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Drainage study of a coastal area

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1.0 SYNOPSIS

1.1 The importance of field drainage in agricultural areas needs no emphasis. The problem is as common in many other countries of the world as in Pakistan.

1.2 This paper presents essential contents of the study conducted in "PEZZA DELLE ROSE" an area located on the Adriatic Coast in the southern part of the Italian Peninsula for exploring the extent and causes of water-logging and salinity in the area and possible remedial measures thereof, and is based on a Research Thesis by Mr. Bagh Ali Shahid submitted in partial fulfilment of his M.Sc. Degree in Italy in 1982. This extensive research on this subject was later cast in the present form of a technical paper by the authors in Pakistan.

1.3 The study covers:

(i) Collection, evaluation, and analysis of the available data regarding shallow ground water in the study area.

(ii) Ground measurements for the base data required for selection of type and design criteria and parameters of the selected drainage system.

(iii) Identification, introduction and selecting the solution for relieving the existing and potential drainage problems and design of the selected drainage system.

1.4 On the basis of research, the authors recommended laying of a sub-surface drainage network (tile-drains) with already existing surface drains to be used as collectors. It has also been recommended to grow salt-tolerant crops with a planned rotation for better crop-yield and saving the soils from getting salinized.

1.5 Although the discussion of geological, physiographic, hydro-logical, climatic and topographic, conditions in this paper relates to the study area, the methodology adopted in approaching the various problems has wide application to drainage problems in general for other coastal areas also.

2.0 GENERAL FEATURES OF THE STUDY AREA

2.1 Geographical Location.

The area is situated at a distance of about 4 Km. from the town of Barletta and 56 Km.

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North-west of Bari an important town of southern Italy. Its latitude is 41° 20′ and its longitude 3° 51′. The whole of the project area is above mean sea level in a coastal belt on the Adriatic shores. The location plan appears as fig: 1.

2.2 Climate

The climatic conditions in the area may be summarized as follow:

2.2.1 – Annual precipitation as observed from 1956 to 1982 varies from 300mm to 1000 mm. the average rainfall being about 700 mm. Some 80% of the total precipitation occurs from October to April. The maximum ever monthly rainfall recorded during this period is 163.6 mm. The maximum precipitation on any single day was recorded as 59.2 mm, on 24.5.1976 which was equalled or nearly so on only 4 occasions in the total analysis period of 27 years.

2.2.2 – The maximum temperature recorded is 43° C. and the minimum 2° C. The average yearly temperature is about 20° C.

2.2.3 – The evaporation of a free water surface may be put at 900 mm. per year.

2.3 Topography

The contour plan (Fig-2) shows that the maximum elevation in the study area is 9 m, and the minimum is 1 m, above sea level. Although the topography is irregular, yet a slope of 0.31% is available towards the Adriatic sea.

2.4 Existing Works.

2.4.1 The initial open drainage network was designed before the First World War in order to collect the seepage water and to evacuate it into the sea (Fig-1). The main outfall of the system is at two points, called north confluence and south confluence respectively. The river Camaggi joins the network from the side of north confluence at about 1500 m. before it outfalls into the sea. Except for short lengths the drains were lined with calcareous rock material and in some parts with cement concrete. This intervention gave good results and it bolstered the development of considerable agricultural activity in the area. Over the years, a critical situation arose, only because of the occasional flooding of the Camaggi river and violent sea storms which by preventing free outflow of water to the sea, provoked a rise of the water table and resultant flooding of the area.

2.4.2. During 1968, some sections of the network were lined and the bed slope of principal channels was modified to allow discharges of the river to flow towards the northern outlet. After some years, the results were not good, and due to bad maintenance of drainage channels, the whole of the network got choked with thick vegetation and the sub soil water level rose almost to the ground surface, thus lowering the yield and creating huge problems for the land-owners.

2.5 GEOLOGY.

The project area is a coastal strip of the Murgia that is representative of a large proportion of Apulia in southern Italy. The general geological features are characterized by a base of carbonatic mesozoic rocks. These carbonic rocks form a huge aquifer locally known as "deep aquifer". These rocks are constituted of limestone, dolomitic limestone, and dolomites. One of the most fundamental and typical characteristics of these rocks in the Murgia area is their low permeability. This property is due to karst and fracturing. In these rocks a red soil called "Terra Rosa" is present. It is a sort of clay-like material which is present in thin layers and fills large or small cavities. Some bore holