
Kapchepkor	Mintililojun			
Kinyach	Chebirebei			
Kipsaraman	Enining			
Kisok	Kisok			
Ngusuria	Ngusuria			
Tugen Hills/ Farmer Coopeative	Mayeluk			
2. Under construction				
Kabluk	BH C 4838 & Tereini	300	8.000	Borehole supply
Kapkong	Torontwo & Kapkong		6,000	Gravity supply
Kaptere	Kukumbuni			
Trimionin	Kiberekei			
3. Under design (Proposed)				
Kapkalewa	Kapkalewa			
Kapsoo	Kipngemoi			
Poi	Small lake or reservoir			

Unfortunately no more specific data could be traced of the majority of the existing and proposed water supplies in the Ministry.

The water supplies from Table 6.1 are plotted on Plate 6.1.

6.2.2. Present surface water use for irrigation

Along the Elgeyo Excarpment traditional irrigation is practised by the Elgeyos by tapping the flow from small streams and rivers (Kipkorir et.al. 1983).

According to ADEC (1981), there are 40 main irrigation furrows between Arror and Chesegon on the Escarpment side of the Kerio Valley. The total length of this traditional irrigation system amounts to 250 km. The system provides water for approximately 1,500 hectares as indicated in Table 6.2.

Table 6.2 Taditional irrigation in Elgeyo Marakwet (ADEC, 1981).

Site	Present irrigated area (ha)	Total irrigible area (ha)
Chesegon	370	400
Embobut (Tot)	400	5,000
Embolot (Kebetwa)	180	3,000
Enou (Chesongoch)	140	2,000
Embamon (Chesetan)] Kiptinos (Mogil)] Chebilet (Kipyebo)]	140	3,000
Arror	270	1,600
	1,500	15,000

There are no reliable data available on the amount of water abstracted for irrigation. It has been estimated (ADEC, 1981), that 50 - 75% of the water is lost by leaks and seepage from the furrows before reaching the plots to be irrigated.

By KVDA an experimental irrigation scheme of approximately 40 ha was started in 1983, some 5 km downstream of Tot, using water from the Embobut. However the intake channel and intake structure are not yet completely finished.

On the Baringo side of the Kerio Valley water from the Yeptos River near Barwesa has been used for irrigation. The intake structure and channels are deteriorated and need to be rehabilitated.

SOGREAH (1981) and PENCOL (1981, 1984) proposed some reservoir sites for major irrigation schemes in the valley; being beyond the scope of this project reference is made to the approximate reports.

6.3 Water demand

To calculate the average daily demand for the Kerio Valley, a consumption per capita is assumed as described in The Design Manual for the MoWD (May 1979).

The demand is specified for rural areas as:

- 25 litres per head per day when served by communal water points
- 75 litres per day per livestock unit (LSU), i.e. 1 grade cattle or 3 native cattle or 15 sheep or goats.

In Table 6.3 the figures are given for the population in the lower part of the Kerio Valley, living approximately below the 1500 m contour line, estimated for 1984 and projected for the year 2000. For the Kerio East Bank figures from PENCOL (1984) have been used.

From a survey by KREMU (1980) a livestock density has been established for Kerio Valley of 11.7 cattle/km^2 and 19.9 sheep and goat/km^2. The area covers approximately 3,000 km^2 and contains thus at present 35,000 cattle and 60,000 shoats (=sheep + goat), or 15,700 livestock units (LSU). The growth of the livestock is estimated to be modest, increasing from 5.2 till 7.3 LSU/km^2, giving a total of 22,000 LSU for the year 2000.

Table 6.3 Population data for Kerio Valley (approx. below 1500 m contour line) at present and estimated for the year 200.

Area	Population 1984	Growth/yr (%)	Population 2000
Elgeyo Marakwet)*			
Endo	15,000	4	28,000
Sambirir	7,000	4	13,000
Arror	5,000	3	8,000
N.Iriong	3,000	2	4,000
S. Iriong	4,000	2	6,000
Soy	10,000	4	19,000
	44,000		78,000
Baringo)**			
Ngorora	3,000	1.5	4,000
Kaboskei	7,000	4.25	14,000
Kammarok	11,000	4.25	22,000
Kabarnet/Sacho	8,000	4.25	15,000
Kakamor	10,000	3.5	17,000
Ribkwo	5,000	1.5	6,000
	44,000		78,000
TOTAL	88,000		156,000

)* estimate WRAP
)** from Pencol (1984).

Table 6.4 gives the figures for the present water demand and the forecast for the year 200.

Table 6.4 Water demand in Kerio Valley for 1984 and 2000. Population and livestock figures are for lower part of valley, approx. below 1500 m contour line

	Total population livestock LSU	Water demand (M m³/y) in 1984	Water demand (M m³/y) in 2000
Elgeyo Marakwet District			
Human consumption			
1984	44,000	0.40	
2000	78,000		0.71
Livestock demand			
1984	5,700	0.16	
2000	8,000		0.22
Baringo District			
Human consumption			
1984	44,000	0.40	
2000	78,000		0.71
Livestock demand			
1984	10,000	0.27	
2000	14,000		0.38
		1.23	2.02

The estimated population living now in the lower parts of the valley is equally distributed on the east and west bank of the Kerio. The population living in the Elgeyo Marakwet side is mainly concentrated in the northern part. In the three northern locations, Endo, Sambirir and Arror the majority of the people are supplied with water from the furrows of the traditional irrigation system.

The two new gravity water supplies at Tot and Chesetan serve approximately 4,000 people. Still the water supply situation is not very satisfactory as is quite evident from many health problems (e.g. a very high rate of trachoma eye disease).

In the southern part only 1200 people are supplied at Muskut, and 2000 by the new Torok water scheme.

An estimated 5000 head of the population living on the eastern Baringo side of the Kerio Valley is served by surface water supplies at Kinyach, Kibonio, Kesok, Kapkong and Kapkalelwa. The supply under construction at Kabluk is designed to supply ultimately 12,000 people but is not operational yet.

The above implies that at present (1984) improved water supplies are needed for approximately 37,000 people on the Elgeyo Marakwet side of the valley and for 39,000 people on the Baringo side. These figures will rise to 60,000 and 50,000 respectively for the year 2000, assuming that the supplies which are now being constructed or have been proposed for construction, will be operational. The boreholes that have been drilled by WRAP can supply approximately 5,000 people with water when they are equipped with handpumps.

6.4 Water resources availability

The term "availability of water" as such is meaningless if not related to the specific purpose for which the water will be used. In this respect the following possibilities for water use in the Kerio Valley can be distinguished:

- domestic use
- cattle watering
- irrigated agriculture: small scale
  large scale
- hydropower

From the hydrological conditions it was concluded in Chapter 5, that groundwater resources in the Kerio Valley are limited and restricted to certain parts of the area. The total annual groundwater recharge of the regional system amounts to only 0.4 x $10^6 m^3$. Assuming that 50% of the recharge can be recovered, the safe yield from the regional system amounts to 0.2 x $10^6 m^3$/year. In Chapter 5 it is explained that sustained yields of the scree fans and alluvial deposits are estimated to be 1 x $10^6 m^3$/year and 1.7 x $10^6 m^3$/year respectively. Thus the total sustained yield of the studied part of the Kerio Valley amounts to 2.9 x $10^6 m^3$/year.

The total domestic water demand for the population living on the valley bottom amounts to approximately 0.8 x $10^6 m^3$/year, increasing to circa 1.4 x $10^6 m^3$/year in the year 2000. This demand can be met by groundwater though locally shortages will occur as groundwater distribution is quite irregular. In addition there is enough groundwater available in the scree fans along the Escarpment and in the alluvial deposits along the Kerio River for cattle watering.

The groundwater quality varies from location to location, no consistent pattern could be found, however. High fluoride concentration exceeding WHO limit of 1.5 mg/l were both found in volcanic rocks as well as in Kerio Valley sediments and alluvial aquifers. At two locations slightly saline water was found. However even in the boreholes which apparently contain safe drinking water, regular chemical and bacteriological testing of groundwater is considered essential.

The availability of surface water is abundant. The total annual surface water outflow from the valley at Tot, amounts to some 300-500 x $10^6 m^3$. However the availability of surface water in the valley is unevenly distributed in time and space.

In general the surface water quality proved to be good. No high fluoride concentration was found indicating that the fluoride contamination from the Fluorspar Mine seems to be under control. Bacteriological analysis have not been carried out, thus no recommendation for treatment requirements can be given.

The use of surface water for the various purposes, including domestic supplies, highly depends on the minimum flows from permanent streams, the duration of the dry spell in between two consecutive periods of river flow for non-permanent streams and suitable sites for intake structures and small or large reservoirs. Because most of the engineering aspects are beyond the scope of the project, no detailed assessment of the surface water availability for the various applications can be made.

A water availability map (Plate 6.2) has been prepared to indicate the regional distribution of the different water resources. The following categories of water availability are distinguished:

I. High potential area

Groundwater	-	Fractured volcanic rocks with interbedded erosional surfaces
	-	Scree fans
	-	Coarse alluvial sediments near the main rivers
	-	Yield: > 5 m^3/h, at 10 m drawdown
Surface water	-	Areas at higher altitudes with abundant rainfall (approximately above the 1100 mm/yr isohyet and with low evaporation, less than 1800 mm/yr)
	-	In areas with major permanent streams. The minimum base flow at the end of the dry season should not be less than 100 l/s.

II. Medium potential areas

Groundwater	-	Fractured Basement rocks + weathered zones
	-	Sandy Kerio Valley sediments
	-	Yield: 1-5 m^3/hr, at 10 m drawdown.
Surface water	-	Areas with intermediate rainfall (approx.between 1100 and 950 mm/yr)
	-	Near major streams with base flow at end of dry season between 10-1000 l/s
	-	Near intermittent streams carrying water for at least 9 months. Topography allows construction of small reservoirs.

III. Low potential areas

Groundwater	-	Clayey Kerio River sediments
	-	Altered volcanic rocks
	-	Fresh Basement rocks + volcanics
	-	Yield: < 1m^3/h, at 10 m drawdown.

Surface water - Areas with no permanent streams or intermittent streams carrying water less than 9 months/yr.

6.5 Water development opportunities

Groundwater development opportunities are principally restricted to hand pumped wells. Assuming an annual production of 2000 m^3 per hand pump, the estimated sustained yield is sufficient for 1450 hand pumps. However, the available groundwater is not evenly distributed.

In the first phase of exploitation the construction of several tens of shallow wells in the alluvial deposits near the Kerio River should be considered. The cost of one dug well amounts to approximately KShs.20 000/=. In addition, few medium deep boreholes (circa 50 m) should be drilled in the scree fans along the Escarpment. Each borehole will cost approximately KShs.50·000/=. The purpose of these wells is not only the water production but also further reconnaissance.

After the first phase circa 850 shallow wells can be constructed in the alluvial deposits and circa 500 hand pumps installed in the scree fans-areas, assuming that the estimates made in Chapter 5 are still valid. However, due to the limited area extent and unfavourable locations of some scree fans the latter number may be too optimistic. Updated estimates are necessary after the first phase of exploitation is evaluated.

Approximately 800 km^2 of the regional aquifer system has been identified as medium to high potential area for groundwater development. Sustained yield in this aquifer is sufficient for circa 100 hand pumps. This implies a maximum borehole density of one borehole per 8 km^2 or a borehole spacing of minimal 3 km. Each hand pump could supply approximately 300 people and would require an initial investment of about KShs.80 000/= including drilling costs. Detailed site investigations are required for each proposed location.

Ample opportunities are present for the development of surface water for domestic use and cattle watering, even for small and large scale irrigated agriculture and hydropower. However, the latter two being beyond the scope of this study, have not been taken into consideration by the project.

Alternative and less costly opportunities for the development of surface water should be developed in the first place, such as small reservoirs for cattle watering at the valley bottom and sand dams with shallow wells in the riverbeds of intermittent streams.

The topographical conditions at the valley bottom as well as the soils permit the construction of small reservoirs for cattle watering and cattle dips. With a natural gradient varying between

0.2 and 0.06 and a dam height of 4-5 metres a rectangular reservoir, 50 metres wide and 150 metres long in the direction of the slope could store between 25 000 - 8 000 m^3. To bridge the four months dry spell between the November and April rainfall for cattle watering only, a total storage capacity of 0.02 x $10^6 m^3$ would be required. Taking into account that the total evaporation minus the average rainfall during that period would result in approximately 700 mm evaporation losses, the net storage capacity of the reservoirs would reduce to between 18 000 and 6 000 m^3. Assuming a daily water demand of 1000 m^3 for 22 000 LSU (Table 6.4), cattle watering thus could be guaranteed by 10-20 small reservoirs, roughly costing between 100 000 and 200 000 Kenya Shillings per reservoir. Depending on the topographical conditions these reservoirs can either be filled by direct runoff or by diverting the flow from intermitten streams. Properly constructed and dimensioned spillways are required to prevent over-topping of the embankment and to by-pass excessive floods.

As these reservoirs can easily develop into a breeding place for harmful insects and could become a health hazard when used for human consumption, a considerable distance to nearby settlements should be enforced.

The possibilities for the construction of sand dams predominantly depends on the topographical conditions such as slope and width of the river bed, as well as the impermeability of the underground. No price indication can be given for the sand dams themselves, they vary from site to site. During a recent construction programme of sand dams in Machakos District the average cost per unit amounted to KShs.80 000. Depending on the depth of the well, a shallow well including the hand pump will cost between 20 000 - 30 000 Kenya Shillings.

To guarantee domestic water supply and the supply for small scale irrigation from surface water, detailed investigations are required to study the various possibilities. In most of the areas the required amount of surface water is available, but a cost-benefit analysis is always required to study the most feasible solution to divert water to a specific location.

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Annex 1.1 - WRAP PROJECT STAFF INVOLVED IN KERIO VALLEY INVESTIGATION

Water Resources Department MoWD

Project Co-Manager	A.M. Nzioki
Hydrologist	D.N. Kimani
Geohydrologist	N. Gathuru
Geologists (drilling)	P.M. Matseshe C.M. Mwakamba
Hydrogeologist	C.K. Mbugua
Geophysicists	F.K. Karanga S.C. Gitonga J.M. Kinya
Groundwater Inspectors	D.W. Mwangi E.M. Okemwa
Groundwater Technicians	J. Wahome D.M. Migwi
Assistant Hydrologists	C.G. Gitonga J.C. Payeni
Instrument Technicians	P.K. Mengich E.G. Githiora
Senior Drilling Inspectors	A.M. Abdallah J.M. Ngari
Drilling Inspector	S. Kipkorir (December 82)
Drilling Crews (Drilling Superintendents, drillers, welders, drivers, labourers, watchmen)	PR2 (April 82 - Dec. 82) PRS3 (May 82 - Aug. 83) PR1 (Jan. 83 - Dec. 83) PRC1 (Jan. 83 - Jan. 84)

Annex 1.1 (Continuation)

Draughtsmen	W. Mbala	
	A. Annam	
Drivers	T. Mainga	GK B762
	J.O. Ohanya	GK B763
	A.O. Ohanya	GK B764
	J.K. Kirubi	GK B765
	N. Mathi	GK A401
		GK A402
	A.N. Muchiri	GK A403
	P.N. Kamau	GK C349
	J.K. Njoroge	GK C350

Netherlands Team

Resident

Project co-manager	P.G. van Dongen
Hydrologist	J.P. Heederik
Hydrogeologist	L. Vasak
Assistant Geophysicist	J. Reckman

Short Missions

Project Supervision	G.F.J. Jeurissen
	G.P. Kruseman
Geophysicists	W. Senden
	I. Ritsema

Annex 1.2 - POPULATION IN KERIO VALLEY

Area	Census 1979 total	In Kerio Valley* (approx.)	km^2	Density
Elgeyo Marakwet District				
Southern Division				
Soy Location	12,156	12,156	432	28
Central Division				
South Iriong	25,045	(6,000)	(200)	30
North Iriong	10,301	(4,000)	(120)	30
Northern Division				
Arror	7,663	7,663	105	72
Sambirir	15,271	(8,000)	(80)	100
Endo	20,118	20,118	270	74
Sub Total		57,937	1207	48
Baringo District				
Kabarnet Division				
Sacho	5,669	5,669	144	39
Kabarnet	13,293	13,293	261	50
Kamnarok	16,520	16,520	365	45
Kaboskei	8,993	(5,000)	(250)	20
Eldama Ravine Division				
Kakamor	5,191	(1,500)	(50)	30
Nginyang Division				
Ribkwo	13,348	(5,000)	(1,000)	5
Tirioko	1,042	(800)	(500)	1
Sub Total		49,782	2,870	17
Total		107,719	4,077	26

*Kerio Valley is assumed to comprise the whole valley area from the Elgeyo Watershed to the Tugen Hills Watershed

Annex 1.2 - POPULATION IN KERIO VALLEY

Area	Census 1979 total	In Kerio Valley* (approx.)	km²	Density
Eldoyo Marakwet District				
Southern Division				
Soy Location	12,156	12,156	435	28
Central Division				
South Irong	25,045	(6,000)	(200)	30
North Irong	10,301	(4,000)	(120)	30
Northern Division				
Arror	7,663	7,663	105	72
Sambirir	15,271	(8,000)	(80)	100
Endo	20,118	20,118	270	74
Sub Total		57,937	1207	48
Baringo District				
Kabarnet Division				
Sacho	5,669	5,669	144	39
Kabarnet	13,293	13,293	261	50
Kamnarok	16,520	16,520	365	45
Kaboskei	8,993	(5,000)	(250)	20
Eldama Ravine Division				
Kakamor	5,191	(1,500)	(50)	30
Mogotio Division				
Kibkwo	13,348	(5,000)	(1,000)	5
Tirioko	1,062	(800)	(500)	1
Sub Total		49,182	2,870	17
Total		107,119	4,077	26

*Kerio Valley is assumed to comprise the whole valley area from the Eldoyo Watershed to the Tugen Hills Watershed

Annex 2 Geology

2.1 Lithostratigraphy of major rock formations

2.1.1 Basement system

The Precambrian rocks of Basement system are the oldest rocks in the project area. The Basement gneisses are predominantly meta-sedimentary paragneisses. The metasediments represent an originally diverse sedimentary sequence of sands, shales and limestones. Hornblende schists and gneisses, originally developed from marls calcareous silts and sands, dominate in the southern and central portions of the outcrop. Biotite schists, occur occassionally interbedded in the successions representing non-calcareous pelitic horizons, several quartzo-felspathic bands are recognised representing psammitic rocks of arkosic type. Marbles and quartzites are also recognised in various isolated pockets.

2.1.2 Tertiary volcanics and sediments

(i) Kimwarer Formation and Turkana Grits

The Kimwarer Formation is apparently the earliest Tertiary rock represented within the present area. It consists of up to 60 metres of sediments seen only over a limited area to the south of Kimwarer. They were deposited in a depression in the Basement surface, the extent and form of which is not fully known. The Kimwarer Formation can be divided into two members. A lower one of arkosic, basement-derived conglomerates, grits, siltstones and shales with chert in which no volcanically derived material is observed and the upper member consisting of basaltic tuffs containing basement fragments and interbedded with basement-fragment epiclastic sediments.

The upper member is to some extent a transition between the sediments and the overlying Elgeyo Formation.

The Turkana Grits, which have comparable stratigraphic position as the Kimwarer Formation, occur in the northern part of the investigated area. They contain fragments of Basement gneisses and abundant quartz. They vary in grade from fine-grained sandstone to coarse grit. In the surroundings of Kolowa and Chemusuk, the grits are overlain by the Kapchererat Basalts.

(ii) Elgeyo Formation and Kapchererat Basalts

The Elgeyo Formation consists of a series of basic volcanic rocks found in the southern end of the Elgeyo Escarpment. They lie conformably between the Kimwarer Formation and the Chof Formation. The name Elgeyo Basalts adopted by Walsh (1967) has been considered inappropriate by Lippard (1972), because he says, basalts are absent. All the rock types represented belong to a more undersaturated series of basinites, tephrites, ankaramites, limburgites and analcitites. All the rocks are highly vesicular and anygdaloidal. The characteristic feature of the Elgeyo Formation is that it contains only 10-15% lava flows, the remainder being massive breccia-agglomeratic accumulations. No description is available for the Kapchererat Basalts, which outcrop east and north-east of Tot.

(iii) Tambach Formation

The Tambach Formation consists largely of sedimentary rocks which occupy the Tambach basin and extends from 0°35'N to 0°50'N a distance of about 30 km. The greatest width is about 2 km. The formation is lithologically a highly complex group of rocks. Fine sub-units can be identified.

- coarse fluviatile, largely basement-derived, epiclastic sediments (conglomerates, pebbly sands, silts, mudstones and clays), poorly fossiliferous.
- fine lacustrine sediments (fissile, grey and green shales and siltstones), abundant fish remains.
- glassy phonolite lava.
- trachytic tuffs and lavas.
- basanitoid silts and plugs.

(iv) Chof Phonolites and Sidekh Phonolites

The Chof Phonolites are found along the southern part of the Elgeyo Escarpment and in the head of the Kerio Valley region. It is a distinctive group of phonolite lavas which is found conformably between Elgeyo Volcanics and the overlying Uasin Gishu Phonolite. Three types of flow are recognised:

- glassy flows
- aphyric to sparsely porphyritic flows
- strongly anorthoclase and nepheline-phyric flows.

The Sidekh Phonolites which belong to the Tugen Hills group, are probably, in part, age equivalent to the Chof lavas. They outcrop along the eastern side of the Kerio River in the northern part of the project area. The Sidekh Phonolites belongs to a typical plateau phonolite type. They consist of several flows which are interbedded with tuffs and sediments.

(v) Uasin Gishu Phonolites

The Uasin Gishu Phonolites consist of a series of plateau phonolite flows which outcrop along the Elgeyo Escarpment between 0°17'N and 0°55'N. They overlie the Chof, Elgeyo and Tambach Formations and the Basement rocks. Jennings (1964) recognised two flows - a lower non-porphyritic and an upper porphyritic phonolite. But according to Lippard (1972) seven members can be identified. The seven members are from top to bottom:

- porphyritic biotite phonolite
- biotite phonolites (2-3 flows)
- aphyric phonolite
- porphyritic biotite phonolite

- nepheline-phyric phonolite
- porphyritic biotite phonolites (2 flows)
- aphyric trachyphonolite

Each flow has a thickness ranging from 30 meters to 280 meters and covers an area of several thousand square kilometers. According to Lippard (1972) the phonolite lava erupted during the period 14.5 - 12 million years ago.

(vi) Tiim Phonolites, Ngorora Formation and Ewalel Formation

Large outcrops of Tiim Phonolites occur in the Tugen Hills, outside of the project area. In the Kerio Valley this formation outcrop in the area between $0^{o}58'N$ and $1^{o}06'N$ where it consists of phonolites and trachyphonolites. The Ngorora Formation which overlies the Tiim lavas, outcrops on the slopes of the Tugen Hills between $0^{o}38'N$ and $0^{o}47'N$, and in the proper valley between $0^{o}57'N$ and $1^{o}05'N$. The formation consists of tuffs, shales, sandstones and conglomerates.

The Ewalel Formation is thin and poorly represented in the northern Tugen area. In the central Tugen Hills it ranges up to 360 meters in thickness. It extends as far west as the Elgeyo Fault-line and as far south as the head of the Kerio Valley. This Formation consists largely of massive plateau phonolite lava with lenses of tuff and epiclastic sediments. In the head of Kerio Valley area the Ewalel sequences contain a considerable thickness of phonolitic ash-flow tuffs interbedded with phonolite lavas.

(vii) Eron Basalts

The Eron Basalt Formation is a group of basic and intermediate lavas outcropping below Kabarnet trachytes. The lavas occur in a series of discontinuous outcrops across the western and central parts of Tugen Hills. The maximum thickness (180-240 metres) of the Eron Formation occurs in the Kapkelelwa-Kesok region in the west and they generally thin eastward into the central part of the range.

(viii) Kabarnet Formation

The Kabarnet Formation consists of a widespread series of lower Middle Pliocene trachytic lavas with subordinate tuffs and sediments. According to Lippard (1972) the formation can be divided into 4 units, from top to bottom:

- Riwo Beds epiclastic and pyroclastic sediments (15 m)
- Kabarnet Trachytes: six flows of fissile sanidine trachytes of which two are strongly feldsparhytic (450 m)
- Kiboino Trachyte: a single flow of trachyte lava type (20 m)
- Kiriumbopsoo 'Comendite': a single soda-rhyolite flow (180 m)

The lower two flows and the porphyritic ones in the Kabarnet Trachytes are restricted to Kabarnet areas while the non-porphyritic Kabarnet Trachytes form widespread flood lava sheets over large areas of the Tugen region (Plate 2.1). The northern limit of the Trachytes is 1°02'N and the southern one is 0°18'N.

2.1.3 Quaternary deposits

(i) Kerio Valley Beds

The Kerio Valley Beds comprise the sedimentary, alluvial fill of the Kerio Valley. They are of later Pleistocene to Recent age and they cover an area of about 1200 km^2 of the valley extending from Kimwarer to a location slightly north of Tot. They also extend from the Kerio River to the foot of the Elgeyo Escarpment and Tugen Hills, west and east of the river respectively. The deposits consist of red and brown silts and earths with numerous irregular, coarse, ill-sorted lenses of torrent wash. The thickness of these sediments is according to Lippard (1972) several hundred meters (see also Section 5.4). Most of the coarse debris in the sediments is basement material which was largely derived from the Escarpment.

(ii) Elgeyo Escarpment Scree Fans

The Elgeyo Escarpment Scree Fans which follow and fill in a series of valley features to depths of several tens of meters occur along the Escarpment between Kimwarer and Koitilial. They consist of massive wedge-shaped fans of extremely coarse chaotic landslip material which include big boulders.

Annex 4 Hydrology

4.1 Rain gauge and evaporation stations

4.2 Monthly rainfall for the period 1982 - 1983

4.3 Monthly evaporation data for the period 1982 - 1983

4.4 Rating curves

4.5 Daily flow data

4.6 Surface water quality data

Annex 4.1-1 Rain-gauge station

Registration number	Location	Co-ordinates Sheets NA 36-12/16 Scale 1:250,000 X	Y	Elevation m-m.s.l.	Record Period	Remarks
a) KMD - no.						
88.35.034 *	Cherangani Forest-Station	757	114	2200	1956 -	
035	Labot (Tambach)	769	124	3000	57 - 1978	
045	Maron Mission	816	121	1450	70 -	3) 4)
046	Chesongoch Mission	798	126	1200	72 -	3)
049	Tot Chief's Office	796	137	1200	73 -	
050	Chesoi Centre	788	118	2150	73 -	
052	Chesoi Forest Station	789	122	2500	79 -	
89.35.002 *	Marakwet A.I.C. Mission	784	091	2300	15 -	
007 *	Eldama Ravine D.O.'s Office	804	006	2200	03 -	3)
010	Kaptagat Forest-Station	778	048	2450	29 -	
014 *	Tambach D.C.	779	067	1850	25 -	
017	Lomut	787	156	980	53 -	
018	Tamkal	775	153	1220	39 -	
020 *	Kabarnet D.C.	805	055	2050	15 -	3)
041	Eureka Estate (Eldoret)	769	065	2300	31 - 69	
046	Ainabkoi Barnes Bros Estate	780	014	2650	37 - 60	
051 *	Kabartonjo D.O.'s Office	811	071	2250	38 -	4)
053	Kipkabus Flax Ltd	778	042	2550	38 - 69	
060	Emening Dispensary	821	016	1580	39 -	
064	Karuna Farm - Moiben	776	081	2300	39 -	
067	Mvita Estate - Kaptagat	775	048	2450	40 -	
077	Kipkabus, Downs Estate	778	026	2450	47 - 64	(2)
080	Nabkoi Forest-Station	777	016	2600	47 -	
091 *	Tenges Dispensary	812	035	1900	48 -	
092	Poi Dispensary	812	082	1700	48 -	
093 *	Chebloch Primary School	798	051	1200	48 - 79	4)
094	Timboiwa Primary School	811	047	2300	48 -	
097	Kapsiliat Estate-Moiben	776	093	2400	47 - 67	
104	Chebiemit D.O.'s Office	778	095	2450	50 -	
106	Elgeyo Forest-Station	782	083	2300	50 -	
108	Kenleg Farm - Moiben	771	087	2150	50 - 77	
117	Kipkabus Lolgariri Estate	780	036	2500	51 -	
121	Ainabkoi Skyline Estate	788	019	2600	52 - 73	(2)
128	Kabarnet Demonstration Holding	808	054	1950	54 -	
131 *	Tambach Chepkorio	782	044	2600	55 -	
133	Eldoret Govt. Exp. Farm	757	063	2150	54 -	1)
134	Kessup Forest-Station	799	069	2300	55 -	
135	Kituro Demonstration Plot	811	054	2130	56 -	
137 *	Timboroa Forest-Station	785	010	2750	54 -	
140	Sirwa Dispensary	809	020	2130	75 -	Very poor data
143	Cheberen - Kabarnet	816	025	1370	60 -	
144	Ratat School	825	033	1340	61 -	
145	Torongo Primary School	790	014	2600	61 -	4)
146 *	Barwesa T.C.	802	078	1700	57 -	
149	Talai T.C.	813	066	2150	59 -	
158	Chebororwa F.T.C.	766	103	2050	64 -	
163	Marigat Irrigation Scheme	832	051	1050	54 -	1)
164	Sabor Forest-St. (Kaptagat)	777	056	2450	65 -	
176	Tenges Forest Nursery	811	035	1450	69 -	
178	Iten Secondary School	779	074	2300	75 -	
184	Kaptarakwa	783	052	2300	73 -	
187	Chemususu Forest-Station	795	010	2300	73	
191	Sacho Dispensary	809	041	2150	75 - 78	
192	Sigoro Primary School	805	014	2130	75 -	
196	Tirimionin Chief's Centre	814	073	2130	76 -	
197	Kapkalelwa Dispensary	802	042	1350	75 -	
199	Mugorwa Health Centre	803	034	1500	75 -	
200	Kimose Agricultural Holding	823	025	1520	75 -	
202	Muskut Chief's Office	792	042	1370	78 -	
204	Iten D.C.'s Office	779	074	2390	78 -	
205	Matete Chief's Office	815	062	1490	80 -	
207	Lorenge Forest Station	781	007	2620	77 -	
209	Biretwo Agriculture Farm	784	062	1350	81 -	
210	Cheptongei	782	105	2400	81 -	
211	Kitany	782	053	2550	81 -	
89.36.020	Kinyang Dispensary	834	107	900	42 -	

Annex 4.1-1 Rain-gauge station (continue)

Registration number	Location	Co-ordinates Sheets NA 36-12/16 Scale 1:250,000 X	Y	Elevation m-m.s.l	Record Period	Remarks
b) MOWD - NO.						
621	Eldama Ravine	804	003	2000	1975 -	
632	Kapsangar Primary School	770	133	3048	82 -	3) 5)
676	Kessup Mission	780	071	2100	76 -	3) 4)
714	Seretunin w/s	811	062	1980	80 -	3) 4)
735	Arror Mission	792	105	1050	82 -	5)
736	Kaptalamwa Primary School	771	123	2987	82 -	5)
737	Tot Mission	796	134	1160	82 -	5)
739	Kolowa Dispensary	807	136	1100	82 -	5)
740	Kinyach Dispensary	799	104	1050	82 -	3) 5)
741	Kiptagich T.C. (Sacho)	810	042	2150	82 -	5)
746	Kimwarer Fluorspar Mine	791	035	1400	82 -	3) 5)

Note
1) Full Meteorological Station
2) Full Meteorological Station until 1956
3) Station with evaporation pan
4) Project rehabilitated stations
5) Project installed station

*) Stations used for analysis

Annex 4.1-2 Evaporation station

Registration number MOWD	Location	Co-ordinates Sheet No. NA 36-12/16 Scale: 1:250.000 X	Y	Elevation m.m.s.l	Record period	Remarks
2	Eldoret met. station			2100	1946 - 1960	
49	Eldoret Govt. Exp. Farm	757	063	2150	1954 -	
60	Cherangani Forest	757	114	2200	56 -	
63	Kabarnet	805	055	2000	57 -	
77	Marigat Irrigation Scheme	832	051	1050	58 -	
114	Sigor	775	165	1050	66 -	
130	Eldama Ravine	804	006	2150	74 -	
136	Kessup Mission	780	071	2100	82 -	1)
144	Kapsangar Primary School	764	123	2700	82 -	1)
145	Kinyach	799	104	1050	82 -	1)
146	Chesongoch Mission	798	126	1200	82 -	1)
147	Maron Mission	816	121	1500	02 -	1)
148	Kimwarer Fluorspar Mine	791	035	1400	82 -	1)

1) Project installed evaporation pans

Annex 4.1-2 Evaporation station

Registration number WMO	Location	Co-ordinates Sheet No. HA 36-12/16 Scale: 1:250.000 X	Y	Elevation m.a.s.l.	Record period	Remarks
3	Eldoret met. station			2100	1964 - 1980	
40	Eldoret Govt. Exp. Farm	757	063	2150	1954 -	
60	Chepkunyuni Forest	757	114	2200	56 -	
63	Kabarnet	805	055	2200	57 -	
77	Marigat Irrigation Scheme	832	051	1050	58 -	
114	Sigot	775	105	1050	66 -	
130	Eldama Ravine	804	006	2150	74 -	
138	Kessup Mission	780	071	2100	82 -	1)
144	Kapsengar Primary School	764	123	2700	82 -	1)
145	Kinyach	790	104	1050	82 -	1)
146	Chebongwok Mission	790	136	1200	82 -	1)
147	Maron Mission	816	121	1500	82 -	1)
148	Kimwarer Fiscrepat Mine	791	035	1400	82 -	1)

1) Project installed evaporation pans

Annex 4.2 Monthly rainfall for the period 1982 - 1983

Annex 4.2-1 Monthly rainfuall for 1982

Registration number	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
a) KMD-No 88.35.034	21.5	15.0	55.0	205.6	174.6	76.0	127.5	203.9	32.2	116.7	166.5	31.0	1226
046	19.6	7.2	51.5	244.9	142.6	32.4	65.6	224.8	85.8	102.3	192.2	20.5	1193
			N/A										
050	32.2	20.5	77.1	331.1	232.0	37.2	85.5	134.2	86.5	105.3	214.5	54.6	1410
052	20.3	19.1	57.1	328.6	264.9	47.4	121.4	253.7	121.7	208.6	218.7	72.7	1740
No 89.35 002	70.6	24.0	82.6	332.7	(175)	96.8	100.5	121.1	62.6	228.6	264.7	80.6	1643
007	26.2	56.4	37.6	226.1	258.5	77.4	90.2	150.1	51.7	83.7	335.1	116.8	1509
010	15.0	50.3	52.0	213.0	207.0	25.2	63.0	92.0	59.7	185.9	218.8	47.0	1229
014	17.7	40.6	70.7	529.8	390.2	51.3	96.4	99.3	103.9	175.1	222.4	92.1	1889
020	33.7	68.0	55.1	444.7	329.0	79.8	56.5	256.9	89.2	102.4	303.8	123.1	1942
051	49.5	20.8	80.0	416.8	356.9	27.4	73.5	226.9	51.7	158.0	210.1	220.5	1894
			N/A										
			N/A										
080	2.2	20.7	27.4	218.7	141.0	42.1	80.6	148.8	77.8	72.0	-	68.6	
091	11.0	35.6	24.5	350.0	390.0	59.3	88.2	213.9	35.3	145.3	300.3	173.2	1826
092	30.0	24.5	32.0	314.6	131.1	24.5	0.0	137.8	77.1	67.6	443.0	116.5	1401
			N/A										
094				417.3	227.8	82.7	86.5	499.3	96.2	189.0	348.5		
104	12.7	6.7	51.1	362.2	333.8	195.0	103.0	132.9	9.5	188.6	192.3	72.0	1550
106	0.0	35.5	41.0	525.4	266.7	30.7	64.5	69.0	65.5	261.0	409.0	251.2	2019
108	9.5	8.1	63.3	184.2	137.8	26.9	103.9						
117	13.0	69.5	42.2	322.1	303.8	59.2	162.4	228.2	79.2	136.5	309.1	199.9	
131											309.9	108.7	
133	0.9	21.3	59.2	170.3	150.6	41.0	104.2	175.3	43.3	91.8	161.3	24.1	1043
134	6.1	25.9	72.6	537.7	366.4	17.9	91.7	59.0	60.4	174.2	287.3	140.4	1840
137	0.0	55.3	13.9	288.6	134.9	36.9	189.7	243.6	92.6	69.1	212.6	57.4	1396
243	6.1	0.0	61.7	175.2	215.8	48.6	58.1	192.1	44.3	63.2	220.4	48.4	1134
145		43.0	18.8	256.8	166.2	80.0	77.3	176.2	142.8	103.6	255.0		
146	15.0	42.0	31.7	294.5	176.9	39.0	46.9	115.8	33.0	116.2	(70)	29.8	1012
149	54.8	21.7	96.8	245.5	311.2	32.8	82.9	174.4	58.9				
158	19.0	12.8	55.8	220.0	131.5	29.2	85.6	106.4	96.9	99.4	164.5	19.9	1041
163	0.6	12.3	18.7	141.7	94.8	18.3	29.9	114.2	7.0	52.7	157.6	23.4	671
164	6.0	50.0	73.0		286.1	40.0	89.0	116.5	48.6	168.1	389.5	76.5	
176	18.7	40.6	29.5	362.1	343.3	49.7	97.2	243.7	21.4	88.5	281.9	106.4	1683
178	14.0	38.6	156.4	530.9	218.4	94.3	44.2	35.5	57.3	(157)			
184	13.0	90.4	213.1		401.6	17.0	11.5	98.9	83.0				
187	35.2	46.4	32.0	286.7	192.2	76.8	114.1	93.0	73.0	74.9	286.2	84.2	1395
191						51.0	70.3	254.3	33.2	83.8	242.8	98.3	
197	20.6	43.5	46.9	356.8	330.4								
199			40.7		370.5		113.0		165.0	204.0			
202	29.1	30.0	44.0	332.8	255.9	75.0	110.4	110.6	84.5	65.1	354.9	73.0	1536
MOWD No 632				260	600	120	120	220	55	70		95	
676	21.8	40.8	-	491	374.9	37.9	74.7	53.6	58.6	187.3	287.9	361.0	
735					139.4	43.2	50.3	236.3	42.7	128.2	205.0	82.8	
736				154.4		53.9	93.6	199.1	70.4	127.2	124.0	39.0	
737						76.2		135.7	7.6	162.4			
739			61.0		208.3	66.0	58.4	118.9	73.0	116.0	116.0	58.0	
740			45.7	454.4	167.6	30.2	62.7	137.0	73.4	97.7	183.1	52.6	1309
743		53	21.6	138.5	250.1	76.5	66.7	(113)	68.6	(153)	157.4	34.5	1135
746			83.6	697.0	265.1	64.8	223.6	55.6	30.5	220.3	388.7	112.1	

Annex 4.2-2 Monthly rainfall for 1983

Registration number		JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
a) KMD-No 88.35	034	50.0				N/A								
	046	11.1	12.5	6.2	137.5	65.7	132.4	78.9	174.6	123.5	144.9	59.5	(17)	966
	050	27.0	53.6	42.9	150.3	106.6	60.3	69.1						
	052	28.0	36.2	13.3	165.3	137.3		104.4	188.6	95.3				
No 89.35	002	49.5		40.3	140.8	178.6	71.8	53.2						1014
	007	6.8	31.9	3.9	194.6	60.5	141.0	118.5						1092
	010	9.0	43.1	4.6	134.7	160.4	119.3	170.3						
	014					N/A								
	020	6.4	103.9	27.0	151.8	96.2	141.1	172.4						1270
	051	2.5	109.5	4.0	168.2	171.3	207.0	182.7						1552
	080	11.8	11.6	22.3	133.9	148.1	65.6	112.1						
	091	11.8	61.0	0.7	127.6	122.7	97.0	159.7						1108
	092	Nil	67.0	Nil	80.5	225.5	72.3							1461
	093	Nil	9.0	15.0	14.0									
	104	6.5	81.9	Nil	101.1	111.9	79.7							
	106	3.2	104.5	6.1	159.7	207.1	143.6	62.7						
	108					N/A								
	117	11.5	120.4	9.5	150.1	232.0	86.7	140.0						
	131	18.7	66.6	13.8	153.2	135.3	143.8	103.1						
	133	7.9	47.8	44.7	149.5	140.3	145.4	109.6						
	134	2.0	24.3	6.9	188.1	147.2	89.1	49.4						
	137		61.9	10.9	138.5	94.0	115.0	134.8						1078
	143	15.5	25.4	5.9	70.4	85.9	42.0	200.1						
	145	16.3	41.4	34.0	268.1	125.0	102.7							
	146	Nil	38.2	10.2	70.0	111.6	42.5	137.3						698
	149	9.0	78.2	10.0	109.9	165.6								
	158	10.1	45.7	13.4	92.2	151.6	56.2	104.2						
	163	1.4	43.6	3.9	59.6	34.6	163.1							
	164	14.4	60.0	5.1	203.0	193.0	115.5	159.5						
	176	Nil	93.0	Nil	153.4									
	178	23.0	65.0	14.2	162.7	212.3								
	184	15.3	56.1	3.0	272.0	225.2	129.3	184.1						
	187	12.7	31.7	10.1	183.5	125.2	99.8	125.8						
	191													
	197	Nil	31.0	26.0	127.6	185.2	124.0	177.4						
	202	Nil	51.7	14.7	114.3	201.7								
MOWD No	632	20	5	-	120	200	-	-	220	135				
					415.4	579.2	30.8	77.1	340.5	93.5	441.1	109.4	49.0	
	735	36.1	13.2	32.5	152.2	124.5	71.1	-	225.0	136.1	172.0			
	736	39.2	40.3	20.4	144.3	113.4	127.8							
	737	Nil	Nil	15.2	-	120.4	127.3	218.7	148	97.5	107.1	51.3	30.3	
	739				74.0	139.0	168.0	79.0	357.0	81.0	118.0	62.0		
	740	13.0	35.3	32.1	108.8	103.4	100.3	107.2	292.1	64.0	162.6	66.5	11.4	1096
	743	11.2	29.3	11.0	92.6	58.2	105.5	154.0	357.2		315			1144
	746	8.8	60.3	18.6	78.4	307.6	131.6	257.4	259.3	194.2	297.8	84.0	228.9	

Annex 4.3 Monthly evaporation data for the period 1982 - 1983

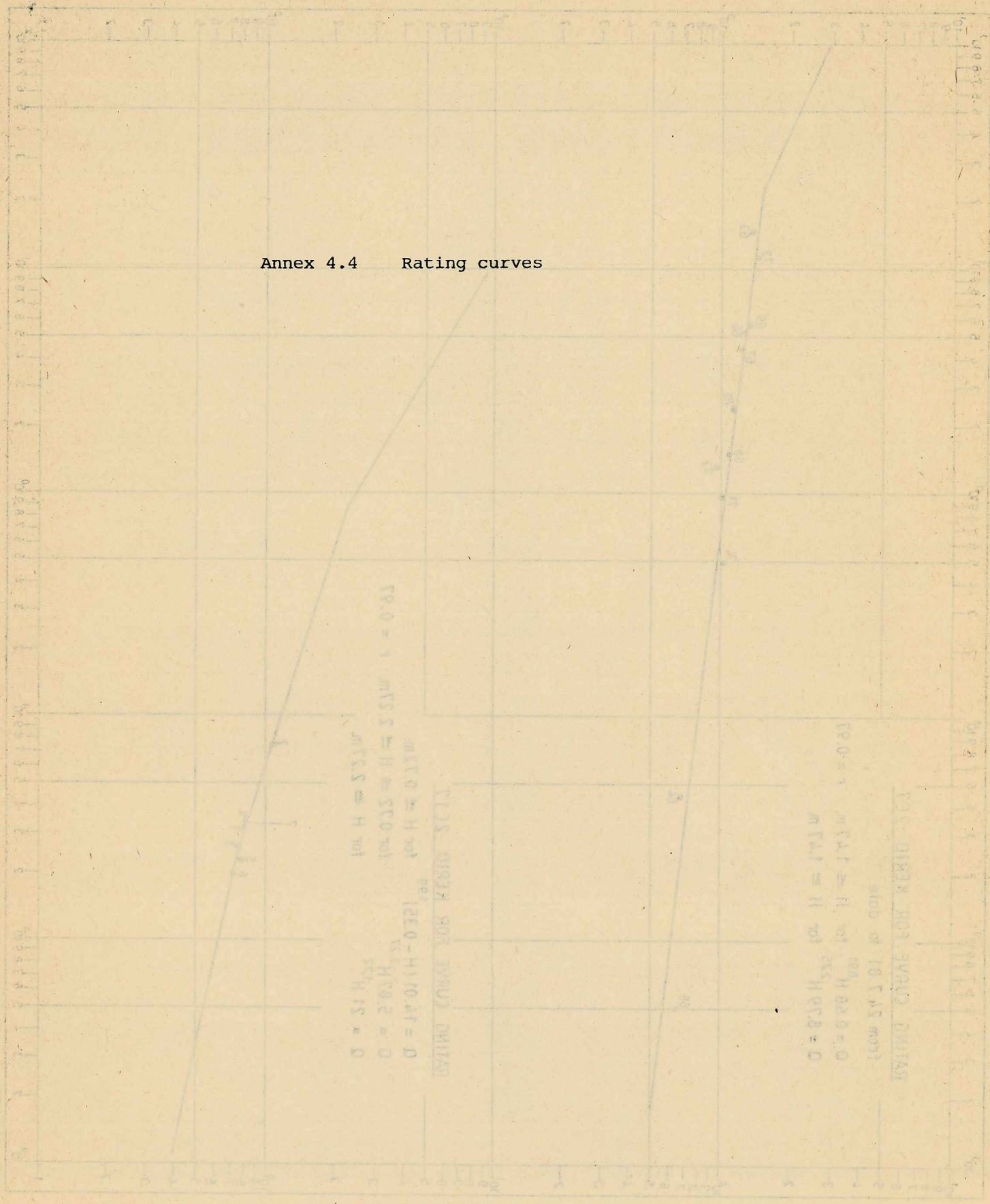
Annex 4.3-1 Monthly evaporation for 1982

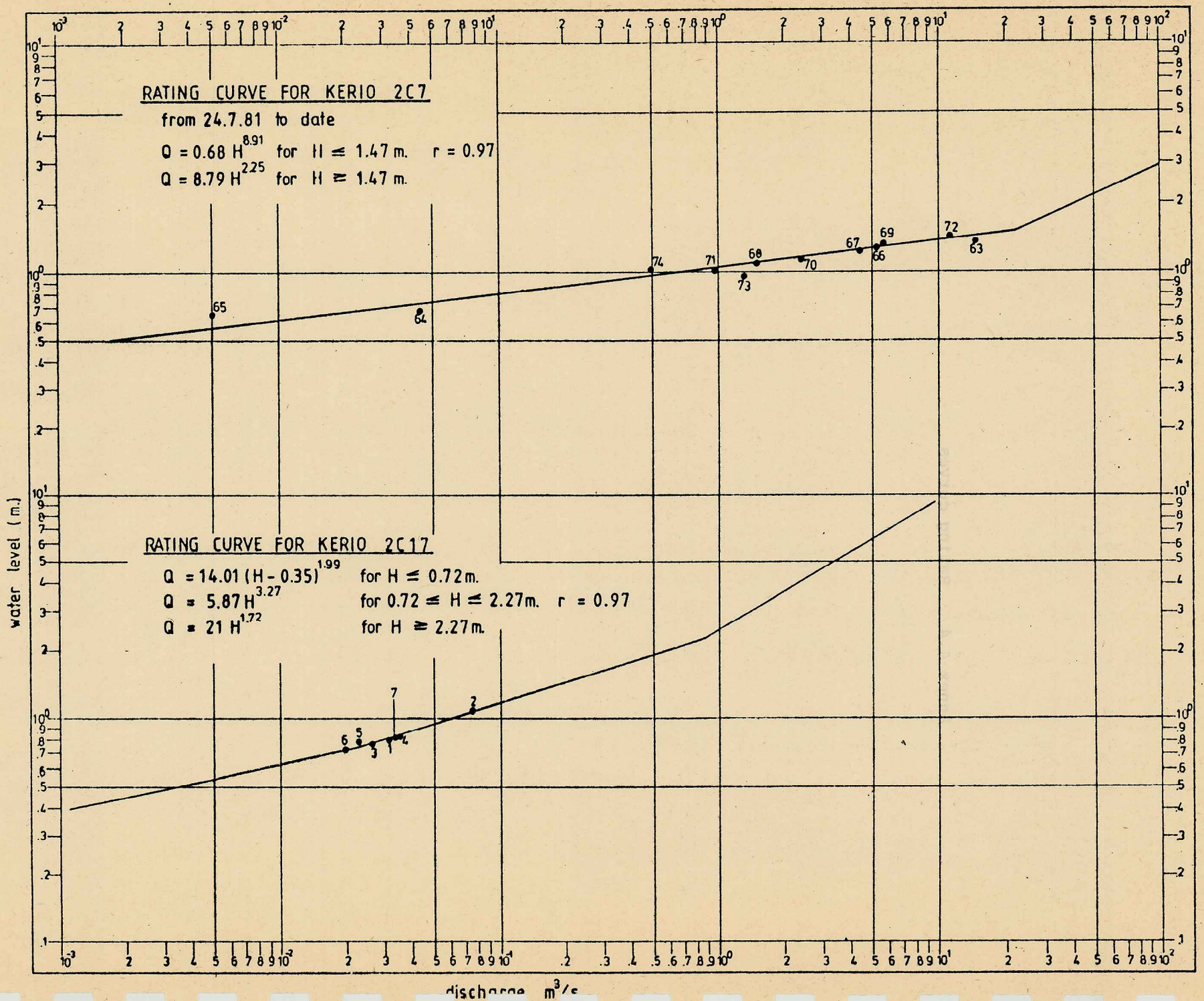
Registration number	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	Total
49	174	170	215	131	121	102	92	96	109	129	103	135	1577
60	140	132	194	83	90	180	118	73	147	115	(94)	170	1436
63	245	203	267	168	127	(127)	116	108	141	147	130	178	1957
77	252	254	311	182	(183)	182	211	141	182	177	156	156	2391
130	195	190	243	144	127	122	137	120	147	126	121	126	1798
136	(252	246	311	190	175	148	133)	115	140	124	148	301	2283
144	(165	156	229)	134	(106)	123	114	134	104	138	(111)	182	1696
145	(285	287	352	206)	237	194	210	192	(206	200)	180	155	2704
146	(253	255	312	183)	170	129	151	256	190	181	163	(156)	2399
147	(269	271	332)	177	183	172	190	209	189	212	163	186	2554
148	(245	247	302	177)	155	159	190	174	223	155	192	106	2326

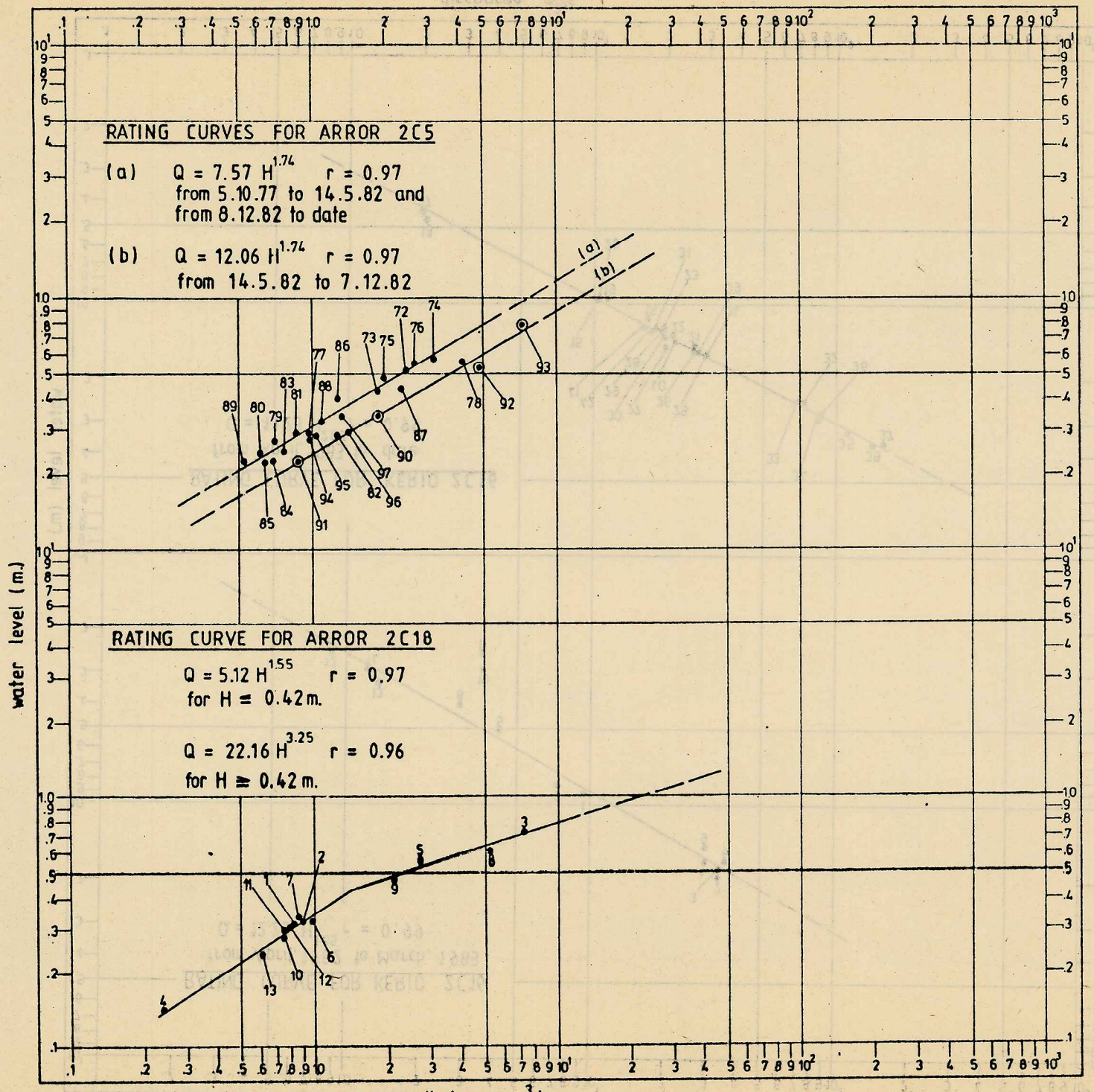
Annex 4.3-2 Monthly evaporation for 1983

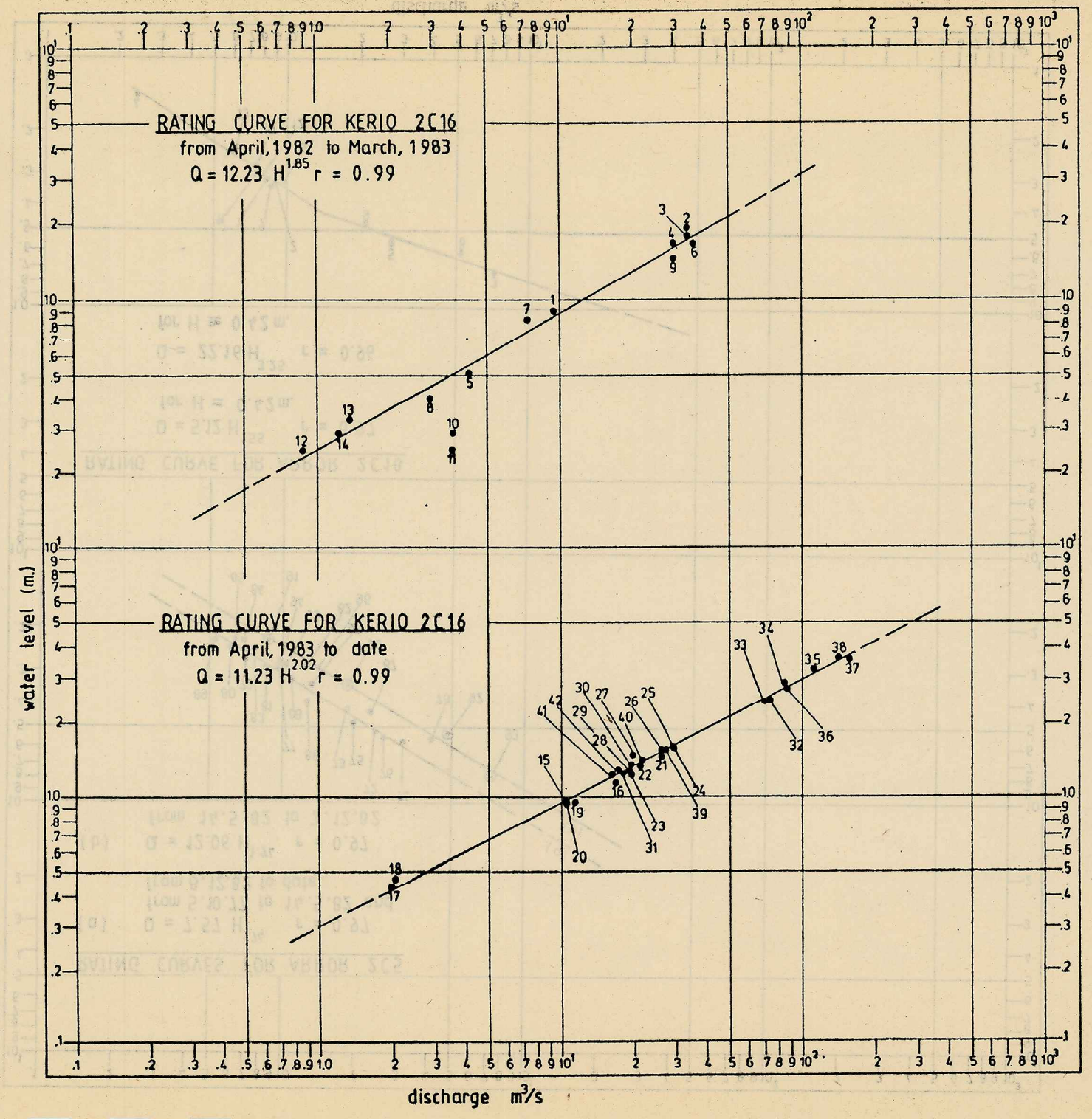
Registration number	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	Total
49	135	128	143	133	129	106	90	108	99	133	112	109	1425
60								107					
63	(157)	168	246	183	115	104	90	95	106	126	135	129	1654
77	206	185	277	210	164	178	162	128	(154	207	174	169)	2214
130	168	154	213	167	150	143	122	116	143	144	138	127	1785
136	(192	182	203	189)	131	122	172	115	128	224	161	204	2022
144	177	(108	120	112)	78	(89	76)	67	97	99	85	(92)	1200
145	(199	179	268)	170	189	168	149	143	162	176	160	177	2131
146	187	178	232	189	166	(170)	155	182	162	172	166	(162)	2121
147	224	241	328	232	209	(213)	155	207	(184	248	208	202)	2653
148	219	196	294	223	174	189	172	162	167	222	154	179	2351

Annex 4.4 Rating curves




RATING CURVE FOR KERIO 2C7
from 24.7.81 to date
Q = 0.68 H^8.91 for H ≤ 1.47 m. r = 0.97
Q = 8.79 H^2.25 for H ≥ 1.47 m.
RATING CURVE FOR KERIO 2C17
Q = 14.01 (H - 0.35)^1.99 for H ≤ 0.72 m.
Q = 5.87 H^3.27 for 0.72 ≤ H ≤ 2.27 m. r = 0.97
Q = 21 H^1.72 for H ≥ 2.27 m.
water level (m.)
discharge m³/s


RATING CURVES FOR ARROR 2C5
(a) Q = 7.57 H^1.74 r = 0.97
from 5.10.77 to 14.5.82 and
from 8.12.82 to date
(b) Q = 12.06 H^1.74 r = 0.97
from 14.5.82 to 7.12.82
(a)
(b)
RATING CURVE FOR ARROR 2C18
Q = 5.12 H^1.55 r = 0.97
for H ≤ 0.42m.
Q = 22.16 H^3.25 r = 0.96
for H ≥ 0.42 m.
water level (m.)
discharge m³/s


RATING CURVE FOR KERIO 2C16
from April, 1982 to March, 1983
Q = 12.23 H^1.85 r = 0.99
RATING CURVE FOR KERIO 2C16
from April, 1983 to date
Q = 11.23 H^2.02 r = 0.99
water level (m.)
discharge m³/s

Annex 4.5 Daily flow data

Daily mean discharge in m^3/s Kerio River 1982

Station: Chebloch Station no: 2C7 Total catchment area: 893 km^2

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1					1.79	33.45	1.89	7.97	8.13	1.30	1.98	*53.02
2				0.90	1.19	28.43	1.53	11.56	7.29	1.24	5.20	*51.81
3				0.30	0.92	24.95	9.79	9.99	6.13	1.19	2.86	*69.08
4				0.18	1.01	23.05	19.47	21.62	6.13	1.14	7.39	*61.26
5				0.09	9.79	22.05	20.70	16.87	5.96	1.14	13.25	*50.76
6				0.07	9.51	21.08	11.85	8.47	6.13	1.14	16.88	*39.50
7				0.06	7.88	18.07	4.97	7.07	4 79	1.14	*27.68	*32.99
8				0.04	7.38	15.47	46.41	5.72	4.62	1.24	*29.39	*35.94
9				0.03	13.38	13.20	50.76	6.49	4.15	1.19	*26.03	*40.88
10				0.04	10.37	11.61	50.24	7.56	3.58	1.14	*22.55	*36.82
11				0.04	20.55	9.23	50.24	7.30	3.45	1.14	*57.26	*32.17
12				0.03	34.55	7.54	49.72	5.52	3.45	1.35	*48.68	*29.01
13				0.39	32.86	6.35	49.46	21.74	3.09	1.19	*40.88	*36.38
14				9.22	34.86	8.24	49.20	24.99	3.01	2.19	*35.73	*32.99
15				4.50	32.67	9.86	48.94	25.95	3.00	1.35	*29.01	*31.36
16				8.42	30.28	8.70	45.18	28.76	2.75	1.35	*14.99	*29.01
17				14.02	29.57	7.10	47.67	35.00	2.75	1.35	*11.99	*27.12
18				1.21	29.68	7.39	4.43	33.96	2.65	5.40	2.55	*25.31
19				20.94	31.22	6.25	4.56	28.02	2.46	15.56	2.27	*21.24
20				9.86	30.37	4.30	1.79	24.08	2.02	6.81	1.94	*21.89
21				15.55	28.02	3.72	1.66	24.47	2.02	10.61	1.79	*21.05
22				15.21	27.05	5.60	1.47	23.59	1.95	5.12	1.59	*17.52
23				4.97	25.66	5.07	5.09	23.19	2.35	2.55	1.41	*14.52
24				13.96	32.69	5.01	12.13	22.53	1.87	1.87	7.81	21.05
25				4.51	35.80	4.54	53.02	21.24	1.66	1.87	19.59	18.07
26				15.30	36.55	3.20	3.58	20.24	1.59	2.04	36.45	15.98
27				20.46	35.59	4.74	2.75	18.44	1.53	1.79	28.63	14.99
28				13.08	33.41	2.58	2.36	15.89	1.35	1.83	50.63	13.63
29				12.91	33.50	3.22	2.02	11.41	1.35	1.79	36.39	12.38
30				3.30	43.77	2.03	2.53	8.92	1.30	2.36	51.97	10.88
31					36.82		4.00	8.35		1.94		10.19
Total $x10^6 m^3$				16.468	63.823	28.169	57.230	46.389	8.857	7.199	54.844	81.199
Monthly mean				6.54	23.83	10.87	21.37	17.32	3.42	2.69	21.16	30.32
Daily max.				92.04	113.72	30.17	107.25	79.43	16.46	38.14	86.30	177.22
Daily min.				0.02	0.68	1.72	1.24	2.55	1.24	1.14	1.35	9.86
Runoff in mm.				18.44	71.47	31.54	64.09	51.95	9.92	(8.06)1)	61.42	90.93

*) estimated from observers reading

Daily mean discharge in m^3/s Kerio River 1983

Station: Chebloch Station no: 2C7 Total catchment area: 893 km^2

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	8.92	* 0.29		0	8.55	4.30	* 2.75	27.28	43.23			
2	8.07	* 0.27		0	2.67	3.86	* 2.55	25.78	35.51			
3	7.29	* 0.24		0	2.53	2.97	* 2.75	25.60	33.93			
4	6.36	* 0.27		0	4.52	2.55	* 2.19	20.79	32.75			
5	5.92	* 0.27		0	3.16	2.27	* 1.87	22.89	39.45			
6	5.15	* 0.24		0	12.18	2.02	* 1.47	19.21	34.24			
7	4.62	* 0.24		0	7.62	2.02	* 1.35	19.32	29.78			
8	4.15	* 0.24		0	10.12	1.87	* 1.24	18.62	33.22			
9	* 2.02	* 0.22		0	17.25	* 1.59	* 1.14	15.66	31.23			
10	* 1.87	* 0.22		0	35.04	* 1.47	* 1.05	17.81	29.39			
11	* 1.87	* 0.22		0	30.54	* 1.35	* 0.96	22.46	37.48			
12	* 1.72	* 0.39		0	24.21	*10.53	* 2.55	*57.26	47.16			
13	* 1.72	* 0.27		0	19.05	* 7.04	* 2.36	*57.26	38.93			
14	* 0.68	* 0.43		0	8.92	* 5.72	*17.52	*41.81				
15	* 0.62	* 0.52		0	5.22	* 8.07	*15.47	*41.81				
16	* 0.62	* 0.47		0	3.86	* 1.87	*21.24	*46.66				
17	* 0.57	* 0.57		0	3.49	* 2.97	*25.31	*49.79				
18	* 0.68	* 0.52		0	3.12	* 6.13	*21.89	*45.67				
19	* 0.52	* 0.62		0	2.75	* 1.87	23.56	*56.70				
20	* 0.47	* 0.74		0	5.63	* 2.97	22.25	*56.15				
21	* 0.47	* 0.62		0	3.55	* 6.13	31.72	30.57				
22	* 0.47	* 0.57		0	2.97	* 5.33	25.32	32.99				
23	* 0.43	* 0.52		0	8.35	* 4.00	18.63	47.85				
24	* 0.43	* 0.47	0	0	9.20	* 3.45	17.59	46.06				
25	* 0.39	* 0.47	0	-	13.56	* 2.97	17.22	44.05				
26	* 0.39	* 0.47	0	-	13.82	* 2.19	38.54	42.47				
27	* 0.36	* 0.43	0	25.31	8.99	* 4.62	31.20	64.97				
28	* 0.36	* 0.36	0	7.75	4.66	* 4.00	29.24	42.69				
29	* 0.36		0	5.12	6.78	* 3.45	33.95	43.07				
30	* 0.92		0	5.92	16.56	* 2.97	30.58	54.94				
31	* 0.32		0		6.82		26.40	45.36				
Total $\times 10^6 m^3$	5.939	0.964	0.50	3.810	26.498	9.724	40.769	102.259				
Monthly mean	2.22	0.40	0.20	1.58	9.89	3.75	15.22	38.18				
Daily max.	9.86	0.74	0.36	63.02*	92.77	11.27	108.06	224.36	113.72			
Daily min.	0.32	0.22	0	2.02	1.72	1.87	10.53	10.53	27.49			
Runoff in mm.	6.65	1.08	0.56	4.27	29.67	10.89	45.65	114.51				

*) estimated from observers readings

Daily mean discharge in m^3/s Kerio River 1982

Station: Kinyach Station no: 2C17 Total catchment area: 2471 km^2

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1						109.34	4.99	2.39	8.02	2.1	3.07	92.30
2						91.97	4.42	2.72	7.10	1.73	3.58	123.62
3					21.15*	73.60	4.11	4.31	7.10	1.83	4.01	177.13
4					15.29*	47.88	3.89	6.69	6.67	1.83	5.49	125.69*
5				2.83	11.86*	33.93	7.10	10.37	6.06	1.73	4.47	118.89*
6				1.73	13.16*	27.86	18.74	17.56	5.87	1.54	11.86	104.36*
7				0.81	37.98*	23.58	13.50	8.02	5.49	1.36	24.29	92.64*
8				0.46	34.58*	20.23	7.56	5.31	5.49	1.28	78.86	87.32*
9				0.32		17.85	5.59	4.79	4.96	1.19	76.19	87.32*
10				0.16	29.59	16.04	4.74	4.47	4.63	1.15	79.65*	80.83*
11				0.10	22.10	14.19	4.11	4.47	4.31	1.11	112.98	69.57*
12				0.12	26.97	12.83	3.81	4.79	3.86	1.11	83.23*	59.45*
13				0.13	57.33	12.18	3.53	4.55	3.72	1.19	52.13*	47.88*
14				3.07	72.83	10.95	3.53*	11.22	3.45	1.45	37.28*	39.40*
15				12.83	116.94	9.81	3.25*	16.83	3.32	2.39	26.20*	46.25*
16				27.86	114.67	10.09	3.39*	16.43	3.19	2.50	21.63*	35.91*
17				49.55	105.07	10.66	2.99*	21.68	3.07	2.83	18.48*	30.80*
18				53.00	100.85	9.81	2.99*	30.19	3.19	2.83	16.43	27.30*
19				33.93	93.33	9.54	2.86*	37.98	3.19	3.07	14.19	25.10*
20				87.98	85.67	8.50	2.61*	29.01	3.07	15.19	13.33	23.10*
21				83.23	77.33	7.55	2.95*	20.69	2.83	11.25	11.86	20.20*
22				101.55	66.42	7.10	2.83*	18.91	2.60	7.32	11.25	18.90*
23				93.00*	56.16	8.50*	2.38	17.23	3.07	8.26	10.09	18.91
24				62.00*	45.61	9.54	3.53	16.43	5.31	7.10	9.54	17.64
25					37.98	7.55	6.41	18.05	3.72	4.47	10.09	15.29
26				88.00*	47.88	6.99	5.32	16.43	3.07	4.01	24.66	13.50
27				45.00*	58.85	6.36	4.11	14.55	2.72	3.32	43.38	12.50
28				90.00*	61.04	5.85	3.67	13.84	2.60	3.32	61.14	11.55
29					66.82	5.59	3.25	12.83	2.39	3.58	89.96	10.09
30				120.00*	100.51	4.90	2.92	11.86	2.19	3.32	87.98	10.09
31					118.15		2.49	9.81		3.32		9.54
Total $x10^6 m^3$				103.427*	162.213	55.363	12.750	35.805	10.909	9.390	90.487	142.825
Monthly mean				39.90	60.56	21.36	4.76	13.37	4.21	3.51	34.91	53.32
Daily max.				124.92	126.45	110.80	26.74	41.60	10.95	20.23	112.98	201.17
Daily min.				0.09	11.86*	4.79	2.38	2.19	2.10	1.11	2.99	9.54
Runoff in mm.				41.86	65.65	22.40	5.16	14.49	4.41	3.80	36.02	57.80

*) estimated from observers reading

Daily mean dicharge in m^3/s Kerio River 1983

Station: Kinyach Station no: 2C17 Total catchment area: 2471 km^2

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	9.54*	1.73	1.03*	0	2.60	5.50*	21.15*	18.91*	105.78*	13.16	13.84	5.40*
2	9.54*	1.59	0.89*	0	8.02	5.14*	21.15*	14.55*	99.46*	12.18	15.66	5.16*
3	7.10*	1.50	0.75*	0	6.26*	4.63*	10.66*	13.50*	89.30*	10.95	24.60	4.91*
4	6.67*	1.41	0.63*	0	3.80*	4.16*	10.02*	12.50*	82.03*	10.37	14.19	4.67*
5	6.06*	1.32	0.51*	0	3.07*	3.79*	9.37*	10.37*	72.85*	13.16	13.16	4.42*
6	6.06*	1.32	0.46*	0	2.60*	3.45*	8.73*	9.54*	67.46*	23.08	18.91	4.16*
7	6.26*	1.28	0.36*	0	3.58*	3.19*	8.09*	9.01*	61.39*	41.60	20.69	
8	6.26*	1.19	0.32*	0	8.02	2.95*	7.45*	8.50*	69.57	47.88	16.43	
9	5.97*	1.15	0.24*	0	5.87	2.72*	6.81*	8.0 *	64.37	53.00	16.04	
10	5.68*	1.03	0.14*	0	9.54	2.60*	6.17*	8.0 *	54.79	54.79	14.19	
11	5.14*	1.03	0.09*	0	14.55	2.50*	5.53*	7.55*		68.51	13.50	
12	4.79*	1.03	0.05*	0	22.10	2.44*	4.89*	27.30*		68.51	11.86	
13	4.47*	1.54	0.04*	0	14.19*	2.39*	4.25*	40.12*		47.88	10.66	
14	4.31*	1.94	0.02*	0	11.55*	2.29*	3.61*	27.30*	52.13	37.28	9.54	
15	4.01*	1.83	0.02*	0	8.63*	3.32*	2.97*	15.66*	37.98	32.02	9.01	
16	3.86*	1.73	0.02*	0	6.26*	2.01*	5.00*	17.64*	31.40	27.86	8.50	
17	3.72*	1.64	0.01*	0	5.14*	2.19*	10.00*	57.56*	32.02	26.74	8.02	
18	3.45*	1.50	0.01*	0	4.01*	2.10*	8.50*	52.13*	27.30	23.08	7.55	
19	3.19*	1.45	0.14*	0	3.45*	2.01*	27.00*	55.70*	54.79	21.15	9.54	
20	2.95*	2.04	0.09*	0	3.19*	1.92*	25.00*	59.85*	70.65	23.08	9.54	
21	2.83*	3.45	0.05*	0	2.95*	3.86*	23.00*	42.35*	70.65	19.34	9.01	
22	2.72*	3.19*	0.02*	0	3.19*	4.79*	30.00*	45.45*	56.62	18.05	8.26	
23	2.60*	2.72*	0.01*	0	3.45*	3.19*	28.00*	71.73*	46.25	33.28	7.78	
24	2.50*	2.29*	0 *	0	3.58*	2.72*	25.00*	112.98*	35.24	53.00	7.10	
25	2.50*	2.10*	0 *	0.01*	9.01*	2.60*	23.00*	124.16*	28.43	32.02	6.67	
26	2.39*	1.73*	0 *	0.01*	6.67*	3.45*	21.00*	110.08*	24.09	24.60	6.47	
27	2.39*	1.45*	0 *	1.28	8.50*	4.47*	29.00*	103.65*	20.69	22.59	6.36	
28	2.29*	1.36*	0 *	6.89	10.37*	10.66*	27.00*	100.50*	18.91	19.34	6.12*	
29	2.19*		0 *	5.14	7.10*	9.27*	25.00*	97.39*	16.83	16.04	5.88*	
30	2.10*		0 *	3.07	4.63*	14.55*	22.00*	93.99*	14.92	14.55	5.64*	
31	2.01*		0 *		5.68*		19.50*	91.30*		13.16		
Total $\times 10^6 m^3$	11.712	4.107	0.510	1.417	18.279	10.442	41.373	126.738	134.964	79.682	28.920	
Monthly mean	4.37	1.70	0.19	0.55	6.83	4.03	15.41	47.32	52.07	29.75	11.16	
Daily max.	9.54	3.86	1.03	6.89	25.00*	17.60	47.88	138.95	105.78*	62.37	29.59	
Daily min.	2.01	1.03	0	0	2.60	1.92	2.5	5.0 *	13.84	10.37	5.52	
Runoff in mm.	4.74	1.66	0.21	0.57	7.40	4.23	16.74	51.29	54.62	32.25	11.70	

*) estimated from observers reading

Daily mean discharge in m^3/s Arror River 1982

Station: Arror Station no: 2C18 Total catchment area: 278 km^2

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1					6.85	5.07	0.56	0.81	0.96	0.54	5.46	3.10
2					4.10	4.33	0.56	0.83	0.88	0.51	5.46	3.37*
3					2.99	3.37	0.56	2.51	0.83	0.46	4.94	3.18*
4					2.48	2.73	0.83	9.94	0.75	0.42	4.33	2.81*
5					2.25	2.41	1.68	10.19	0.77	0.42	17.26	2.65*
6				0.80	3.18	2.04	1.01	5.46	0.99	0.42	11.62	2.65*
7				0.80	4.45	1.84	0.68	3.37	0.81	0.42	17.23	7.62*
8				2.76	3.18	1.54	0.62	2.48	0.69	0.47	35.30	23.63*
9				3.40	2.48	1.37	0.58	2.04	0.58	0.58	23.76	10.30*
10				1.29	2.41	1.29	0.49	1.84	0.56	0.56	17.50	6.95*
11				1.90	2.73	1.26	0.46	1.54	0.52	0.56	14.64	6.33*
12				1.43	3.47	1.17	0.34	1.43	0.65	0.56	11.86	5.74*
13				5.20	6.61	1.12	0.20	1.87	0.60	0.73	8.89	5.20*
14				3.35	9.56	1.14	0.17	2.58	0.52	0.95	7.62	4.69*
15				3.77	16.87	1.24	0.19	2.99	0.82	0.97	6.33	3.77*
16				3.88	17.61	1.12	0.24	3.68	0.75	1.29	5.33	3.37*
17				3.18	10.60	1.05	0.54	3.88	0.85	1.10	4.33	2.99*
18				3.18	6.95	1.14		3.18	0.60	3.12	3.67	2.81*
19				2.81	7.97	0.85	0.24	2.65	0.51	4.65	3.47	2.81*
20				2.33	5.68	0.69	0.30	2.73	0.49	10.85	3.37	2.48*
21				2.95	4.45	0.65	0.27	2.95	0.49	7.78	3.18	2.18*
22				2.18	3.57	0.60	0.24	3.08	0.49	4.45	2.48	2.04*
23				5.05	3.08	0.69	0.24	4.57	0.86	3.18	2.11	2.04*
24				4.95	2.99	0.63	2.15	4.10	0.87	2.46	2.25	2.04*
25				3.48	2.48	0.65	4.82	3.57	0.56	2.11	3.79	1.65*
26				3.18	2.18	0.54	1.78	2.90	0.54	1.84	3.39	1.65*
27				2.48	2.73	0.60	1.10	2.25	0.56	1.90	2.80	1.54*
28				3.77	3.47	0.56	0.90	1.84	0.54	4.22	2.90	1.43*
29				9.49	11.79	0.60	0.79	1.54	0.52	15.48	4.16	1.38
30				9.08	8.51	0.58	0.71	1.26	0.56	11.44	3.18	1.33
31					6.18		0.67	1.10		6.79		1.33
Total $x10^6 m^3$				8.988	15.021	3.704	2.136	8.222	1.738	7.876	20.962	10.805
Monthly mean				3.47	5,58	1.43	0.80	3.07	0.67	2.94	8.09	4.03*
Daily max.				22.16	25.97	6.03	8.70	16.90	1.33	29.32	37.95	23.63*
Daily min.				0.74	2.04	0.52	0.17	0.71	0.49	0.42	2.04	1.31
Runoff in mm.				32.33	54.03	13.32	7.68	29.57	6.25	28.33	75.40	38.87

*) estimated from observers reading

Daily mean discharge in m^3/s Arror River 1983

Station: Arror Station no: 2C18 Total catchment area: 278 km^2

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	1.33	0.60	0.63*	0.64	1.58		4.72	1.29	3.18	0.90	2.51	0.77
2	1.33	0.60	0.60*	0.52	1.29	1.43*	4.21	1.21	2.33	1.14	6.52	0.73
3	1.29	0.62	0.56*	0.52	1.10	1.10*	3.18	1.05	1.84	0.96	4.33	0.69
4	1.14	0.63	0.52*	0.52	0.92	1.05*	2.18	0.83	1.59	0.94	2.99*	0.67
5	1.14	0.63	0.56*	0.52	0.92		1.65	0.77	1.37	1.37	13.07*	0.67
6	1.14	0.60	0.52*	1.06	8.16	1.24*	1.29	0.77	1.31	2.96	11.63*	0.67
7	1.14	0.58	0.52*	1.13	5.74	1.19*	1.10	0.69	1.19	4.63	9.48*	
8	1.10	0.56	0.52*	0.92	6.52	0.96*	1.05	0.60	1.21	7.48	7.62*	
9	1.10	0.56	0.52	0.96	8.14	0.92*	1.01	0.60	1.14	8.33	6.33*	
10	1.10	0.58	0.52	0.96	10.16	0.88*	0.96	0.60	1.01	5.33	5.20	
11	1.05	0.60	0.52	0.83	6.95	0.88*	0.92	0.73	1.31	4.56	4.45	
12	1.01	0.93	0.52	0.83	4.45	0.88*	0.71	1.69	1.17	3.67	3.67	
13	0.96	0.75	0.52	0.81	3.57	0.83*		1.43	0.96	2.99	3.27	
14	0.88	0.71	0.71	0.92	2.99	0.88*		1.82	0.94	2.56	2.90	
15	0.83	0.70	0.63	0.96	2.48	0.67*		2.81	0.98	2.81	2.56	
16	0.83	0.71	0.60	0.83	2.04	0.56*	0.62	2.65	0.92	2.73	2.25	
17	0.79	0.71	0.71	0.83	1.65	0.56*	0.79	3.99	0.98	2.90	1.78	
18	0.75	0.71	0.63	0.75	1.33	0.56*	1.10	6.48	1.14	2.73	1.37	
19	0.67	0.71	0.63	0.73	1.29		1.14	8.30	1.29	2.81	1.31	
20	0.67	1.13	0.63	0.77	1.29	0.79	1.29	11.40	1.19	2.90	1.29	
21	0.67	0.92	0.52	0.75	1.24	0.79	1.24	7.62	1.43	2.18	1.24	
22	0.65	0.79	0.46*	1.05	1.24*	0.81	2.04	6.79	1.37	7.98	1.17	
23	0.65	0.79	0.56*	1.14*	1.05*	0.85	1.65	7.51	1.17	9.66	1.10	
24	0.69	0.83	0.52*	1.05*	1.19*	0.77	1.97	11.92	1.07	8.20	0.98	
25	0.83	0.88*	0.60*	1.01*	1.43*	0.83	2.04	9.08	0.98	5.60	0.94	
26	0.79	0.63*	0.56*	1.10*	3.77*	0.81	1.54	6.33	0.96	4.56	0.88	
26	0.77	0.63*	0.52	1.19*	1.43*	1.03	1.43	4.56	0.96	4.10	0.83	
28	0.79	0.63*	0.52	1.33*	1.19*	1.56	1.29	4.33	0.92	3.88	0.83	
29	0.76		0.52	1.01	1.19*	2.04	1.33	3.47	0.92	3.27	0.79	
30	0.63		0.52	0.88	1.14*	2.26	1.43	3.27	0.77	3.08	0.79	
31	0.62		0.67		1.19*		1.31	3.08		2.73		
Total $x10^6 m^3$	2,428	1,704	1.515	2.291	7,658	2.604	4.323	10,167	3.249	10,363	8,993	
Monthly mean	0.91	0.70	0.57	0.88	2.86	1.00	1.61	3.80	1.25	3.87	3.47	0.70
Daily max.	1.33	1.65	1.07	6.63	20.75	3.77	6.03	18.12	6.95	14.63	23.63	0.79
Daily min.	0.62	0.56	0.52	0.52	0.88	0.56	0.60	0.60	0.75	0.75	0.79	0.67
Runoff in mm.	8.73	6.13	5.45	8.24	27,55	9.37	15.55	36.57	11.69	37.28	32.35	

* estimated from observers reading

Daily mean discharge in m^3/s Kerio River 1982

Station: Tot Station no: 2C16 Total catchment area: 3710 km^2

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1					90.10	126.17		3.15	10.27	1.95	6.41	72.24
2					41.87	90.06		3.21	9.45	1.80	5.99	87.66
3					28.44	71.40		12.97	8.47	1.85		156.81
4					22.77*	50.40		10.50	8.28	1.76		171.80
5				9.34		37.46		17.48	7.18	1.76		128.25
6				6.31		28.88		21.11	6.66	1.76		90.04
7				4.92		27.63		14.64	6.49	1.71		78.22
8				4.19		24.75		9.46	5.99	1.67		76.64
9				5.60		22.14		8.86	5.52	1.67		72.49
10				5.88		19.82		7.55	4.61	1.67		66.72
11				4.59	36.23*	17.77		7.20	4.33	1.67		57.29
12				4.33	29.40	16.31		7.73	3.89	1.67		47.36
13				4.33	52.58	14.94		7.55	3.65	1.67		
14				6.46	72.46	13.66		13.56	3.40	1.67		
15				35.13	128.48	12.87		22.40	4.81	2.25		
16				32.45	148.88	12.08		20.40	5.05	2.25	25.23	
17				66.60	109.75	13.17		28.11	3.27	2.05	22.17	
18				61.41	97.73	15.43		31.71	3.15	2.57	20.28	
19				47.82	91.06	10.99		35.09	3.09	3.98	18.06	
20				69.59	74.47	9.96		33.09	2.80	14.84	16.34	
21				79.67	68.13	9.28		25.42	2.68	19.08	15.58	
22				100.88	59.63	7.87	2.97	21.85	2.60	11.43	14.58	
23				98.66	54.55	8.92	2.30	22.15	5.92	10.48	13.50	
24				69.83	50.93		5.12	23.69	5.60	9.35	12.11	
25				34.48	40.06		8.34	20.98	4.19	7.01	18.64	
26				88.28	45.02		9.15	20.98	3.27	5.75	20.71	
27				55.34	50.48		6.47	18.18	2.91	4.98	34.90	
28				109.13	57.68		5.28	16.59	2.52	4.33	52.46	
29				184.55	65.77		4.64	15.57	2.30	7.96	78.72	9.86
30				171.02	116.16		4.33	13.66	2.10	10.38	67.96	9.05
31					137.07		3.60	12.48		7.82		8.09
Total $\times 10^6 m^3$				120.000*	175.000*	62.000*	13.000*	45.553	12.480	13.028	80.000*	125.000*
Monthly mean				52.34	70.79	28.78	5.22	17.01	4.82	4.81	26.10	75.10
Daily max.				210.00*	161.37	147.93	10.58	38.02	22.77	23.98	133.11	181.89
Daily min				4.19	24.88	7.37	2.30	3.15	2.05	1.67	5.83	2.00
Runoff in mm.				32.35*	46.80*	16.70*	3.50*	12.28	3.36	3.51	21.50*	33.50*

*) estimated from observers reading

Daily mean discharge in m^3/s Kerio River 1983

Station: Tot Station no: 2C16 Total catchment area: 3710 km^2

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	7.54			0.17	5.70	8.19	20.66	23.78*	119.20	15.60	16.36	4.56
2	6.83			0.22	5.15	8.28	34.83	16.23*	112.42	14.99	19.67	4.42
3	6.32			0.13	12.97	7.07	22.30	14.89*	87.44	14.12	25.57	4.21
4	5.67			0.11	6.61	5.31	13.99	14.89*	74.62	12.87	18.05	3.94
5	5.21			0.13	5.08	4.85	10.02	13.47	53.16	14.82	16.92	
6	4.76			0.16	4.28	4.43	8.09	11.12	46.44	20.58	20.89	
7	4.47			0.41	8.87	4.07	6.80	11.92	52.91	47.12	25.80	
8	4.47			0.57	8.65	3.67	5.95	9.91	41.03	80.50	24.61	
9	4.76			0.41	14.50	3.48	5.23	9.33	48.36	87.04	24.11	
10	4.76			0.46	16.09	3.00	4.63	8.86	55.59	54.41	19.97	
11	4.19			0.44	23.89	3.90*	4.00	8.10*	59.36	59.03	18.05	
12	4.05			0.35	27.84	3.90*	3.48	21.63	61.68	73.15	15.95	
13	3.15			0.33	19.67	5.00*	3.06	26.40	61.68	56.19	14.63	
14	2.68			0.30	15.82	4.85*	2.94	19.37	60.61	40.82	13.24	
15	2.35			0.39	13.74	4.70*	2.39	18.34	44.60	33.56	12.51	
16	2.05			0.53	11.12	2.70*	2.14	19.36	35.16	29.74	11.34	
17	1.85			0.44	8.48	2.30*	8.94	52.40	31.24	28.28	11.00	
18	1.58			0.53	6.80	1.86	13.05	58.73	41.47	25.80	9.80	
19	1.32			0.48	5.78	1.77	9.90	84.38	52.67	22.96	9.59	
20	1.24			0.48	5.15	1.77	25.92	69.41	60.35	24.95	11.46	
21				0.53	4.49	1.86	22.18	53.64	75.54	21.05	10.78	
22				0.44	4.56	2.64	22.77	84.06	55.68	20.28	9.49	
23				0.91	5.00	3.80	29.19	115.93	46.90	35.40	9.08	
24				0.99	4.56	2.77	22.86	207.16	37.20	49.96	8.05	
25				0.99	6.22	2.45	18.05	170.02	30.86	36.38	7.43	
26				0.92	9.80	2.93	15.95	161.23	26.32	27.92	6.37	
27				4.20	9.39	2.77	22.08	112.42	23.12	25.12	6.28	
28				2.82	9.16	11.16	33.14	118.56	21.67	23.94	5.78	
29				10.97	8.48	17.50	26.15	114.47	19.07	19.67	5.31	
30				6.53	6.54	11.46	22.79	104.94	17.62	17.62	4.93	
31			0.13		5.62		26.17	105.38		16.50		
Total $\times 10^6 m^3$	7.500*	2.000*	0.900*	3.140	25.921	12.480	40.578	160.733	134.349	90.743	35.685	
Monthly mean	3.96	0.84*	0.36*	1.21	9.68	4.81	15.15	60.01	51.80	33.88	13.77	
Daily max.	8.09	1.04*	0.59*	15.15	33.56	25.80	39.74	231.88	124.33	170.76	32.01	
Daily min.	0.94	0.61*	0.13*	0.11	4.28	1.77	2.10	5.15	16.50	12.39	4.85	
Runoff in mm.	2.00*	0.50*	0.25*	0.85	6.99	3.36	10.94	43.32	36.21	24.46	9.62	

*) estimated from observers reading

Annex 4.6 Surface water quality data

Annex 4.6-1 Surface water quality data (MOWD-records 1975-1981)

Sampling date	River	RGS-reg.no	pH	Color	Conduct. µS/cm	Turbitity	Permang. value	Concentration in mg/l							
								Fe	Mn	Ca	Mg	Tot.hard $CaCO_3$	Tot.Alkal $CaCO_3$	Cl	F
13.05.75	Kimwarer	1)	7.3	20	120	nil	-	8.0	nil	8.0	4.3	38	-	5.0	0.7
22.08.75	"	1)	6.9	65	68	nil	-	0.4	0.07	5.5	1.0	18	-	4.0	0.2
10.12.81	"	2C14	7.4	5	74	-	-	0.9	0.1	3.4	1.8	-	39	2.9	0.2
13.05.75	"	2)	9.1	3,500	850	2,000	-	60	3.2	9.6	8.6	60	-	7.0	165
22.08.75	"	2)	9.3	90	282	150	14.1	-	-	-	-	12	104	3.3	4.5
13.05.75	Mong	1)	7.1	50	102	49	-	nil	nil	8.8	1.9	30	-	2.0	0.8
22.08.75	"	1)	7.1	140	82	40	-	1.0	0.5	6.5	1.5	22	-	12.0	0.2
29.04.76	"	2C15	7.8	30	120	49	8.2	-	-	-	-	40	72	-	0.38
02.02.77	"	"	8.2	10	94	12	12.0	0.84	0.01	-	-	38	66	5.5	0.28
10.12.81	"	"	7.7	5	90	-	-	0.2	0.1	2.2	1.0	21.6	5.3	2.5	-
13.05.75	"	2)	7.4	60	108	56	-	6.0	0.2	11.2	4.8	48	-	4.0	-
25.04.76	Kerio	3)	8.8	85	214	100	7.8	-	-	-	26	114	-	5.3	2.9
16.05.75	Kerio	2C7	7.2	800	108	637	-	10.0	10.0	11.2	5.3	50	-	3.0	9.5
02.07.75	"	"	6.6	100	144	50	-	0.8	0.1	11.2	2.9	40	-	3.0	1.5
22.07.75	"	"	8.3	600	153	-	-	-	-	-	-	38	-	-	-
21.11.75	"	"	8.3	108	220	-	-	-	-	-	-	276	-	-	-
17.12.75	"	"	8.1	50	154	-	-	-	-	-	-	85	-	-	-
10.12.81	"	"	7.9	-	118	-	-	2.4	0.1	10.3	2.7	94	76	5.2	-
02.12.81	Kerio	4)	7.1	750	143	170	-	4.8	0.2	13.6	1.4	40	-	3.0	0.8
11.12.81	Arror	2C5	-	5	110	-	-	0.7	0.1	10.4	4.5	137.6	-	3.2	-
03.02.75	Kerio	5)	7.0	375	150	120	-	4.0	0.1	15.2	2.4	48	-	1.0	0.7
02.07.75	Embobat	2C12	6.8	5	98	nil	-	0.2	nil	11.2	2.4	38	-	1.0	0.2
10.12.81	"	"	-	5	76	-	-	0.2	0.1	8.2	2.8	68.8	-	2.1	-
27.02.75	Kessup	6)	8.4	5	225	nil	-	1.2	nil	10.4	3.4	40	-	9.0	0.6

1) at intake of the Fluorspar Mine
2) upstream of confluence Kimwarer-Mong river
3) downstream of confluence of Kimwarer-Mong river
4) at Koitilial (2C17)
5) at Tot (2C16)
6) at the bridge

Annex 4.6-2 Surface water quality data (November 1982 - October 1983)

Sampling Site No.	Location	Date of sampling	pH	EC	mg/l												
				µS/cm	Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2	Hard*	TDS
SW1	Mong River	12.11.82	6.8	76	14	-	0.5	0.4	6.4	0.0	6	49	5	-	0.2	-	0	46
	at 2 C 15	10.3.83	7.3	110	-	-	9.6	3.4	-	0.0	1	76	0	-	0.3	-	38	66
		10.5.83	7.1	90	-	-	6.4	5.6	-	0.0	3	12	2	-	0.4	-	-	54
		12.6.83	7.5	72	-	-	6.4	6.2	-	0.0	0	44	0	-	0.2	-	42	43
		20.8.83	7.4	90	-	-	5.6	2.8	-	-	1	49	0	-	0.3	-	24	54
		19.9.83	7.8	80	9.8	5.3	4.8	1.9	0	0.0	2	53	0	-	0.1	-	20	50
SW2	Kimwarer	12.11.82	6.5	54	5	-	5.8	1.4	0.2	0.1	5	24	0.5	-	0.1	-	-	32
	River at	5.2.83	7.1	90	-	-	12	4.3	0.5	0.1	1	46	1	-	0.2	-	24	54
	2 C14 (Mine)	10.3,83	7.7	150	-	-	12	10	-	0.0	1	117	1	-	0.3	-	33	90
		10.5.83	7.3	64	-	-	4.8	3.4	-	0.0	1	17	1	-	0.3	-	24	38
		12.6.83	7.2	100	-	-	4	2.4	-	0.0	-	31	0	-	0.2	-	20	60
		20.8.83	7,2	39	-	-	1.6	2.2	-	0.0		20	1	-	0.2	-	12	23
		19.9.83	7.2	30	5.3	2.3	2.4	1	0	0.0	2	27	0	-	0.0	-	10	20
SW3	Kerio River	12.11.82	7	76	12	-	1.2	1	6	0.1	6	44	2	-	0.3	-	16	46
	downstream	6.2.83	7.9	140	-	-	8	3.4	0	0.1	2	87	1	-	0.4	-	0	84
	Mine	10.3.83	7.8	180	-	-	8.8	12	0.1	0.0	4	143	1	-	0.6	-	64	108
		12.5.83	7.4	100	-	-	7	2.8	-	0.0	10	16	17	-	0.7	-	28	60
		12.6.83	7.8	90	-	-	4.8	3.6	-	0.0	-	61	0	-	0.5	-	0	54
SW4	Kimwarer/	12.11.82	6.8	62	9	-	1.9	1	2.2	0.0	5	39	2	-	0.3	-	13	46
	Mong River	5.2.83	7.6	120	-	-	8	3.4	0.1	0.1	1	73	1	-	0.3	-	20	72
	Confluence	10.3.83	8	150	-	-	13	3	-	0.0	1	10	1	-	-	-	44	90
		12.5.83	7.4	100	-	-	11	3	-	0.0	1	17	6	-	0.4	-	40	60
		12.6.83	7.6	80	-	-	7.2	1.4		0.0	0	53	0	-	0.5	-	24	48
		13.9.83	6.8	60	-	-	4	4.4	-	-	1	34	0	-	0.4	-	28	36
SW5	Mokorwa	13.11.82	8	280	24	-	30	12	1.5	0.0	7	195	2	-	0.6	-	130	168
	River	5.2.83	8.3	300	-	-	23	6.4	0.1	0.1	3	191	0	-	0.7	-	0	180
		10.3.83	8.2	290	-	-	12	10	-	0.0	5	195	0	-	0.7	-	68	174
		12.6.83	8.4	250	-	-	19	7.7	-	0.0	2	168	1	-	0.8	-	80	150
		20.8.83	7.4	100	-	-	9.6	2.8	-	-	1	73	1	-	0.5	-	34	60
SW6	Kailel	13.11.82	7.3	80	11	-	2	11	4.1	0.1	4	63	1	-	0.3	-	17	48
	Stream	10.3.83	8.3	430	-	-	22	24	-	0.0	6	341	0	-	0.7	-	142	260
		10.5.83	8.0	190			19	4.4	-	0.0	2	30	4	-	0.8	-	64	114

* Total hardness in mg $CaCO_3$ /l - not determined

Annex 4.6-2 (continue)

Sampling Site No.	Location	Date of sampling	pH	EC	mg/l													
				µS/cm	Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2	Hard*	TDS
SW7	Kerio River	15.11.82	6.4	80	12		9.2	3.3	0.7	0.2	7	40	0	-	0.3	-	38	48
	at 2C7	4.2.83	7.8	200	-	-	14	4.3	0.1	0.1	1	89	1	-	0.5	-	44	120
	(Chebloch)	10.3.83	8.1	210	-	-	20	4.4	-	0.0	3	240	-	-	0.6	-	66	126
		27.4.83	7.3	80	-	-	11	2.5	-		4	15	5	-	0.6	-	100	48
		11.5.83	7.2	100	-	-	5.6	5.1	-	0.0	10	15	15	-	0.6	-	32	60
		20.8.83	7.3	90	-	-	6.8	3.1	-	0.0	2	52	1	-	0.4	-	28	54
		14.9.83	7.7	80	11	4.4	7.2	1.4	0.3	0.0	2	66	0	-	0.0	-	25	50
SW8	Lake	15.11.82	6.9	80	11	-	0.6	0.4	7.1	0.1	7	58	0	-	0.0	-	16	48
	Kamnarok	4.2.83	7.5	110			12	4.8	0.1	0.2	2	68	7	-	0.6	-	40	66
		10.3.83	7.5	150	-	-	13	3.4	-	0.0	4	95	-	-	0.7	-	46	90
		11.5.83	6.9	180	-	-	12	6.2	-	0.0	5.3	26	5	-	1.5	-	54	110
		11.6.83	8.1	200	-	-	12	19	-	0.0	10	85	-	-	1.2	-	110	120
SW9	Kabluk Spring	15.11.82	6.1	92	13	-	9.7	2.1	0.1	0.0	8	58	0	-	0.3	-	33	55
		4.2.83	6.6	85	-	-	6	1.6	3.7	0.1	1	39	1	-	0.2	-	0	51
		10.3.83	6.9	84	-	-	4	1.1		0.0	3	51	1	-	0.2	-	14	50
		11.5.83	7.2	100	-	-	9.6	4.5	-	0.0	10	61	10	-	0.6	-	40	60
		12.9.83	7.3	105	-	-	8	1.6	-	0.0	2	61	0	-	0.2	-	26	63
SW10	Erom Stream	4.2.82	7.6	110	-	-	6	2.4	3.6	0.1	4	55	0	-	0.6	-	0	66
	north of	10.3.83	7.4	136	-	-	10	9.6	-	0.0	5	90	0	-	0.4	-	50	82
	Kiboino	11.5.83	5.6	80	-	-	4	0.5	-	0.0	2	150	1	-	0.3	-	12	48
		11.6.83	7.4	130	-	-	2.4	2.1	-	0.0	1	40	0	-	0.2	-	16	78
		20.9.83	7.1	100	12	7.5	4	1.4	0.0	0.0	2	63	0	0.0	0.4	4	16	60
SW11	Erron River at Laimil	15.11.82	7.6	86	10	3.6	4	1.9	1.6	0.0	2	54	0	0.0	0.4	20	18	51
SW12	Kirumbopsoo River	15.11.82	7.6	59	8.5	3.5	2.4	0.5	0.8	0.0	2	334	0	0.0	0.3	28	8	35
SW13	Muskut Water	15.11.82	7.7	500	53	7.8	38	24	0	0.0	8	350	20	0.0	1.4	32	196	300
	Supply	5.2.83	8.4	650	-	-	60	40	0.2	0.1	13	390	44	-	1.3		256	390
		10.3.83	8.1	800	-	-	27	73	-	0.1	1	490	36	-	1.6	-	324	480
		11.5.83	7.7	520	-	-	14	13	-	0.1	11	114	24	-	1.0	-	208	312
		12.6.83	8.4	700	-	-	8	72	0	0.0	15	400	35	-	1.3	-	274	420
		13.9.83	8.3	560	-	-	50	32	0	0.0	9	440	16	-	1.0	-	240	336

* Total hard[illegible] in mg $CaCO_3$/l [illegible] not determined

Annex 4.6-2 (continue)

Sampling Site No.	Location	Date of sampling	pH	EC	mg/l													
				µS/cm	Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2	Hard*	TDS
SW14	Torok River	16.11.83	8.1	49	6.6	1.5	1.6	1.9	0	0.0	4	24	3	-	0.3	0	12	29
	north of	7.2.83	7.2	95	-	-	6	2.2	-	-	2	46	2	-	0.1	-	-	46
	Biretwo	10.3.83	7.2	104	-	-	4.8	2.2	-	0.0	17	-	1	-	0.2	-	20	62
		27.4.83	6.8	50	-	-	2.4	1.7	-	0.0	2	5	-	-	0.2	-	1.2	30
		11.5.83	6.8	51	-	-	2.4	0.6	-	0.0	1	7	1	-	0.2	-	8	30
		14.6.83	7.5	90	-	-	2.4	3.8	-	0.0	2	29	2	-	0.1	12	22	54
		19.9.83	7.1	30	6.2	1.9	2.4	1.4	-	0.0	2	-	0	-	0		12	48
SW15	Embamachukwa	18.11.82	8.7	240	15	6.2	24	7.7	0	0.0	10	136	10	-	0.4	0	92	144
	River	7.2.83	8.4	400	-	-	27	19	-	-	-	223	7	-	0.6	-	146	240
SW16	Kipnai Spring	18.11.82	7.6	270	61	9.1	1.4	4.8	1.8	0.0	2	166	29	1.5	4.4	18	18	162
		7.2.83	7.6	700	-	-	9	2.9	-	-	17	376	-	-	8.1	-	34	420
		10.3.83	8.2	800	-	-	16	3.6	-	0.0	20	475	10	-	9	-	54	480
		15.6.83	8.4	270	-	-	14	6.8	-	-	20	-	-	-	8.4	-	64	162
SW17	Arror River	18.11.82	8.8	93	5.3	2.2	11	2.9	0	0.0	2	58	-	-	0.3	0	40	62
	at 2 C18	10.3.83	7.6	210	-	-	22	10	-	0.0	5	160	0	-	0.2	-	92	126
		15.6.83	8.1	250	-	-	20	6.7	-	0.0	2	102	2	-	0.1	-	78	150
		24.8.83	6.6	70	-	-	9.6	11	-	-	1	43	0	-	0.5	-	62	42
SW18	Kinyach	18.11.82	7.7	97	13	4.3	5.6	0	0.3	0.0	1	56	1	0.0	1.0	16	14	53
	River																	
SW19	Kerio River	18.11.82	7.9	117	12	4.6	9.6	1.9	1.3	0.0	2	78	0	0.0	1.1	12	32	65
	at 2 C17	7.2.83	7.7	200	-	-	20	3.9	-	-	4	126	2	-	0.6	-	-	120
	(Arror)	10.3.83	8.3	320	-	-	28	15	-	0.0	9	265	-	-	1.1	-	124	192
		18.4.83	8.3	430	-	-	13	33	-	0.0	12	71	-	-	2.5	-	152	258
		15.6.83	8	150	-	-	14	28	-	0.0	-	100	-	-	0.8	-	150	90
		24.8.83	6.6	70	-	-	9.6	11	-	-	1	43	0	-	0.5	-	62	42
SW20	Kerio River	18.11.82	7.7	126	11	4	12	1	0.9	-	2	78	0		0.8	12	36	70
	at 2 C16	8.2.83	8.1	300	-	-	18	9.5	-	-	3	157	2	-	0.4	-	129	157
	(Tot)	10.3.83	8.1	260	-	-	27	3.0	-	0.0	6	190	6	-	0.7	-	-	156
		18.4.83	7.9	230	-	-	31	7.2	-	0.0	4	41	0		0.4	-	104	138
		16.6.83	8	130	-	-	16	3.8	-	-	10	10	0	-	0.5	-	56	78
		19.9.83	7.9	100	13	4.1	8.8	3.4	0.3	0.0	2	78	0	-	0.1	-	36	60

* Total hardness in mg $CaCO_3$/l - not determined

Annex 4.6-2 (continue)

Sampling Site No.	Location	Date of sampling	pH	EC	mg/l													
				µS/cm	Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2	Hard*	TDS
SW21	Embobut River north of Tot	21.11.82	6.9	65	3.3	0.9	7.2	0	0	0.0	1	39	2	-	0.2	-	26	37
		8.2.83	7.6	80	-	-	9.8	1.0	-		1	44	2	-	0.1	-	28	48
		10.3.83	7.2	86	-	-	10	3.0	-	0.0	1	80	1	-	0.2	-	36	51
		28.4.83	7.7	70	-	-	8.0	2.2	-	-	2	12	2	-	0.2	-	28	42
		15.6.83	7.7	80	-	-	8.0	0.3	-	0.0	0	53	2	-	0.1	-	44	48
		15.8.83	7.5	110	-	-	3.6	5.6	-	-	2	80	0	-	0.2	-	54	66
		19.9.83	7.8	83	4	1	8.8	3.8	0	0	2	58	0	0.0	0	-	38	50

* Total hardness in mg $CaCO_3$/l - not determined

Annex 5 Hydrogeology

5.1 Interpretation of aerial photographs

5.2 Geological well logs

5.3 Auger hole data

5.4 Analysis of well test data

5.5 Groundwater level fluctuations and well hydrographs

Annex 5.1

5.1 PHOTO-INTERPRETATION

Photo-interpretation is a technique of remote sensing from which semantic information about the earth's surface from aerial photographs is extracted through stereoscope observation. The correct interpretation of the photo-image is dependent upon the level of knowledge of the interpreter who must master his own field of science before he can use airphoto-interpretation as an additional tool.

Direct and indirect observations are combined in geological surveying, soil survey, agronomy, archaelogy and surveys of the environment. Combination of data from aerial survey with those from other sources further widen the field of application.

The project area, Kerio Valley, is covered by over seventy photographs distributed over three flight lines. The photographs have a scale of about 1:62,000 each covering about 190 square Kilometres of the ground.

The photo-interpretation was carried out in the office and preliminary hydrogeological map made. Field investigation followed to confirm or refute the information gathered on the photographs. Corrections were then done on the preliminary map and a draft of the final map was produced.

Four main features have to be observed on the photographs when interpreting for hydrogeology. They are namely lithology, faults (fractures and joints), drainage pattern and density, and finally vegetation cover.

Lithology

Various characteristics of photographs can be used to insert lithological boundaries but the main ones are the lines defining changes in tone, drainage pattern and vegetation cover.

In Kerio Valley for example the basement has a lighter tone, dendritic drainage and scarce vegetation as opposed to Kerio Valley sediments which have darker tone, parallel drainage and relative higher vegetation cover.

Different lithologies have different groundwater qualities i.e. porosity, permeability, groundwater retention etc.

Faults (fractures and joints)

These are observed as lineaments on the photographs. The lineaments are as a result of displacement of one groundsurface relative to the other. One good example in the project area is the Elgeyo Escarpment. There are several small faults on the volcanics (e.g. Kabarnet Trachyte on the east side) in which displacements are not appreciable but in most cases they define stream courses.

Faults and fractures provide see page zones of surface water into the ground. A rock formation which is highly faulted or fractured provides in most cases a good aquifer. This is evident in the volcanics mainly the Kabarnet Trachytes (in Kerio Valley) which are fairly fractured and joined. The boreholes at Kiboino, and Kinyach in this formation show relative high yields. The basement on the other hand is less fractured and its groundwater potential is therefore minimal as its porosity is almost nil.

Drainage pattern and density

They constitute stream and river channels which can be traced easily from a photograph. Drainage pattern and density (drainage density is defined as number of stream channels per unit area) of one rock formation is not necessarily the same as for another, for example the basement in our area of study has a dendritic pattern of drainage while Kerio Valley sediments have a parallel type of drainage. This, as has been discussed before, is due to different lithological qualities. The Kerio Valley sediments have a higher drainage density than for example the volcanics.

If a rock unit or the overlying weathered material has higher drainage density, it implies that most of the water from the rainfall becomes run-off and very little water goes down to recharge groundwater. This type of rock overburden is considered to be impervious and the rock formations underlying them do not form good aquifers unless the aquifers are of a confined type, i.e. they are being recharged from a distant source.

In the project area the trachytes have a low drainage density hence a lot of rainwater sinks into the ground to aquifer either in the erosional surface between lava flows or in the fractured, jointed and faulted zones.

On the gneisses drainage density is higher since almost all of the rainwater becomes run-off. Prospects for groundwater are very low here. Water can only be found in the shallow weathered areas or the fractured zones.

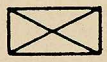
In some areas of the Kerio Valley Beds along the foot-hill of the escarpment high drainage density can be observed. Gullies and badlands are evident. These sediments hold some impervious materials like clay and hence recharge of aquifers through such layers is very unlikely.

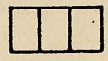
Vegetation cover

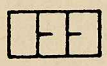
A thick vegetation cover in a semi-arid area indicates where the water table is near the surface. In some parts of the project area, where there are alluvial sediments, thick vegetation covers are observed especially between River Torok and Arror, and along the Kerio River. Shallow aquifers are very likely here.

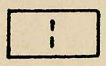
Annex 5.2 Geological well logs

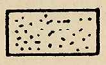
LEGEND TO THE LOGS


unknown


clay

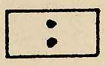

loam


clayey

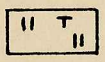

fine sand


medium sand

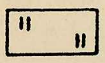

coarse sand


sandy

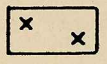

gravel



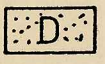
tuff


volcanic ash

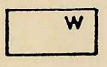

volcanic agglomerate



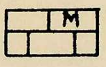
lava (P=phonolite, T=trachyte)



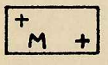
diatomite



weathered



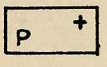
marble



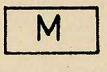
gneiss



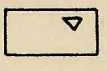
quartzite

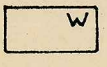


pegmatite

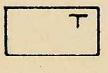


schist

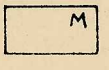

chert, chalcedony



weathered

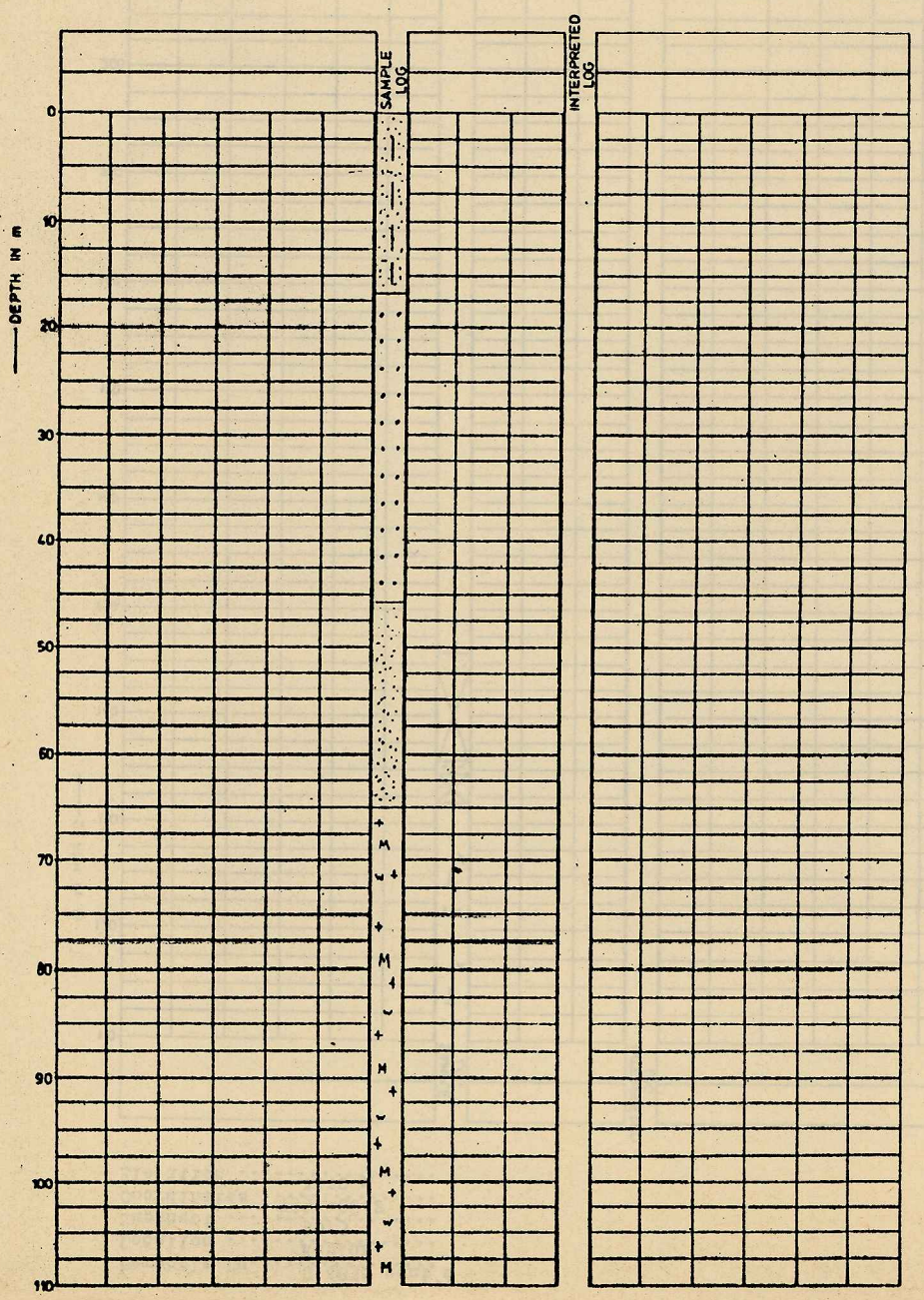


consolidated

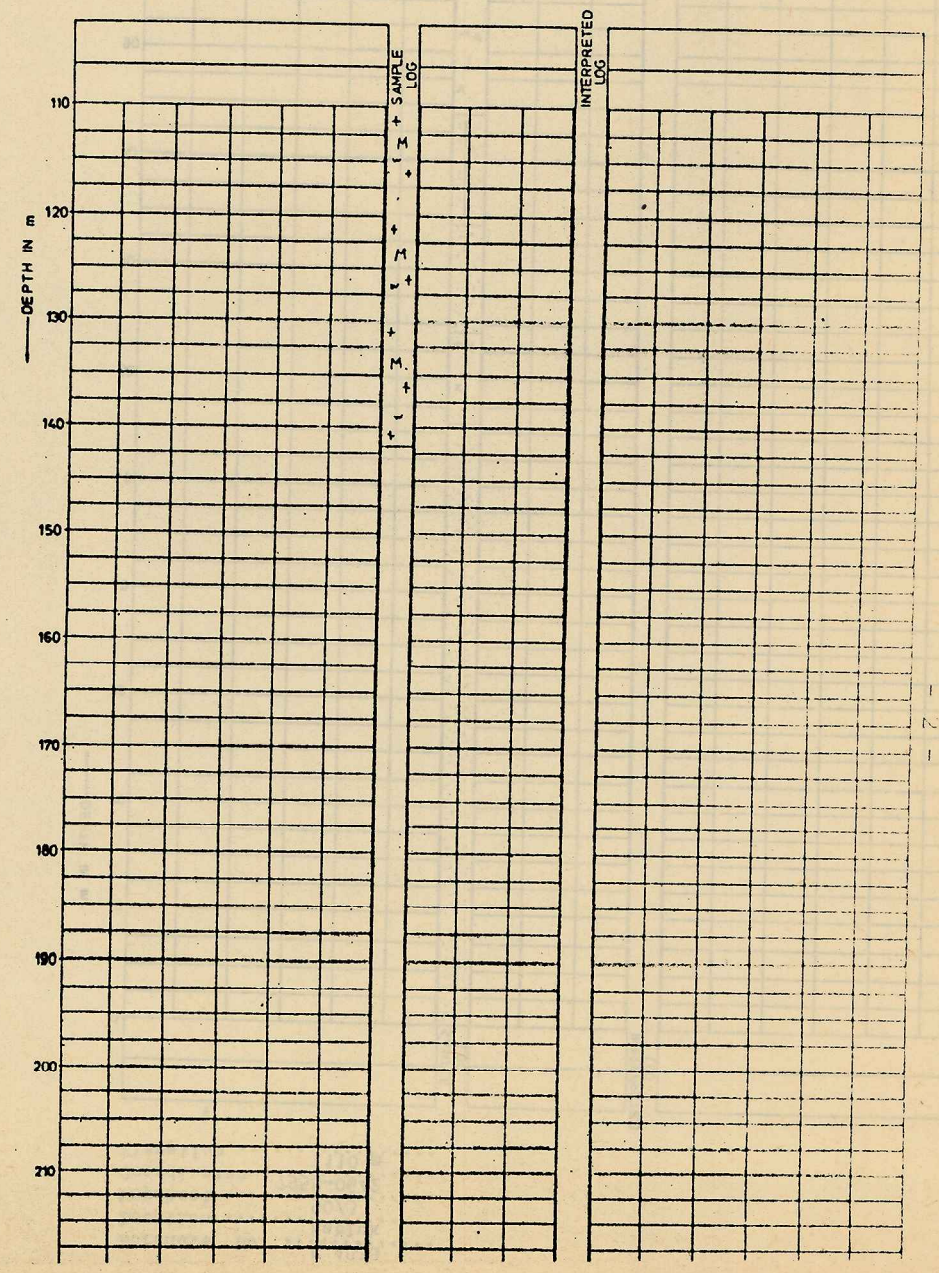


metamorphic

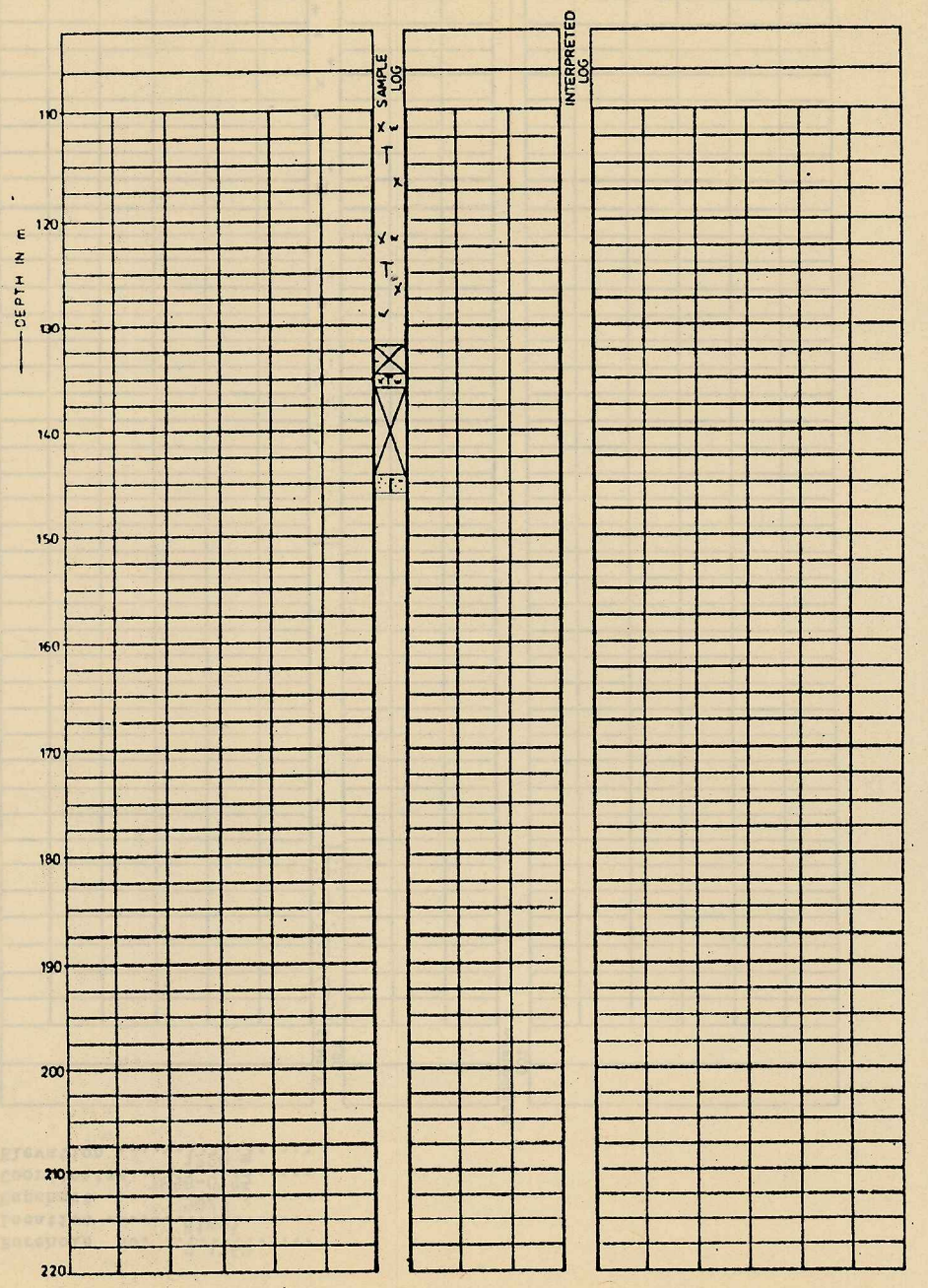
Borehole No. ..C.1167.....
Location .....Rimoi.....
Mapsheet .....90/3.....
Coordinates .7858-0795.....
Elevation .....1220 m.....



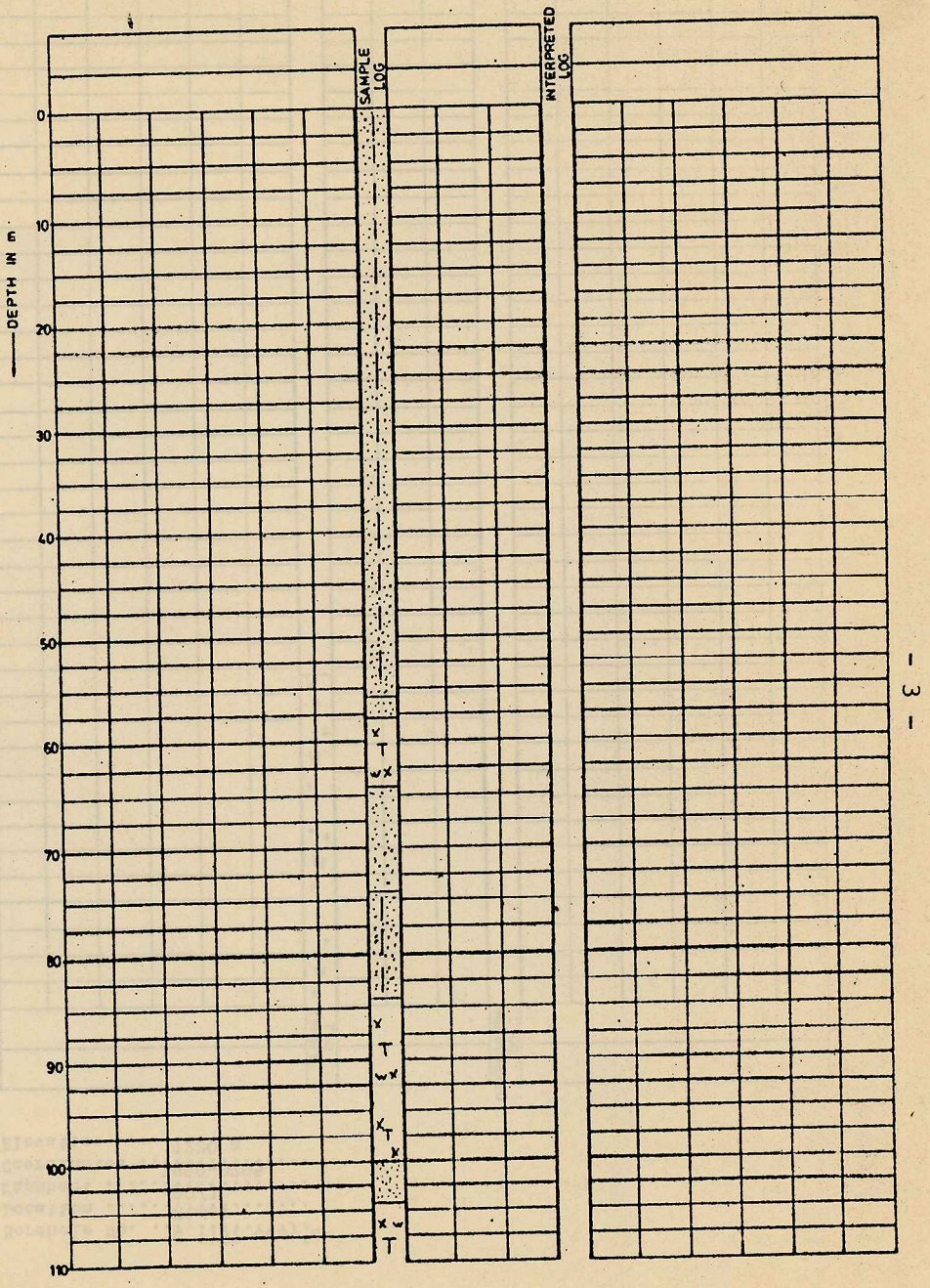
Borehole No. ..C.1167.cont'd
Location .....Rimoi.....
Mapsheet .....90/3.....
Coordinates ..7858-0795....
Elevation .....1220.m.....



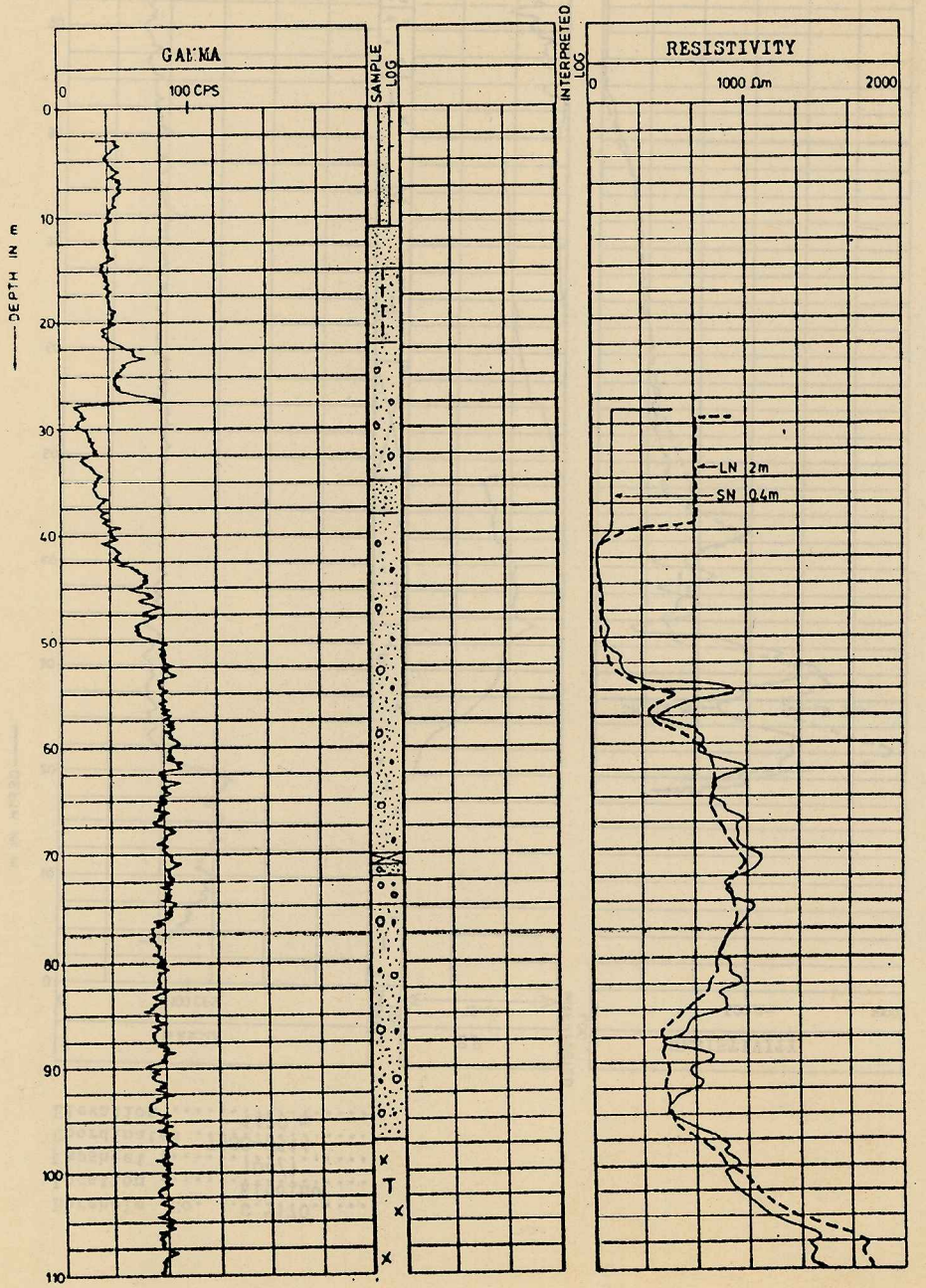
Borehole No. ...C 4838 cont'd
Location .....Kabluk.....
Mapsheet .....90/3.....
Coordinates ..7958-0642....
Elevation .....1110 m.....



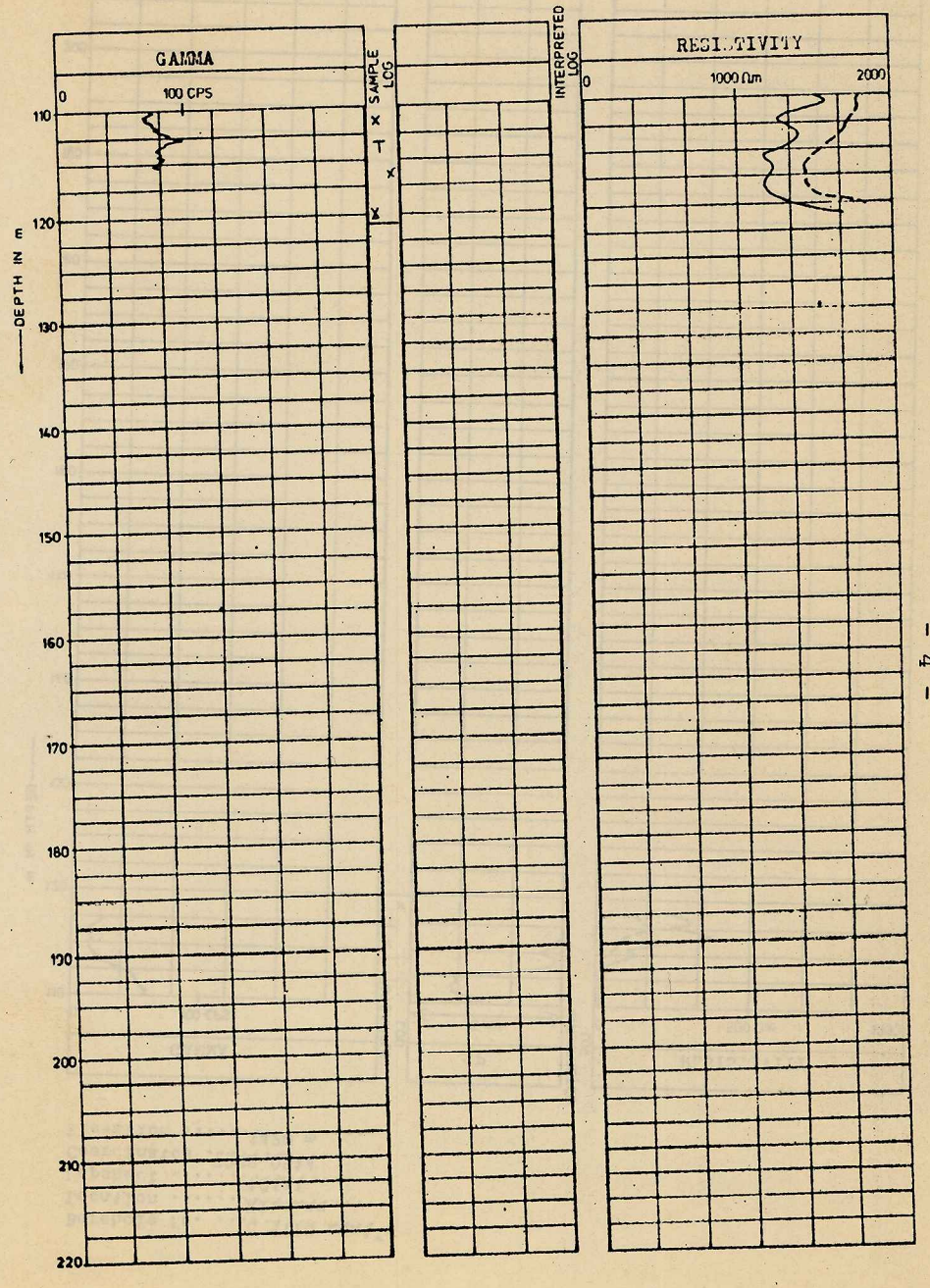
Borehole No. ...C 4838.....
Location .....Kabluk.....
Mapsheet .....90/3.....
Coordinates ..7958-0642....
Elevation .....1110 m.....



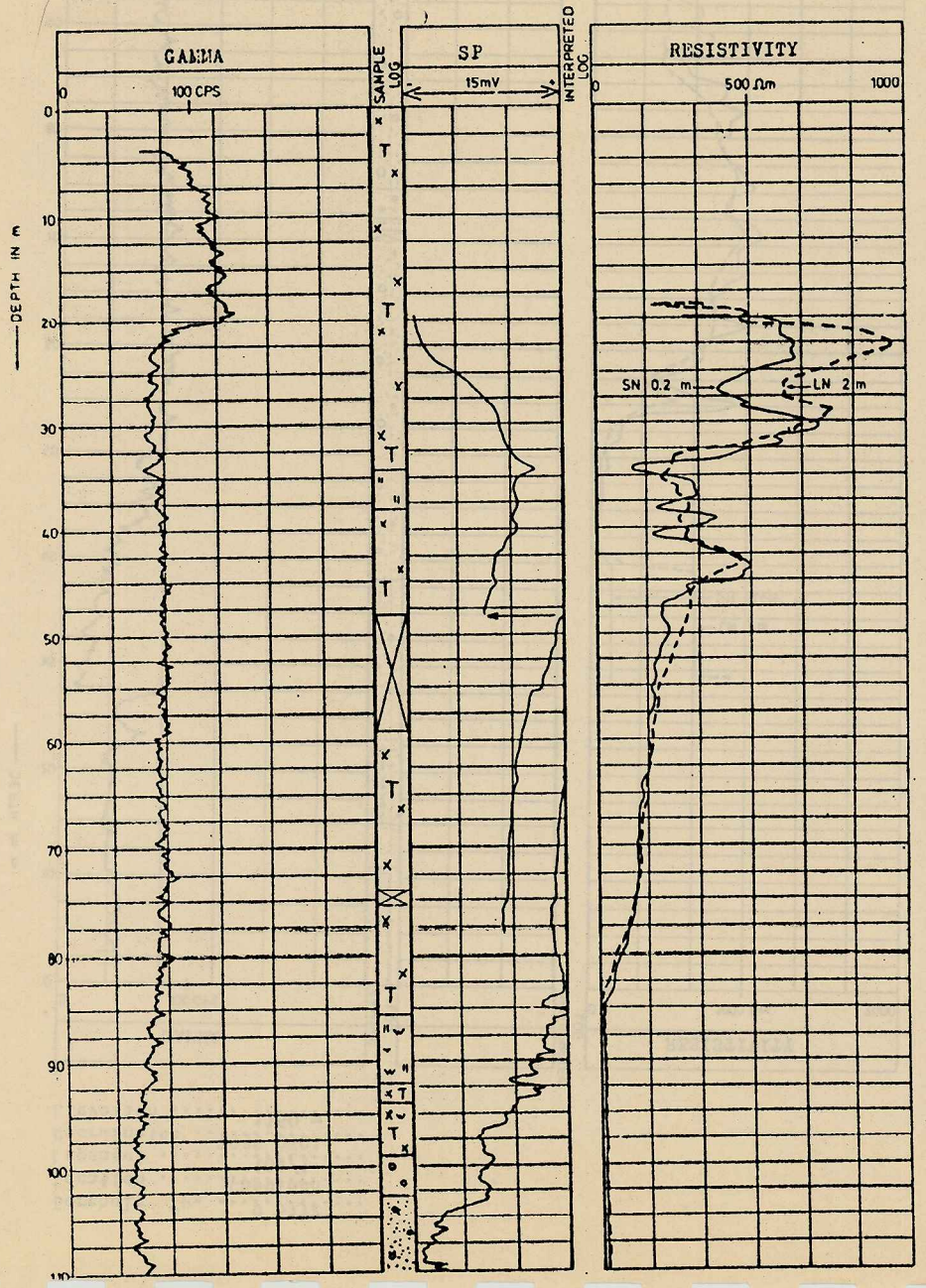
Borehole No. ...C.5112....
Location .....Chebloch....
Mapsheet .....104/1.....
Coordinates ..7935-0501....
Elevation .....1150.m....



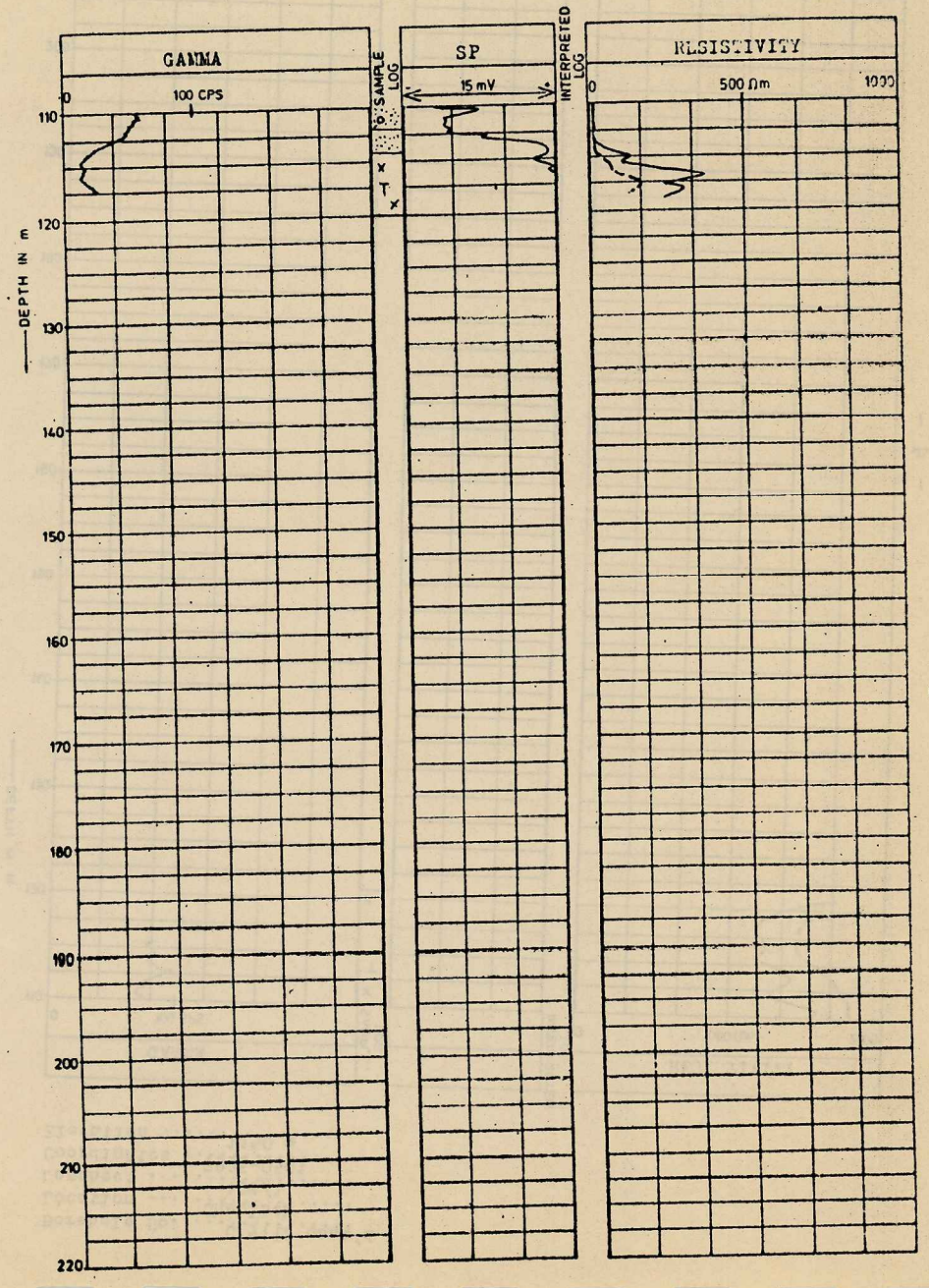
Borehole No. ...C.5112 cont'd
Location .....Chebloch.....
Mapsheet .....104/1.....
Coordinates ..7935-0501....
Elevation .....1150.m.....



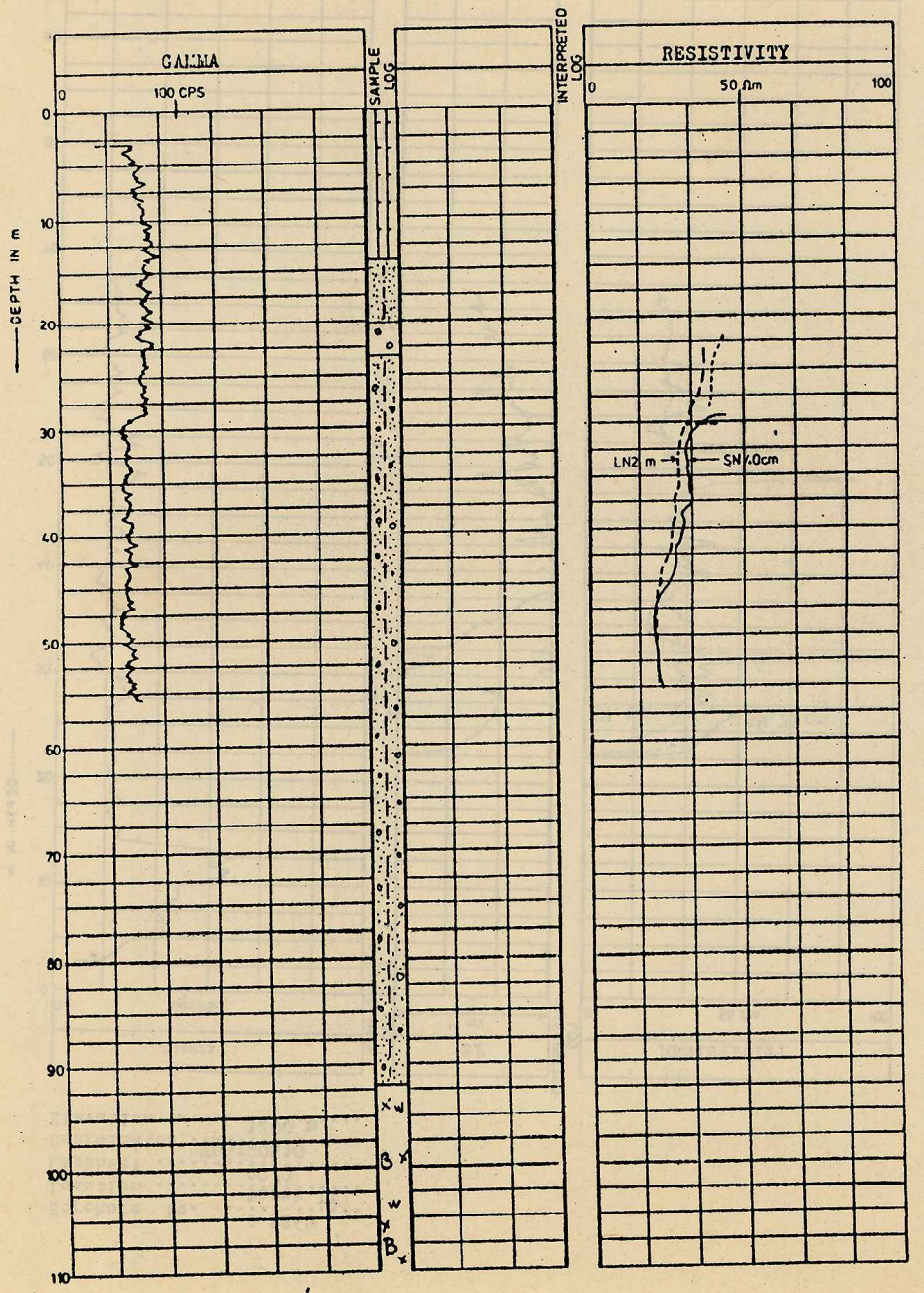
Borehole No. ..C.5170.....
Location .....Kiboino....
Mapsheet .....104/1.....
Coordinates .7988-0514.....
Elevation .....1420 m.....



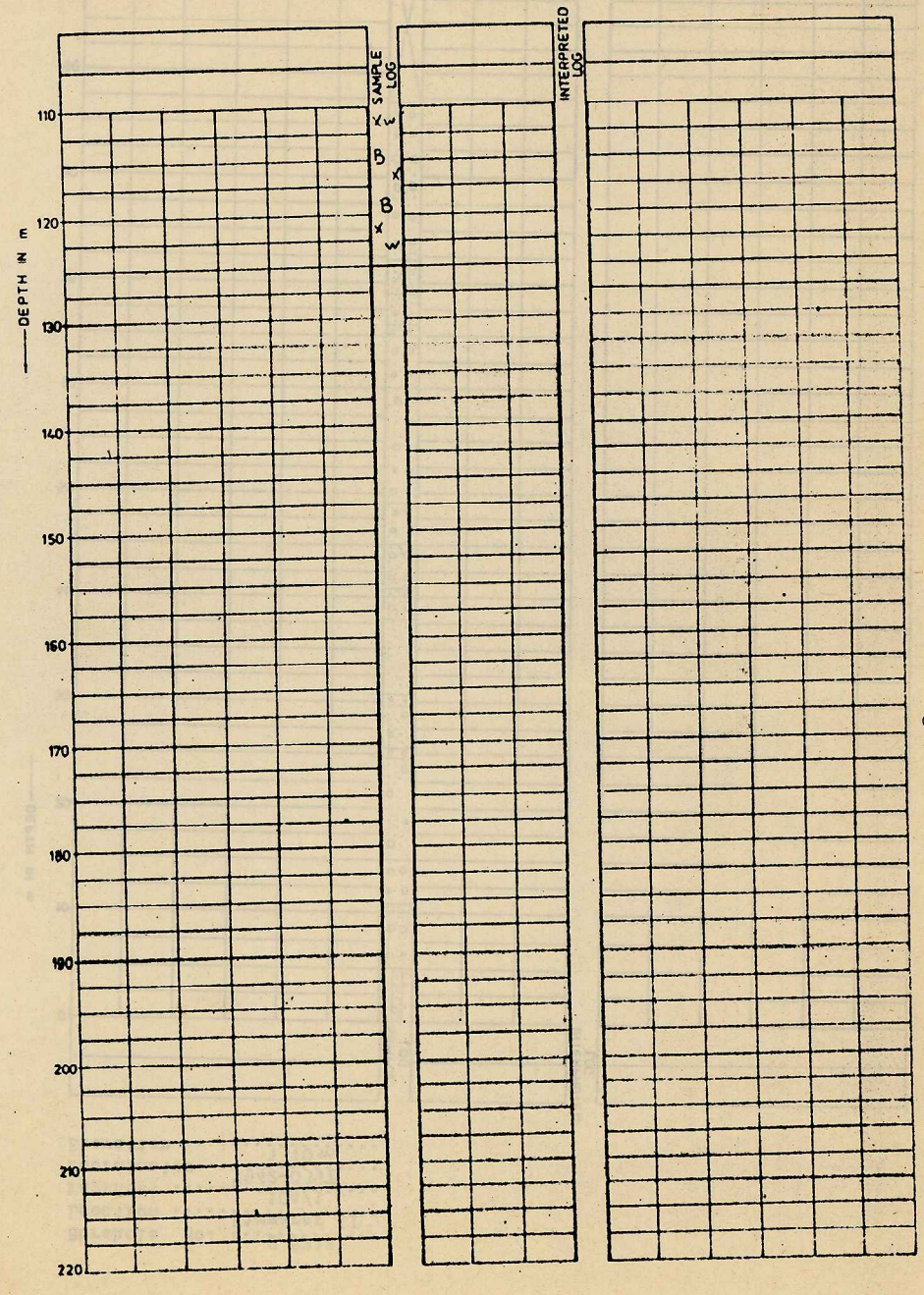
Borehole No. ...C.5170 cont'd
Location .....Kiboino....
Mapsheet .....104/1.....
Coordinates .7988-0514.....
Elevation .....1420 m.....



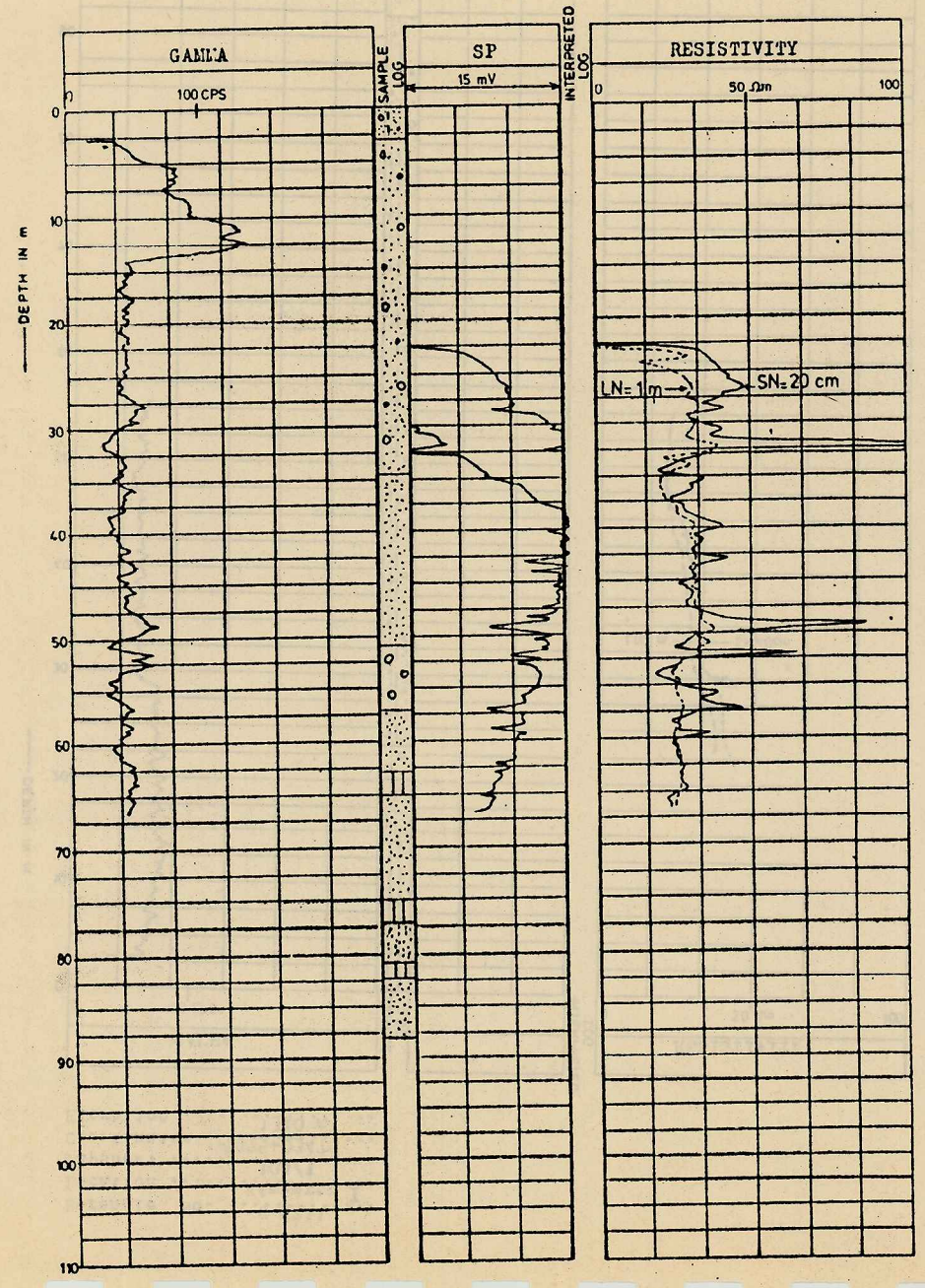
Borehole No. ...C 5211....
Location .....Kimwarer I.
Mapsheet .....104/1.....
Coordinates ..7975-0347....
Elevation .....1340 m....



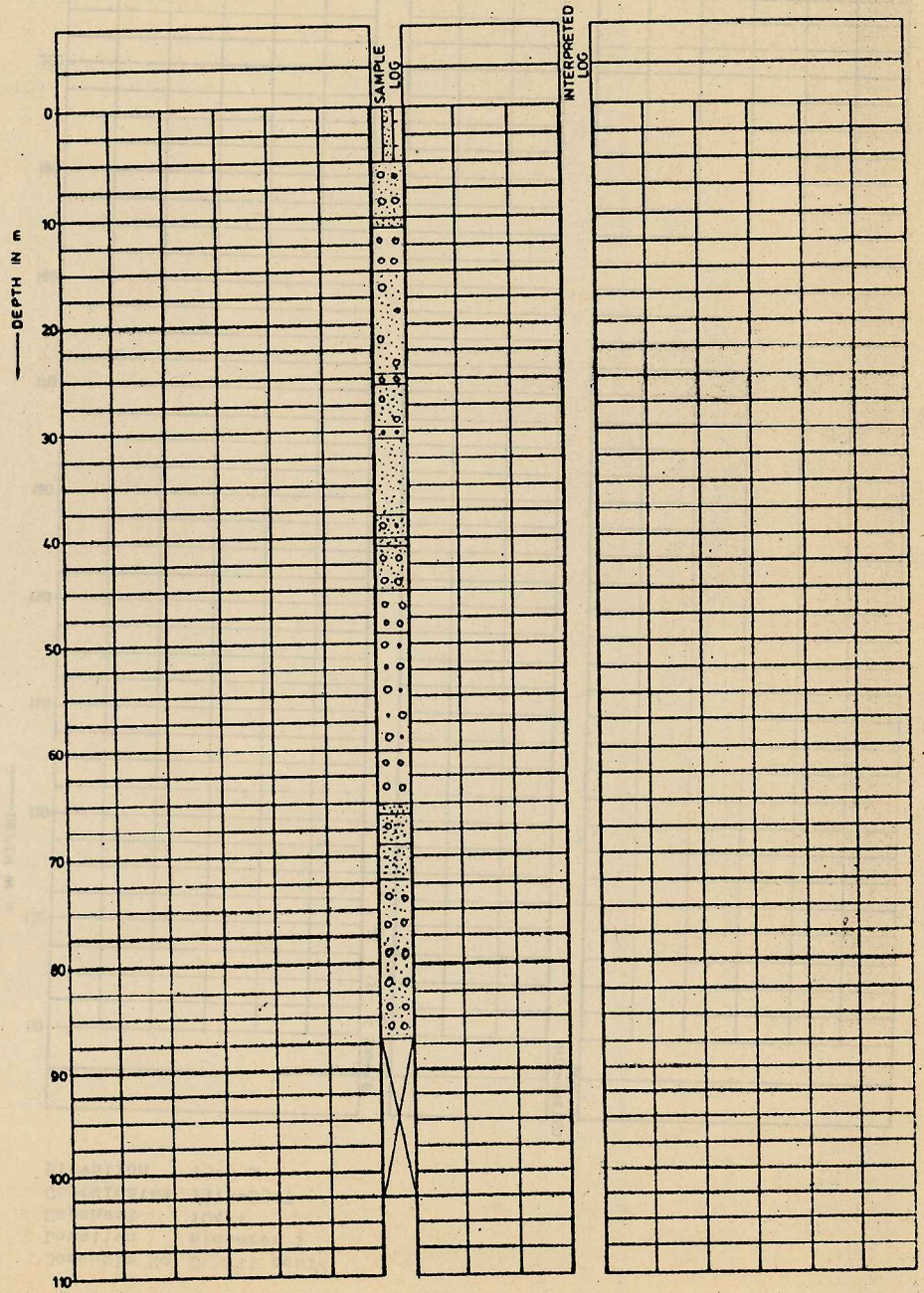
Borehole No C 5211 cont'd
Location Kimwarer I
Mapsheet 104/1
Coordinates 7975-0347
Elevation 1340 m



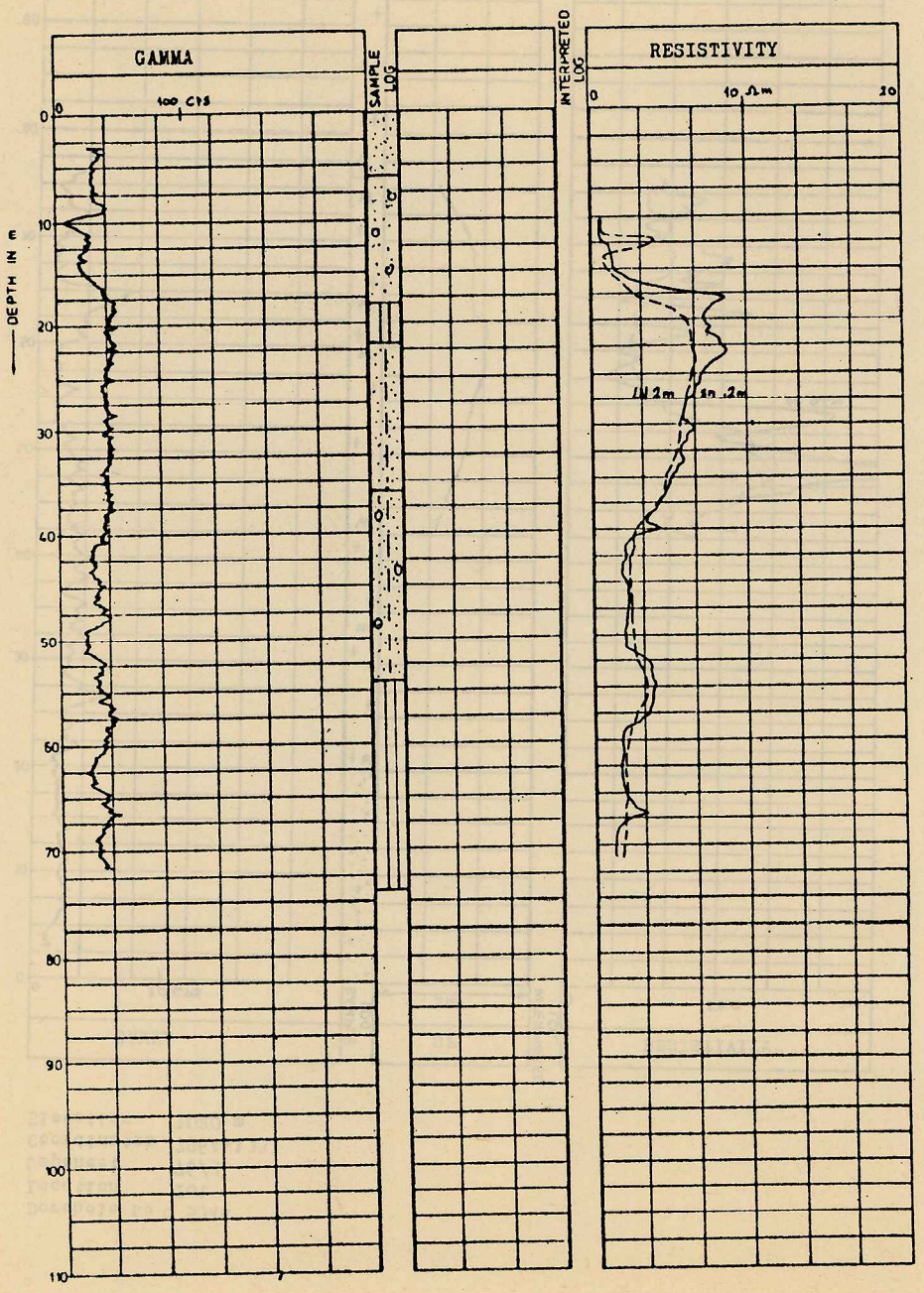
Borehole No. C 5268
Location Torok II
Mapsheet 99/3
Coordinates 7851-0610
Elevation 1200 m



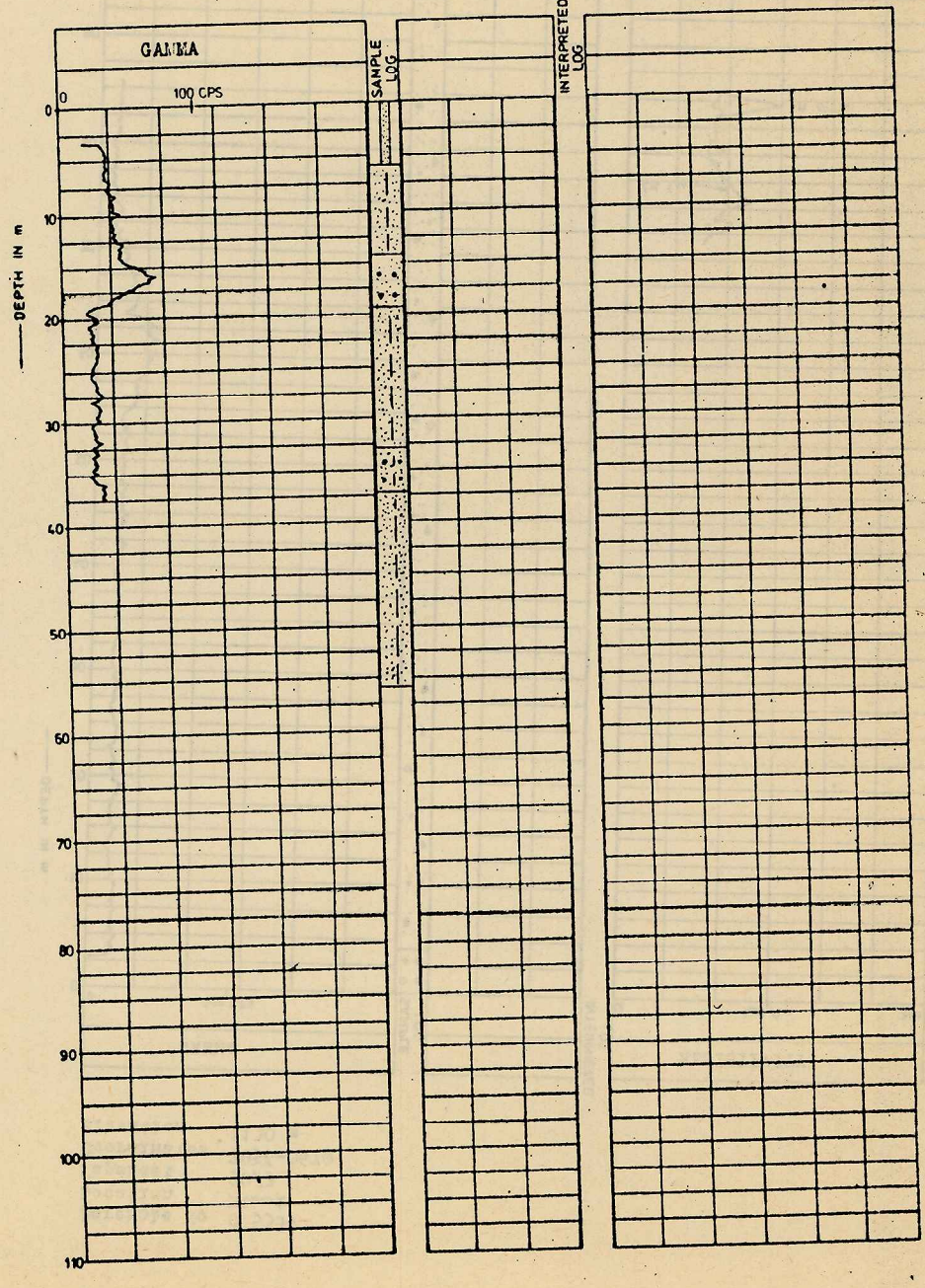
Borehole No. C 5212
Location Kimwarer II
Mapsheet 104/1
Coordinates 7942-0397
Elevation 1310 m



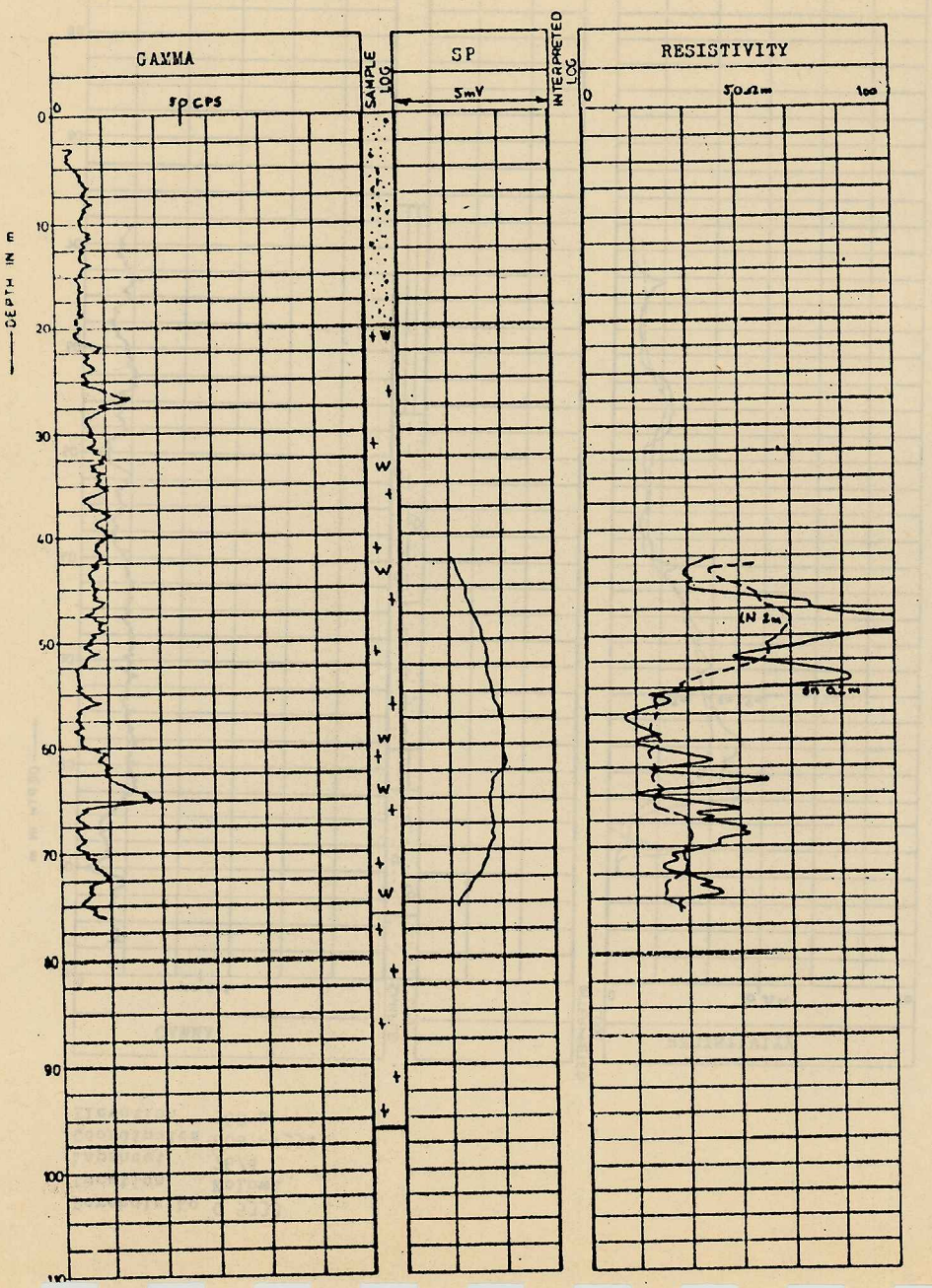
Borehole No C 5333
Location Kolowa
Mapsheet 76/4
Coordinates 8067-1354
Elevation 960 m



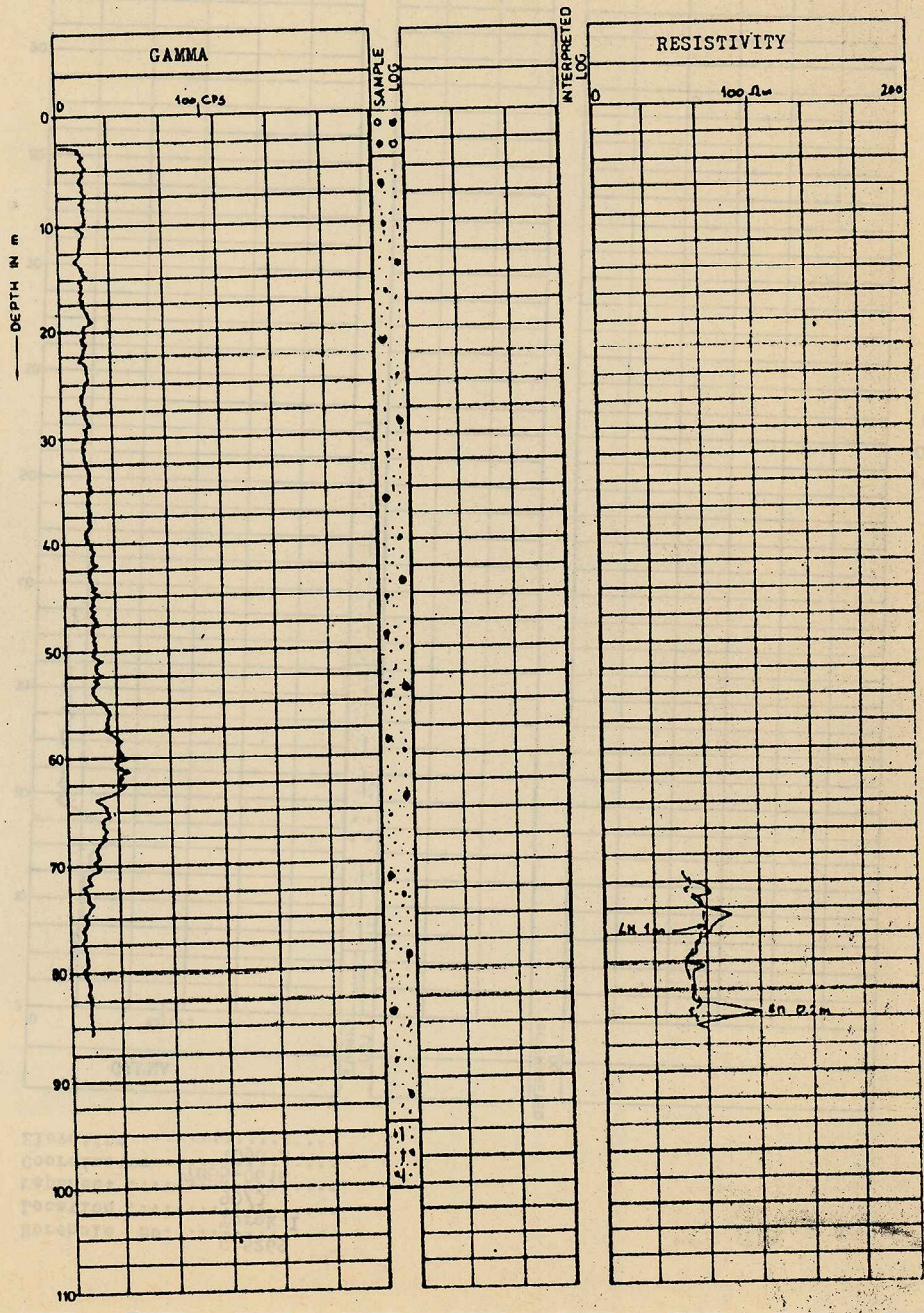
Borehole No. C 5269
Location Torok I
Mapsheet 90/3
Coordinates 7885-0616
Elevation 1090 m



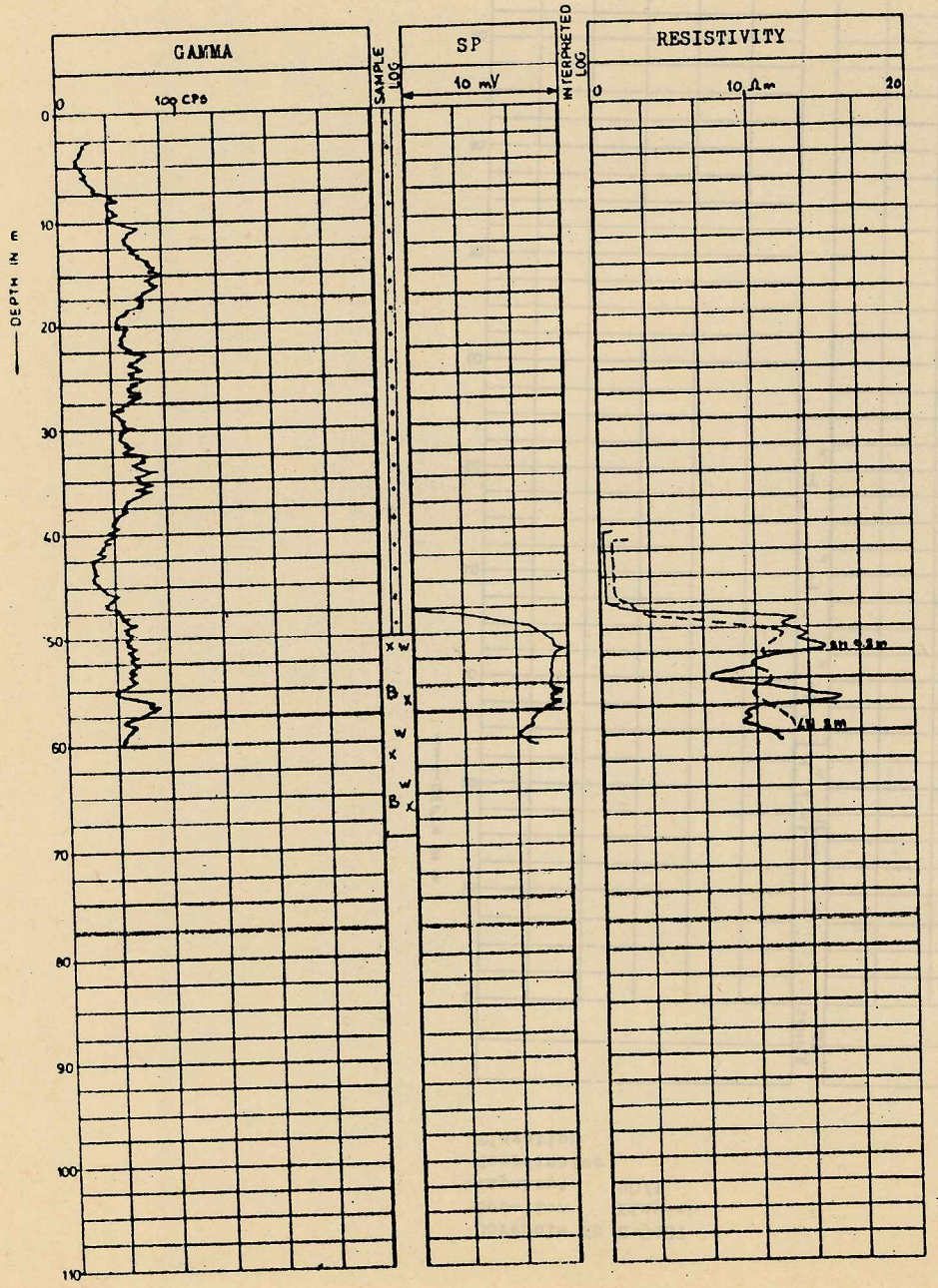
Borehole No C 5346
Location Tot
Mapsheet 76/3
Coordinates 7964-1333
Elevation 1020 m



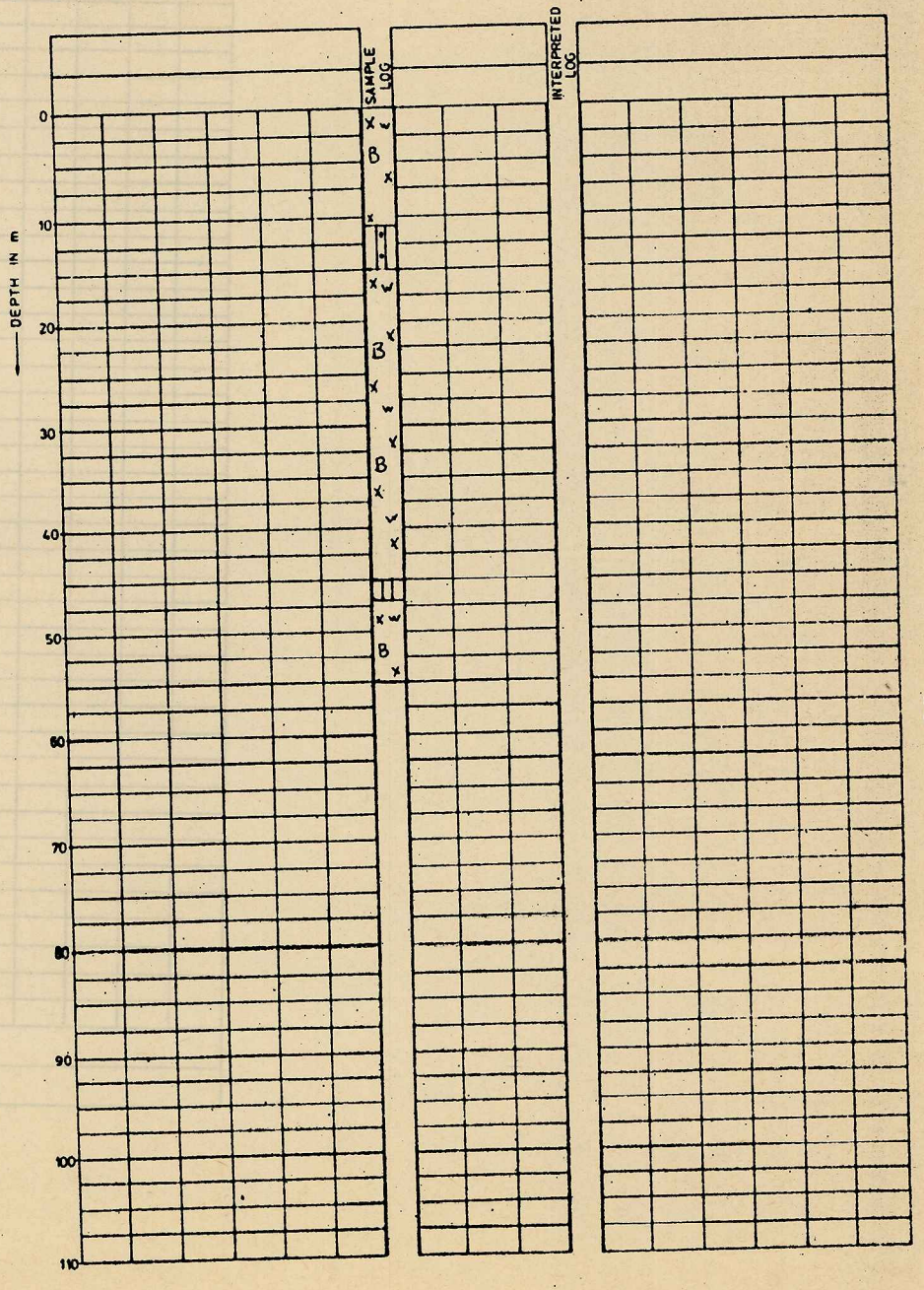
Borehole No C 5334
Location Rimoi
Mapsheet 90/3
Coordinates 7856-0670
Elevation 1130 m



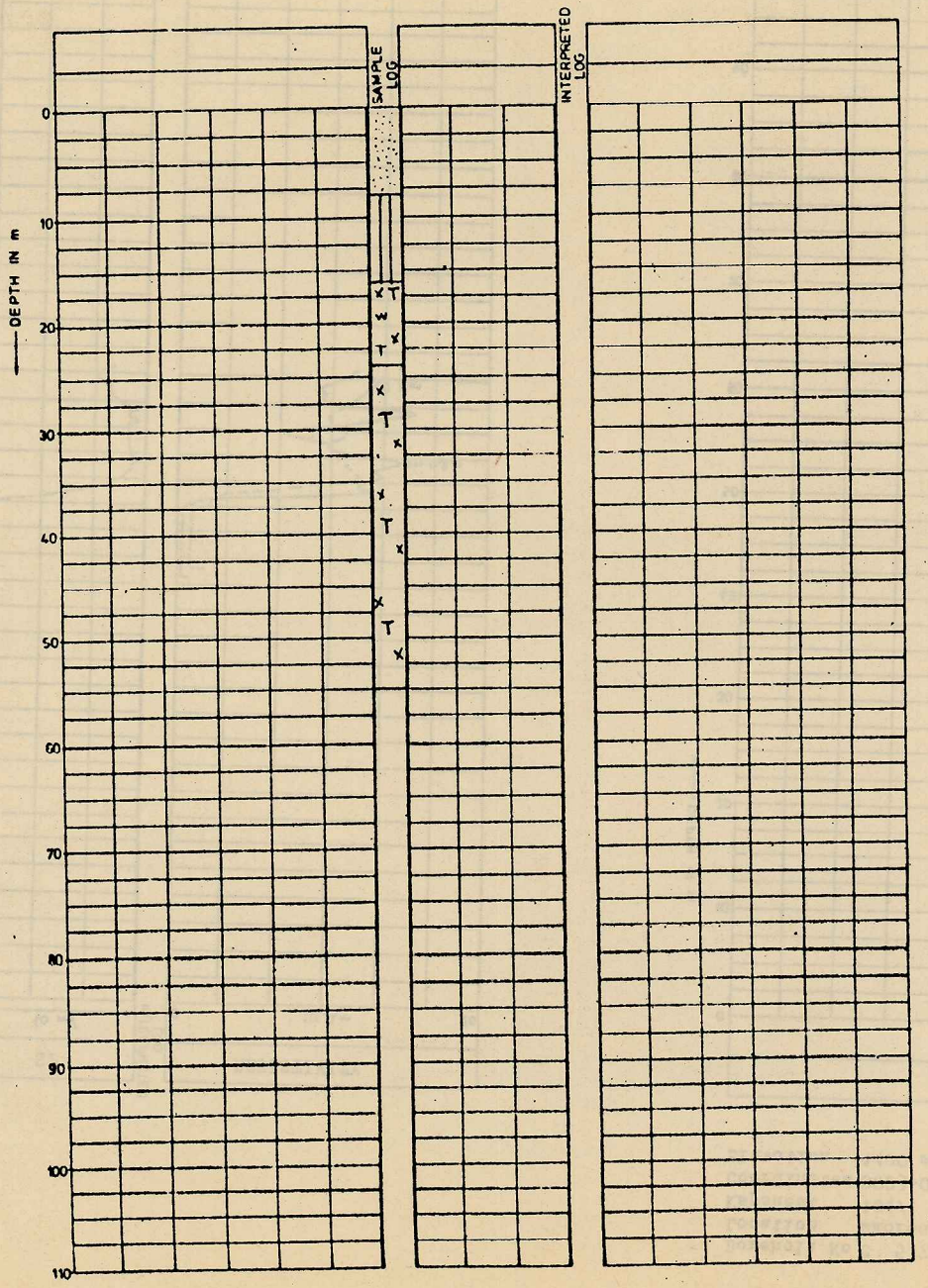
Borehole No C 5350
Location Tot
Mapsheet 76/3
Coordinates 7978-1337
Elevation 985 m



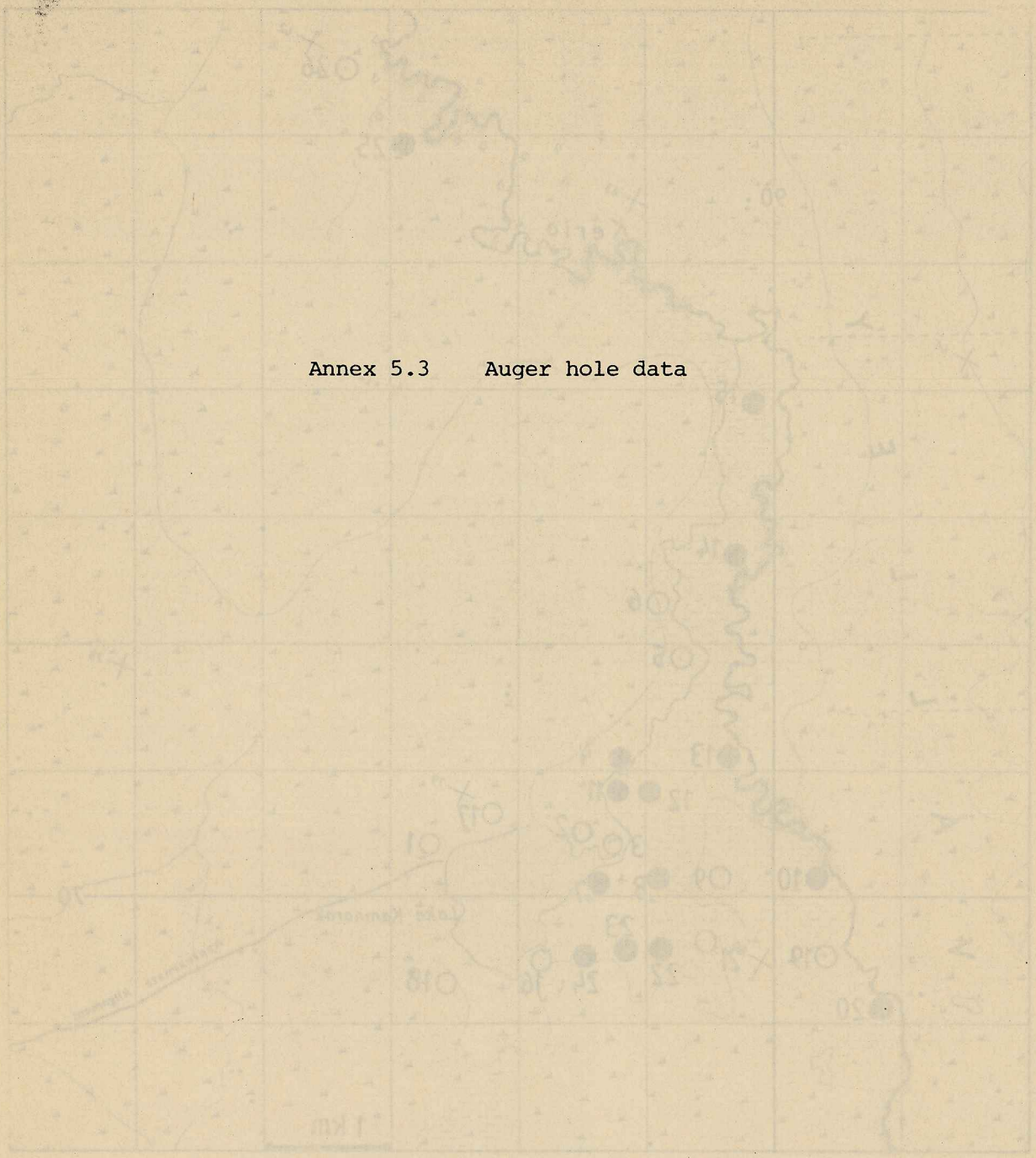
Borehole No C 5370
Location Mkorwa
Mapsheet 104/1
Coordinates 3023-0345
Elevation 1400 m

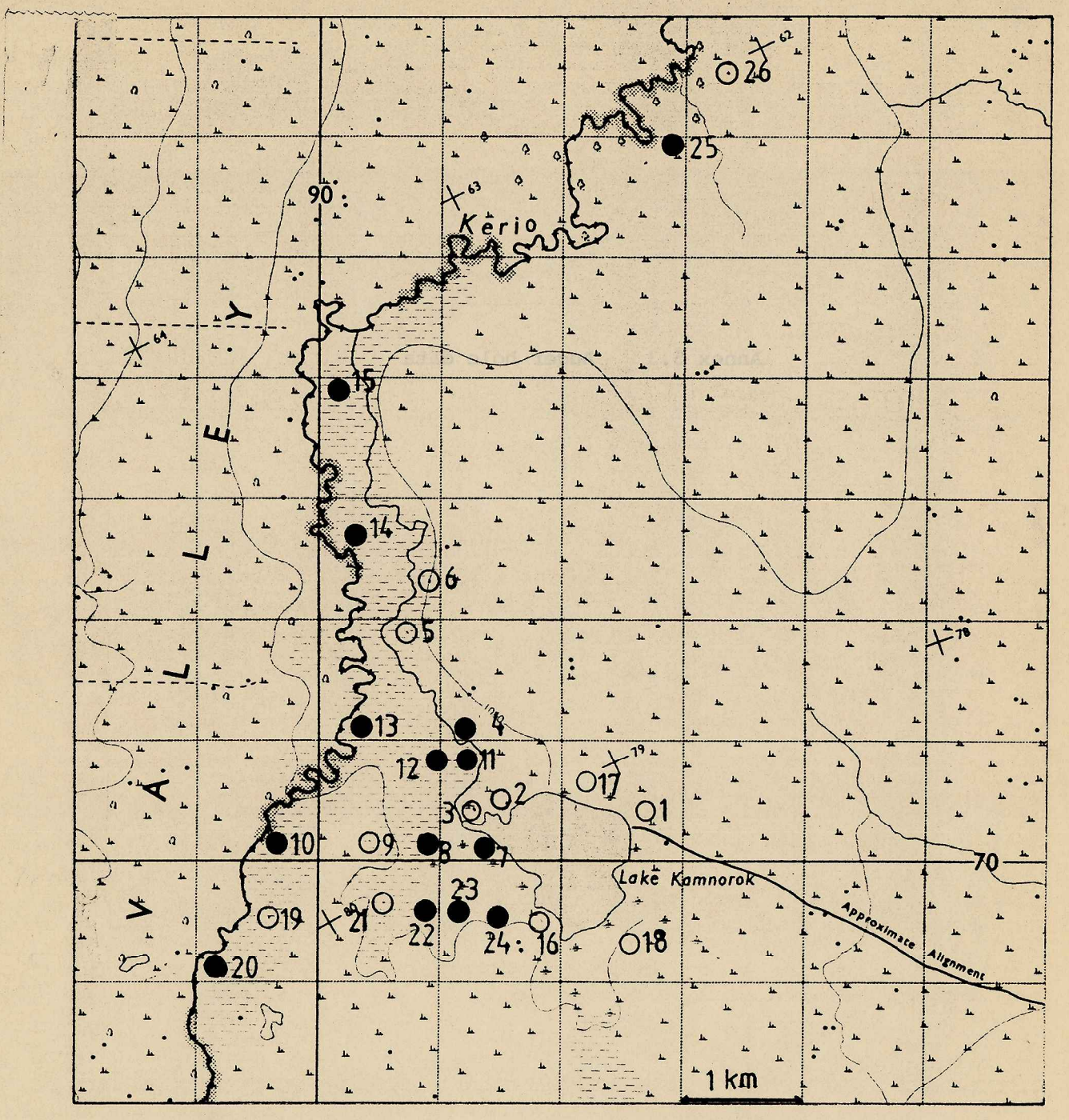


Borehole No C 5487
Location Kinyach
Mapsheet 90/1
Coordinates
Elevation



Annex 5.3 Auger hole data





● hole with water ○ dry hole

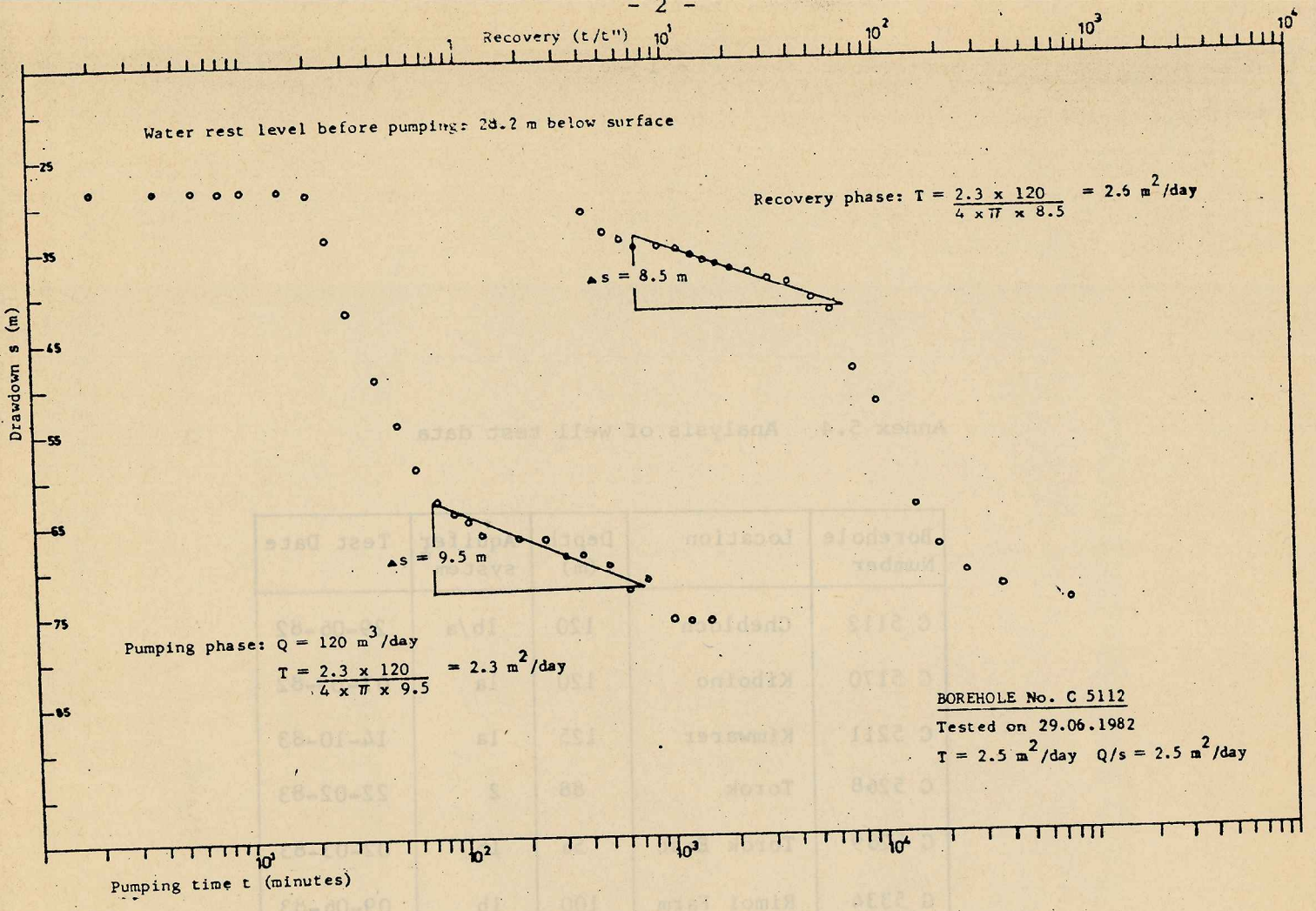
Hole no.	Depth (m)	Water level (m) struck	rest	Hole no.	Depth (m)	Water level (m) struck	rest
1	11.5	dry	-	14	10.0	3,5	2.2
2	7.0	dry	-	15	9.0	3.5	n.m.
3	6.0	dry	-	16	10.0	dry	-
4	13.0	dry	-	17	12.0	dry	-
5	7.0	dry	-	18	8.0	dry	-
6	8.0	dry	-	19	12.0	dry	-
7	11.0	4.0	n.m.	20	10.0	4.5	n.m.
8	12.0	10.5	10.5	21	11.5	dry	-
9	13.0	dry	-	22	10.0	6.5	n.m.
10	6.0	2.5	n.m.	23	12.0	11.0	8.8
11	10.0	3.5	2.9	24	7.0	3.5	4.9
12	10.5	5.5	5.2	25	8.5	2.5	3.6
13	10.0	2.5	3.2	26	3.0	dry	-

n.m. = not measured

Annex 5.4 Analysis of well test data

Borehole Number	Location	Depth (m)	Aquifer system*	Test Date
C 5112	Chebloch	120	1b/a	29-06-82
C 5170	Kiboino	120	1a	07-09-82
C 5211	Kimwarer	125	1a	14-10-83
C 5268	Torok	88	2	22-02-83
C 5269	Torok East	56	1b	02-03-83
C 5334	Rimoi Farm	100	1b	09-06-83
C 5346	Tot Centre	96	4	22-07-83
C 5349	Tot Bridge	28	3a	28-07-83
C 5370	Mokorwa	55	1a	06-09-83
C 5487	Kinyach	55	1a	24-11-83

* see section 5.4



Recovery phase: $T = \frac{2.3 \times 120}{4 \times \pi \times 8.5} = 2.6\ m^2/day$

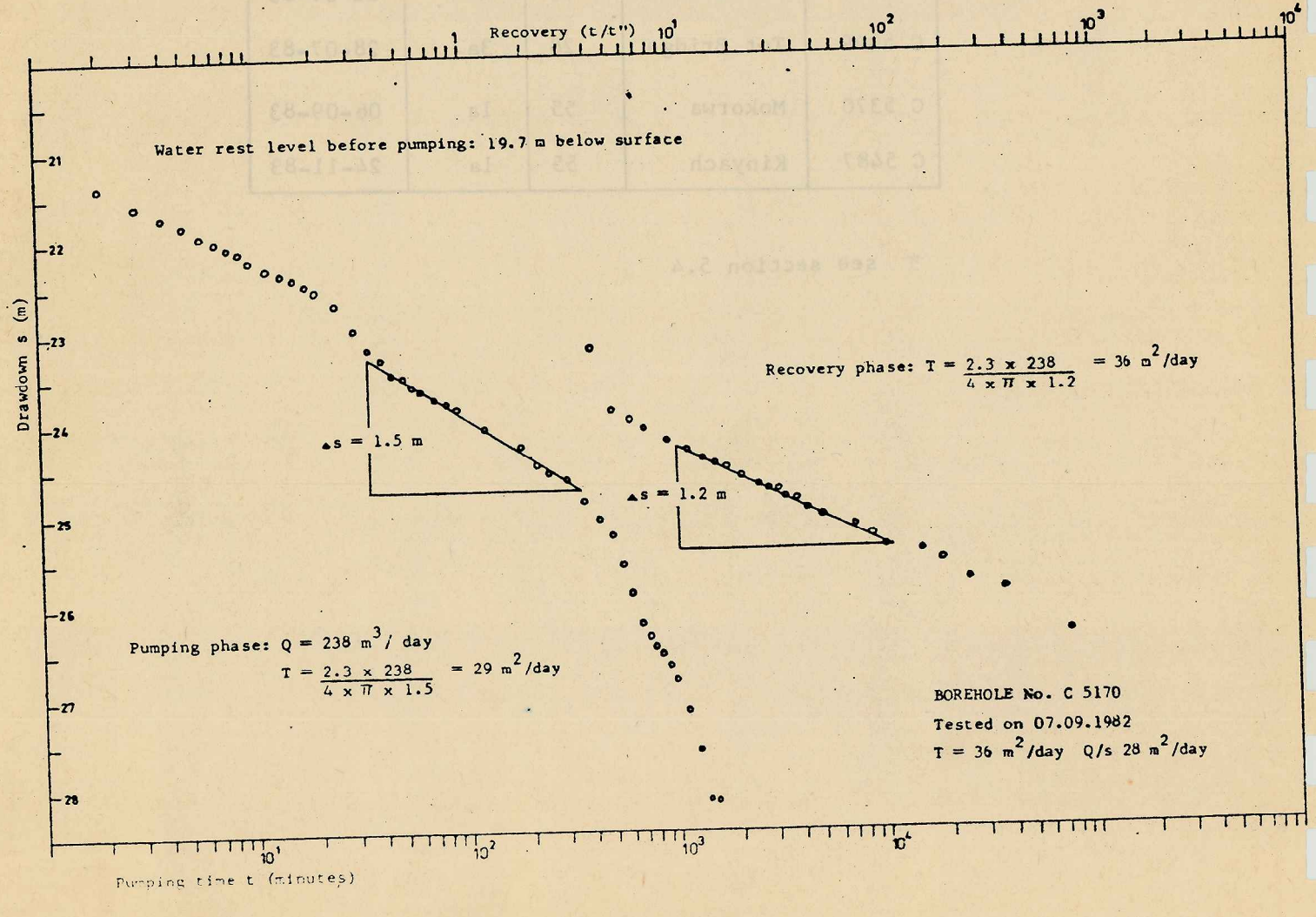
Pumping phase: $Q = 120\ m^3/day$

$T = \frac{2.3 \times 120}{4 \times \pi \times 9.5} = 2.3\ m^2/day$

BOREHOLE No. C 5112

Tested on 29.06.1982

$T = 2.5\ m^2/day$ $Q/s = 2.5\ m^2/day$



Recovery phase: $T = \frac{2.3 \times 238}{4 \times \pi \times 1.2} = 36\ m^2/day$

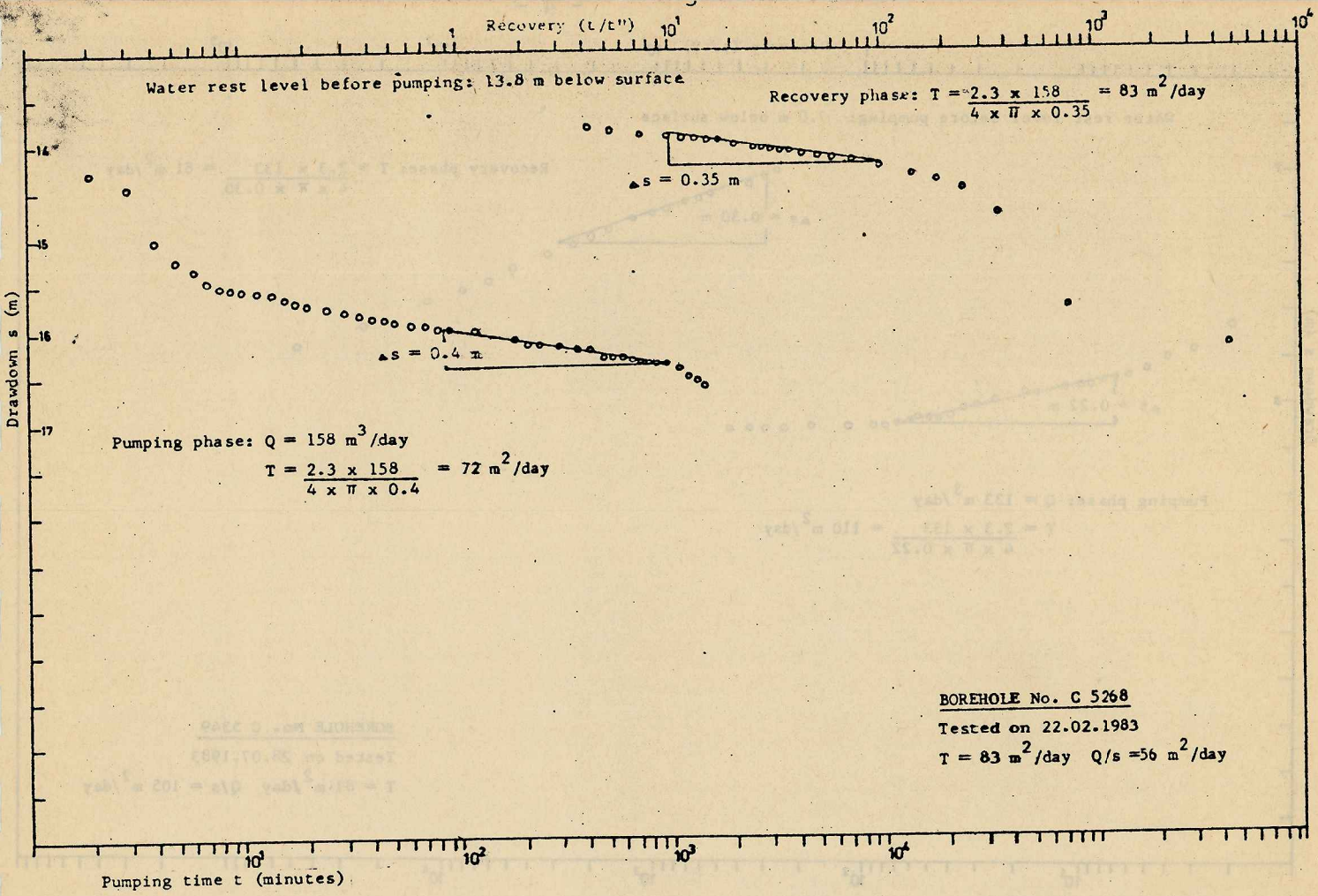
Pumping phase: $Q = 238\ m^3/day$

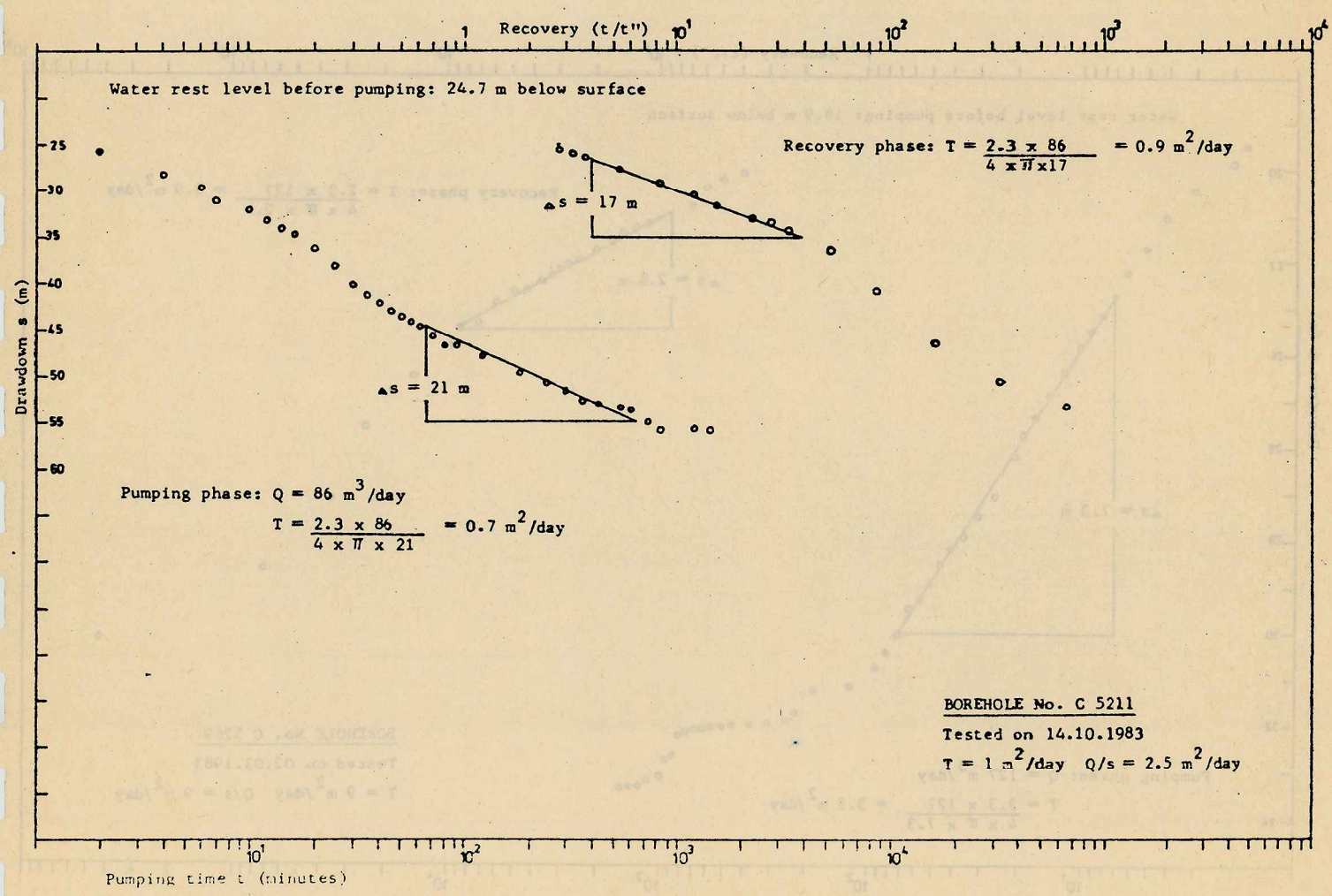
$T = \frac{2.3 \times 238}{4 \times \pi \times 1.5} = 29\ m^2/day$

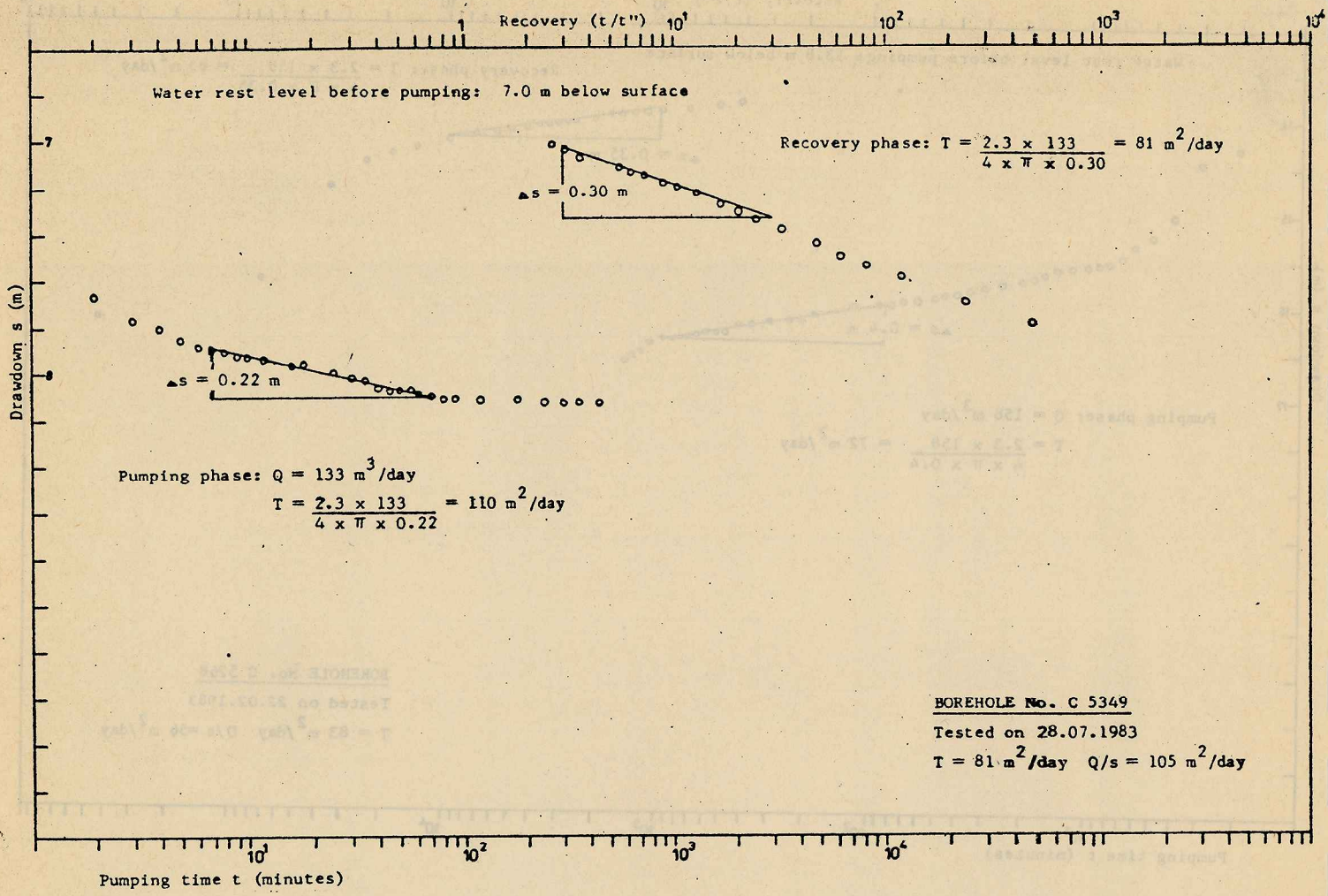
BOREHOLE No. C 5170

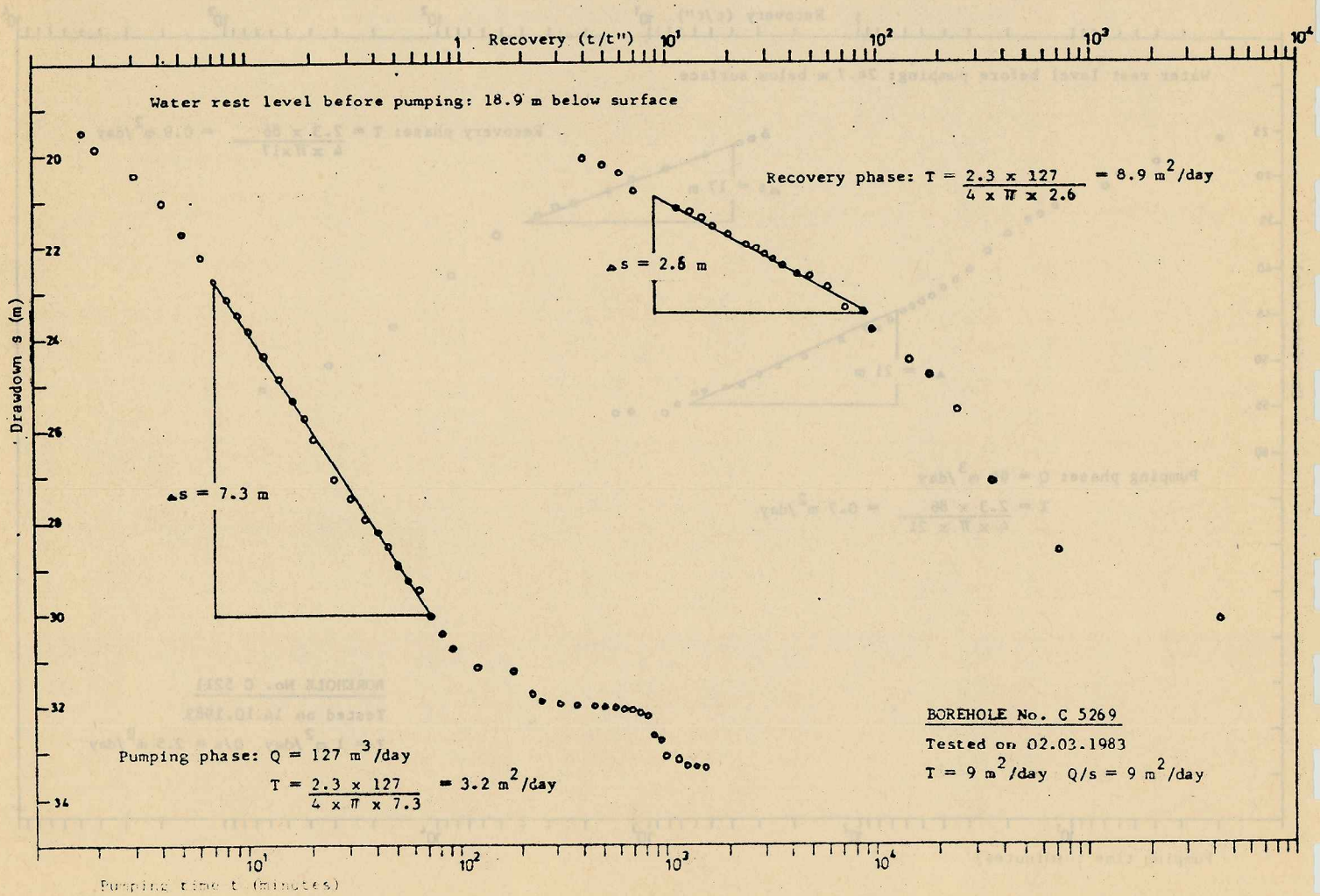
Tested on 07.09.1982

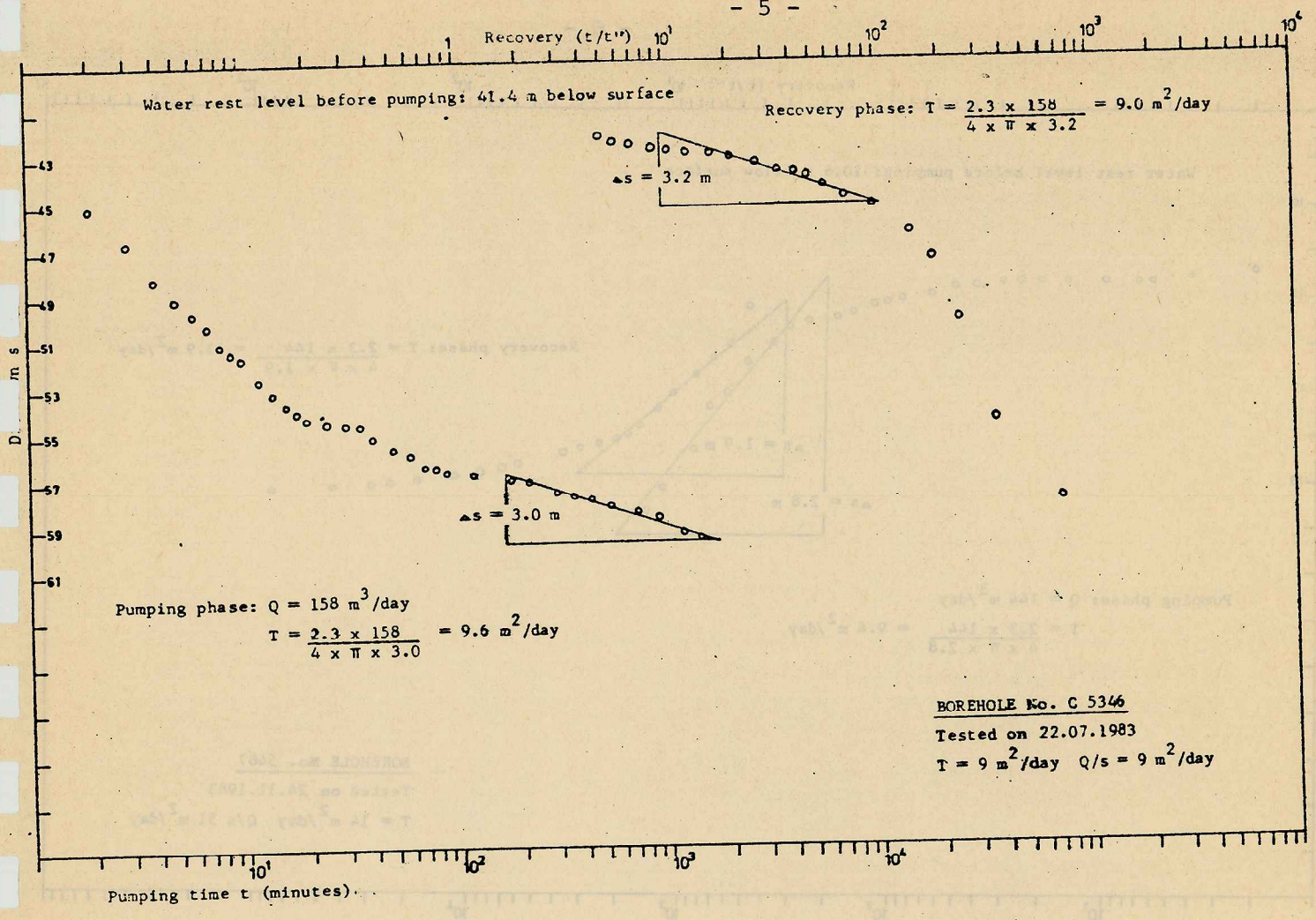
$T = 36\ m^2/day$ $Q/s\ 28\ m^2/day$

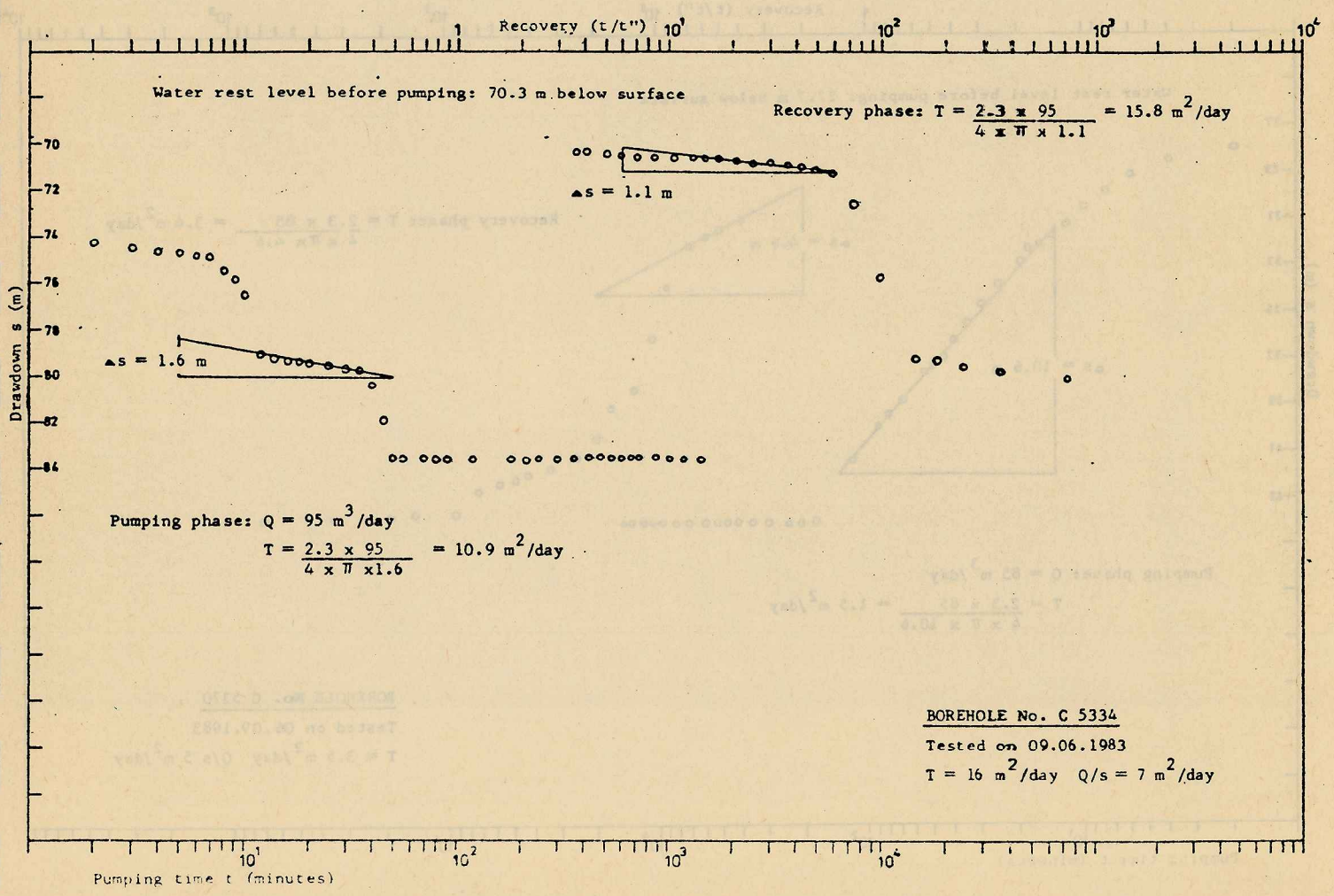

Recovery (t/t")
1
10¹
10²
10³
10⁴
Water rest level before pumping: 13.8 m below surface
Recovery phase: T = 2.3 x 158 / 4 x π x 0.35 = 83 m²/day
▲s = 0.35 m
▲s = 0.4 m
Drawdown s (m)
14
15
16
17
Pumping phase: Q = 158 m³/day
T = 2.3 x 158 / 4 x π x 0.4 = 72 m²/day
BOREHOLE No. C 5268
Tested on 22.02.1983
T = 83 m²/day Q/s = 56 m²/day
Pumping time t (minutes)

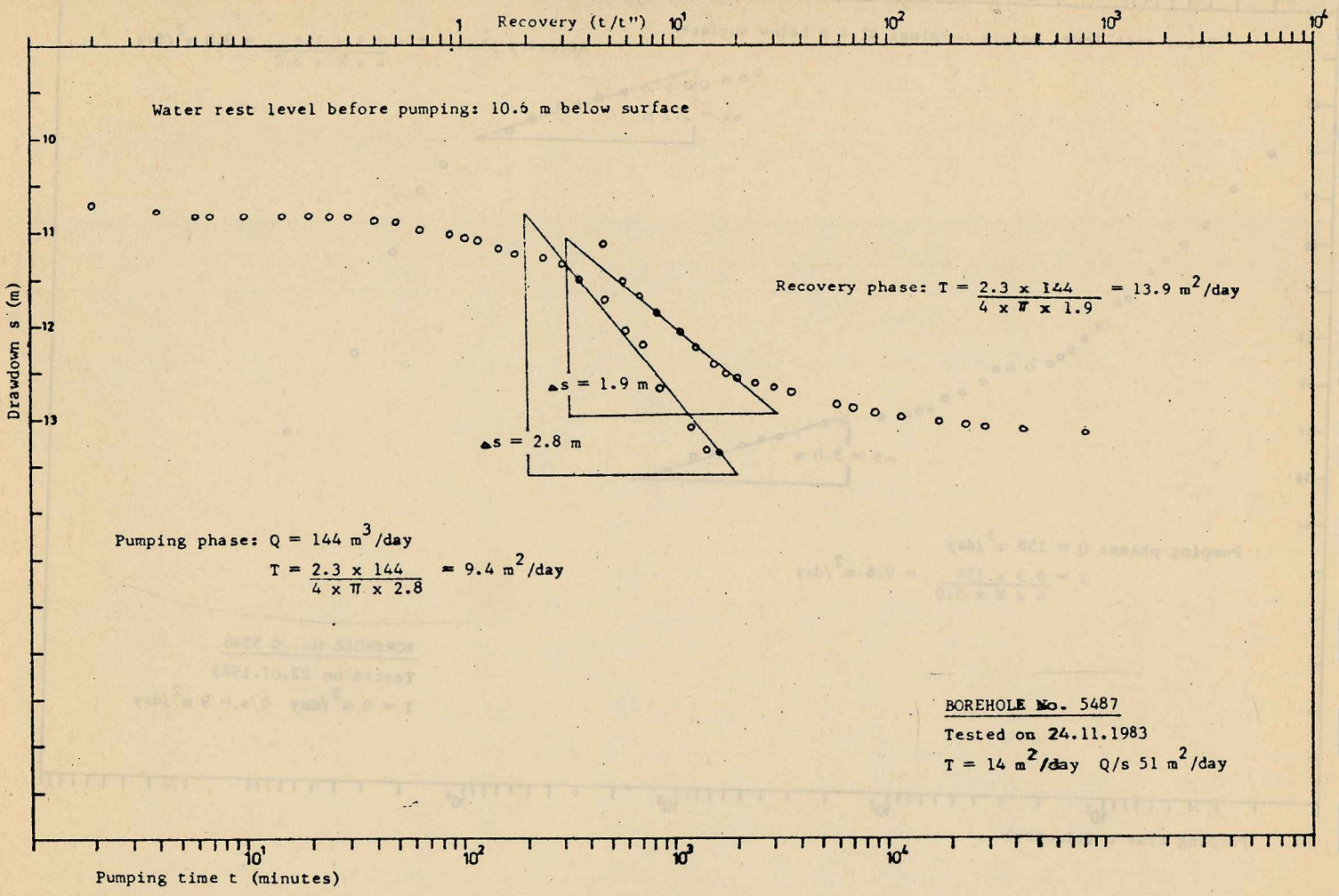

Recovery (t/t")
1
10¹
10²
10³
10⁴
Water rest level before pumping: 24.7 m below surface
Recovery phase: T = 2.3 x 86 / 4 x π x 17 = 0.9 m²/day
▲s = 17 m
▲s = 21 m
Drawdown s (m)
25
30
35
40
45
50
55
60
Pumping phase: Q = 86 m³/day
T = 2.3 x 86 / 4 x π x 21 = 0.7 m²/day
BOREHOLE No. C 5211
Tested on 14.10.1983
T = 1 m²/day Q/s = 2.5 m²/day
Pumping time t (minutes)

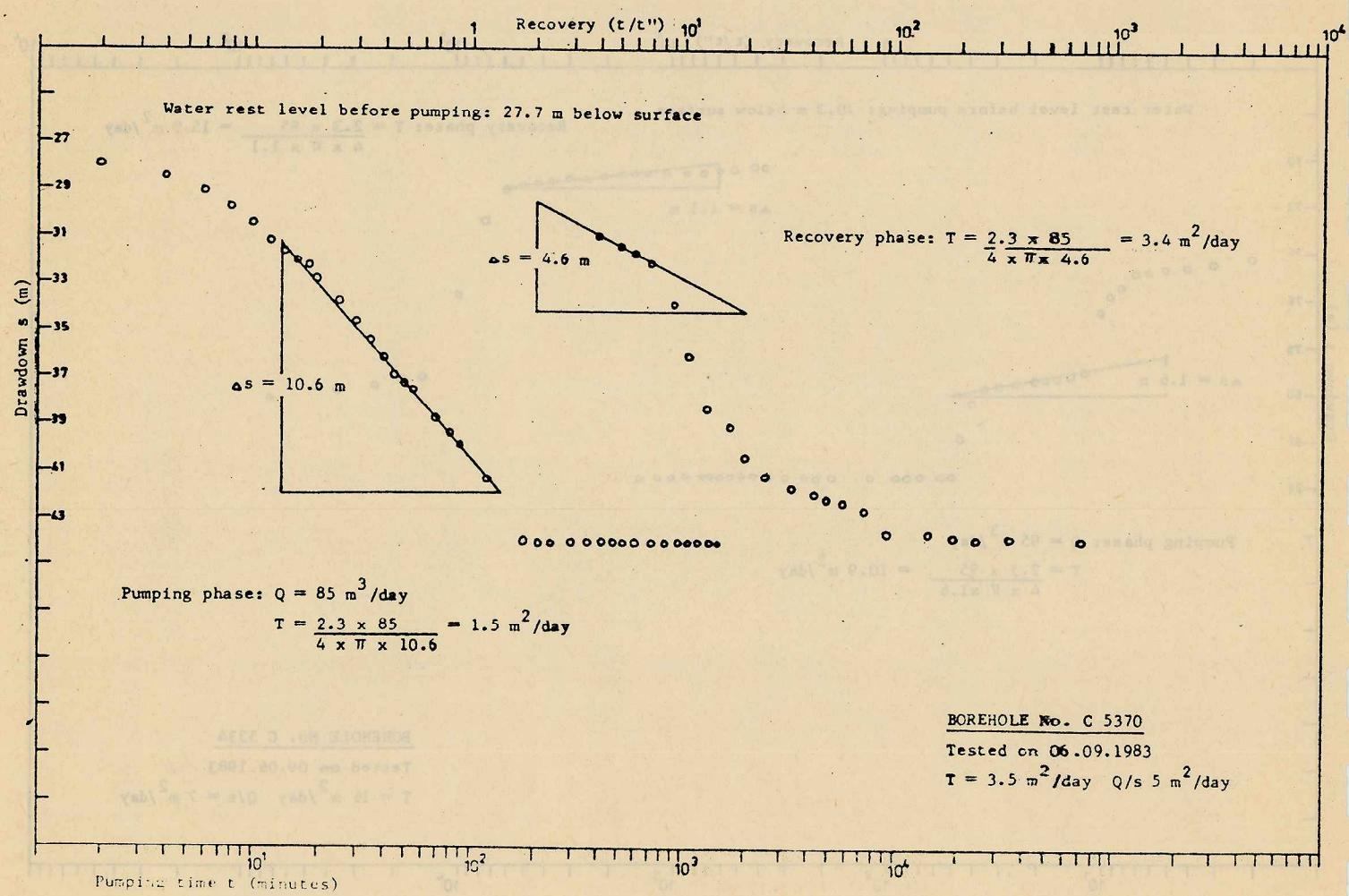

Recovery (t/t")
1
10¹
10²
10³
10⁴
Water rest level before pumping: 7.0 m below surface
Recovery phase: T = 2.3 x 133 / 4 x π x 0.30 = 81 m²/day
Δs = 0.30 m
Δs = 0.22 m
Drawdown s (m)
7
8
Pumping phase: Q = 133 m³/day
T = 2.3 x 133 / 4 x π x 0.22 = 110 m²/day
BOREHOLE No. C 5349
Tested on 28.07.1983
T = 81 m²/day Q/s = 105 m²/day
Pumping time t (minutes)


Recovery (t/t")
1
10¹
10²
10³
10⁴
Water rest level before pumping: 18.9 m below surface
Recovery phase: T = 2.3 x 127 / 4 x π x 2.6 = 8.9 m²/day
Δs = 2.6 m
Δs = 7.3 m
Drawdown s (m)
20
22
24
26
28
30
32
34
Pumping phase: Q = 127 m³/day
T = 2.3 x 127 / 4 x π x 7.3 = 3.2 m²/day
BOREHOLE No. C 5269
Tested on 02.03.1983
T = 9 m²/day Q/s = 9 m²/day
Pumping time t (minutes)


Recovery (t/t") 1 10¹ 10² 10³ 10⁴
Water rest level before pumping: 41.4 m below surface
Recovery phase: T = 2.3 x 158 / 4 x π x 3.2 = 9.0 m²/day
▲s = 3.2 m
▲s = 3.0 m
Pumping phase: Q = 158 m³/day
T = 2.3 x 158 / 4 x π x 3.0 = 9.6 m²/day
BOREHOLE No. C 5346
Tested on 22.07.1983
T = 9 m²/day Q/s = 9 m²/day
Drawdown s (m)
43 45 47 49 51 53 55 57 59 61
10¹ 10² 10³ 10⁴
Pumping time t (minutes)


Recovery (t/t") 1 10¹ 10² 10³ 10⁴
Water rest level before pumping: 70.3 m below surface
Recovery phase: T = 2.3 x 95 / 4 x π x 1.1 = 15.8 m²/day
▲s = 1.1 m
▲s = 1.6 m
Pumping phase: Q = 95 m³/day
T = 2.3 x 95 / 4 x π x1.6 = 10.9 m²/day
BOREHOLE No. C 5334
Tested on 09.06.1983
T = 16 m²/day Q/s = 7 m²/day
Drawdown s (m)
70 72 74 76 78 80 82 84
10¹ 10² 10³ 10⁴
Pumping time t (minutes)


Recovery (t/t")
1
10¹
10²
10³
10⁴
Water rest level before pumping: 10.6 m below surface
Drawdown s (m)
10
11
12
13
Δs = 1.9 m
Δs = 2.8 m
Recovery phase: T = 2.3 x 144 / 4 x π x 1.9 = 13.9 m²/day
Pumping phase: Q = 144 m³/day
T = 2.3 x 144 / 4 x π x 2.8 = 9.4 m²/day
BOREHOLE No. 5487
Tested on 24.11.1983
T = 14 m²/day Q/s 51 m²/day
Pumping time t (minutes)

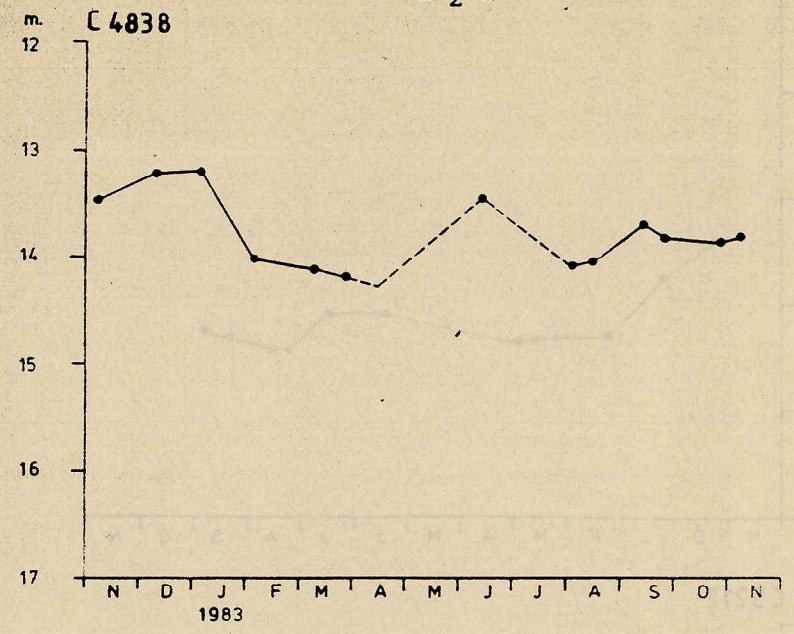

Recovery (t/t")
1
10¹
10²
10³
10⁴
Water rest level before pumping: 27.7 m below surface
Drawdown s (m)
27
29
31
33
35
37
39
41
43
Δs = 4.6 m
Δs = 10.6 m
Recovery phase: T = 2.3 x 85 / 4 x π x 4.6 = 3.4 m²/day
Pumping phase: Q = 85 m³/day
T = 2.3 x 85 / 4 x π x 10.6 = 1.5 m²/day
BOREHOLE No. C 5370
Tested on 06.09.1983
T = 3.5 m²/day Q/s 5 m²/day
Pumping time t (minutes)

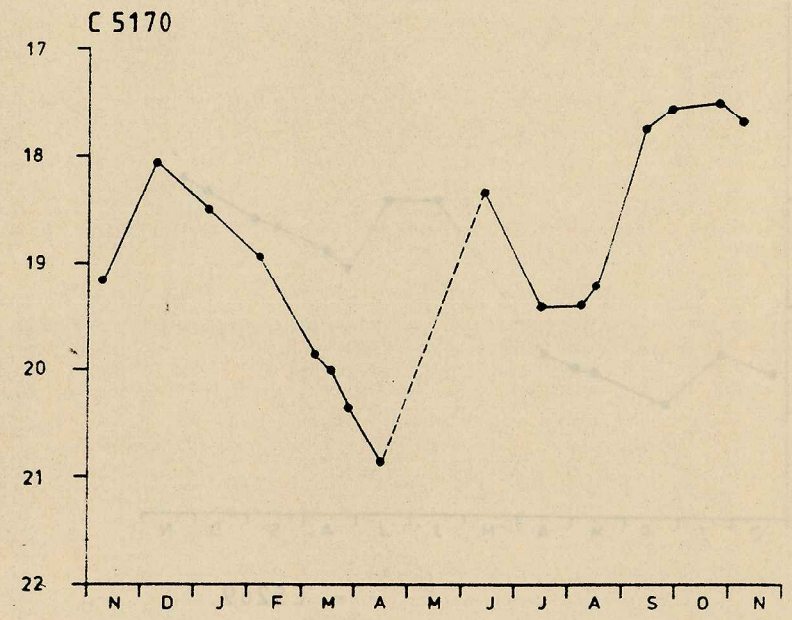
Annex 5.5 Groundwater level fluctuations and well hydrographs

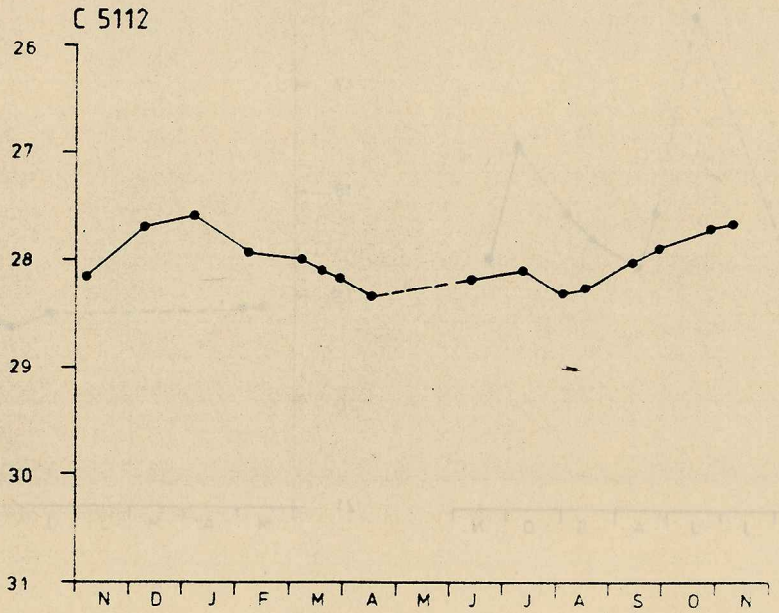
Annex 5.5 Monitoring of ground water levels (m below surface)

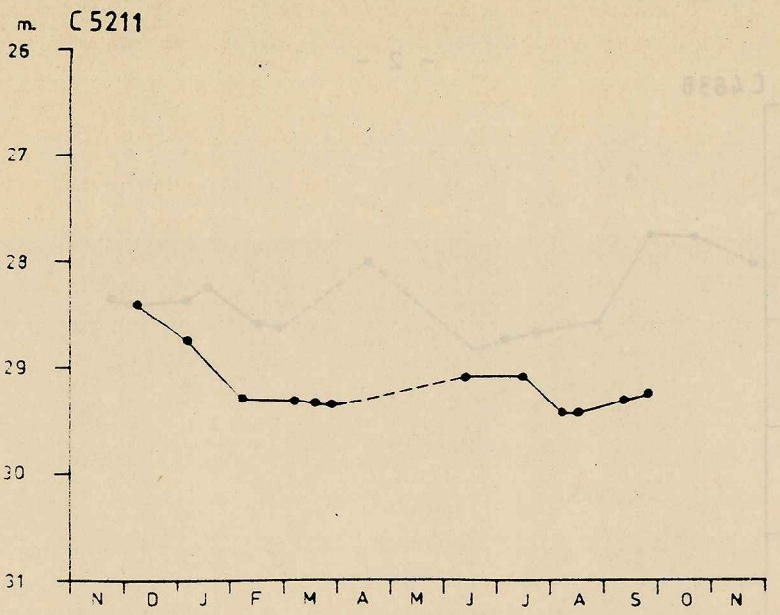
	1982		1983															
Borehole No.	5-11	9-12	5-1	5-2	2-3	17-3	28-3	19-4	11-6	15-7	2-8	16-8	13-9	27-9	4-10	25-10	7-11	Max. Δ (m)
C 1167	-	-	-	44.19	-	44.87	45.18	-	-	-	46.37	-	-	-	-	42.62	42.80	3.75
C 4838	13.48	13.23	13.20	14.02	-	14.12	14.20	-	13.45	-	14.13	14.04	13.71	13.60	-	13.62	13.56	1.00
C 5112	28.14	27.70	27.50	27.94	27.99	28.08	28.15	28.34	28.19	28.12	28.27	28.17	28.02	27.90	-	27.71	27.66	0.76
C 5170	19.15	18.03	18.50	18.90	19.84	20.01	20.35	20.88	18.35	19.41	19.38	19.20	17.75	17.56	-	17.52	17.69	3.36
C 5211	-	28.40	28.75	29.29	29.31	29.34	29.33	-	29.11	29.12	29.47	29.47	29.32	29.25	-	22.15*	21.54	1.07
C 5212	-	68.64	68.45	68.94	-	68.62	68.58	68.45	67.0	66.99	67.65	67.49	67.27	67.20	-	66.96	66.80	2.14
C 5268	-	-	-	-	-	15.25	16.08	-	-	11.30	13.21	13.71	13.46	13.20	-	12.55	13.82	4.78
C 5269	-	-	-	-	-	19.08	19.12	-	-	19.17	19.29	19.24	18.46	18.53	-	18.40	18.00	1.29
C 5333	-	-	-	-	-	- -	-	-	-	9.69	9.99	-	-	-	7.98	11.64	8.00	3.66
C 5334	-	-	-	-	-	-	-	-	-	70.30	70.63	-	70.39	70.52	-	70.25	70.20	0.43
C 5346	-	-	-	-	-	-	-	-	-	-	41.74	-	41.41	40.69	40.79	41.13	40.83	1.05
C 5349	-	-	-	-	-	-	-	-	-	7.06	7.46	-	6.85	6.30	6.43	6.91	6.56	1.16
C 5350	-	-	-	-	-	-	-	-	-	40.86	39.76	-	39.28	38.90	38.94	39.45	38.96	1.96
C 5370	-	-	-	-	-	-	-	-	-	-	-	-	-	25.80	-	-	24.95	0.85
C 5487	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

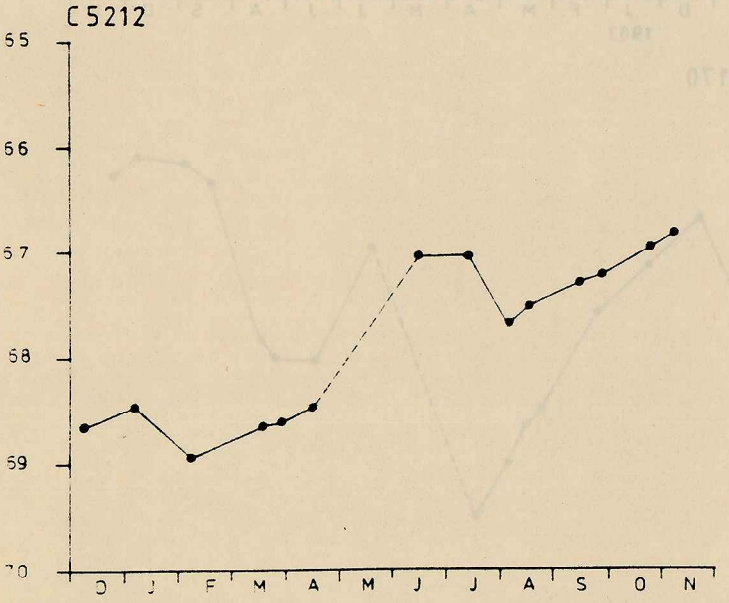
* Borehole deepened

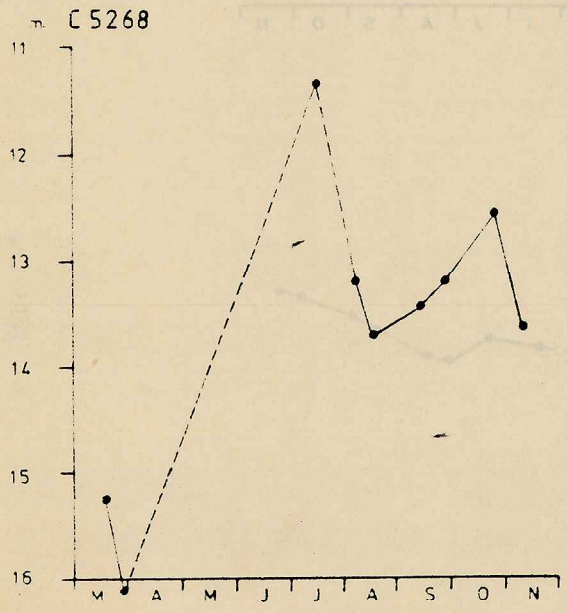

m.
C 4838
12
13
14
15
16
17
N D J F M A M J J A S O N
1983

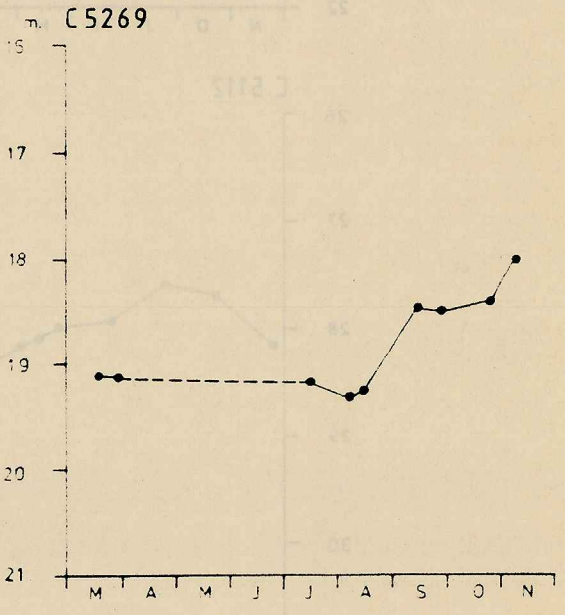

C 5170
17
18
19
20
21
22
N D J F M A M J J A S O N


C 5112
26
27
28
29
30
31
N D J F M A M J J A S O N

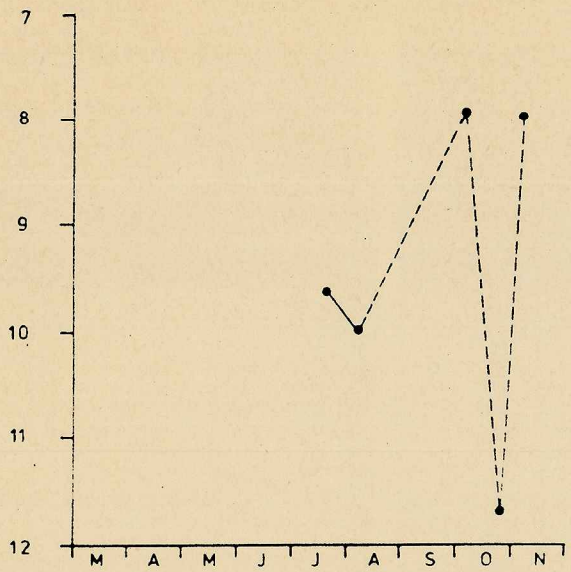

m.
C 5211
26
27
28
29
30
31
N D J F M A M J J A S O N


C 5212
65
66
67
68
69
70
O J F M A M J J A S O N

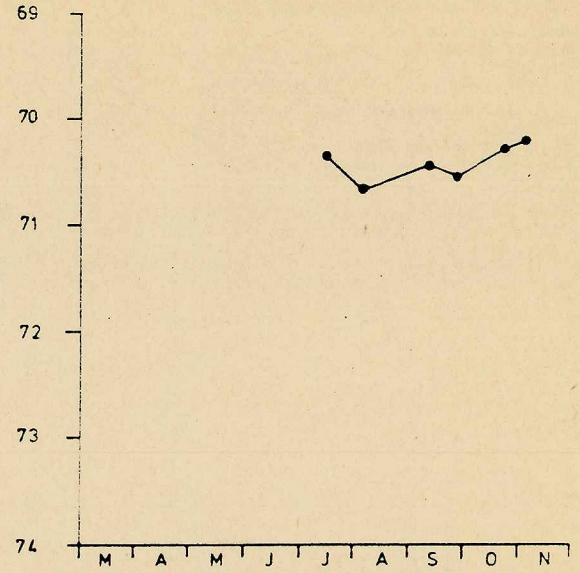

m.
C 5268
11
12
13
14
15
16
M A M J J A S O N


m.
C 5269
16
17
18
19
20
21
M A M J J A S O N

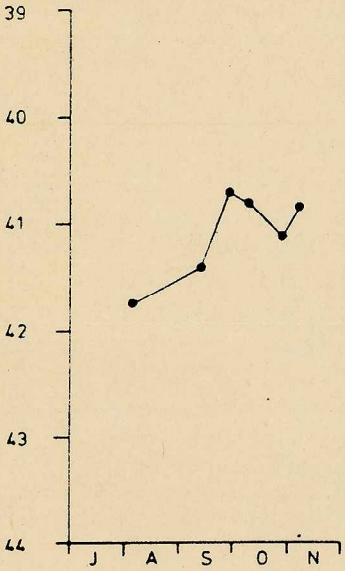
C 5333



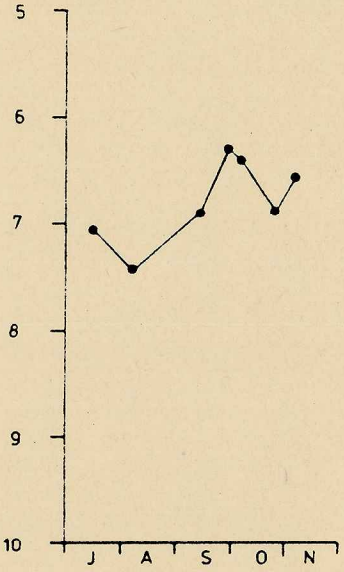
C 5334



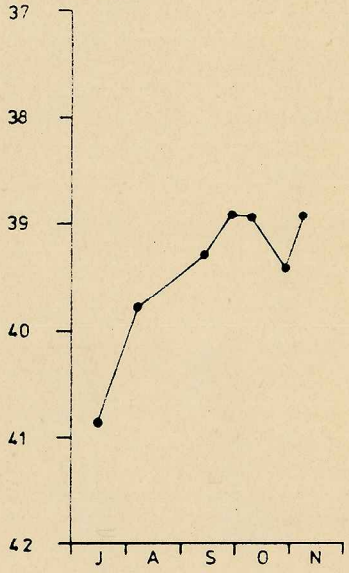
C 5346



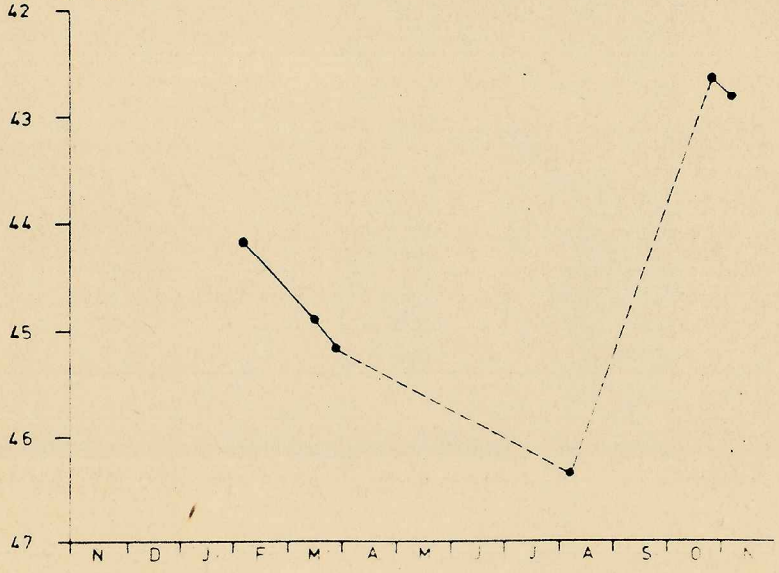
C 5349

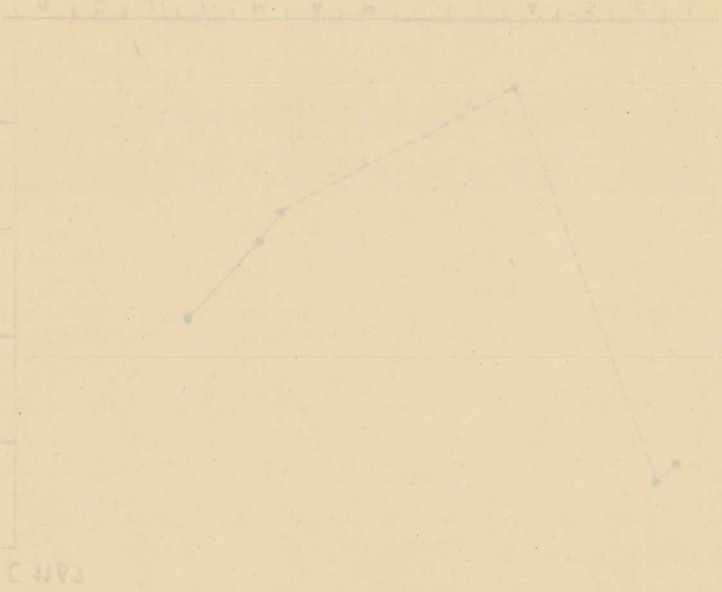


C 5350



C 1167

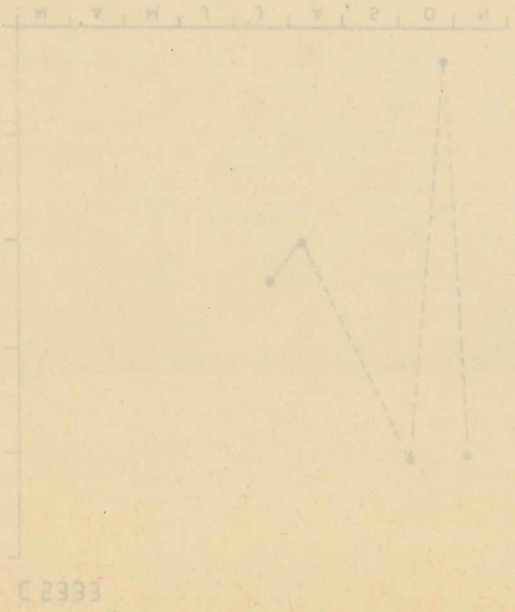


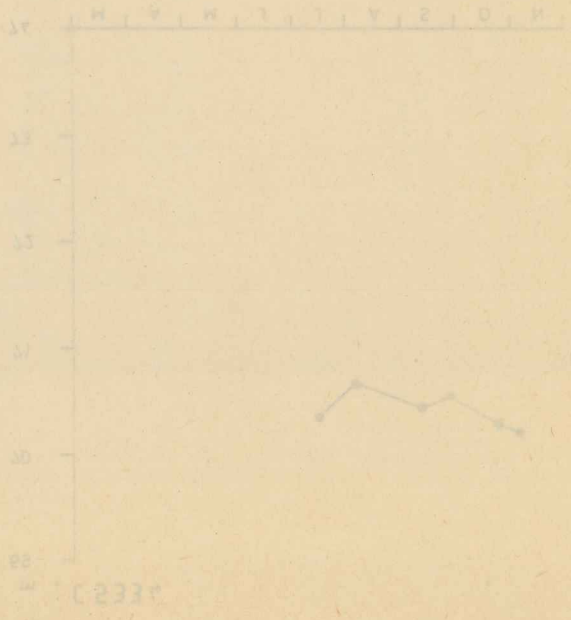












LIST OF PLATES

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4.2 Isohyetal map

5.1 Hydrogeological map

6.1 Existing water supplies

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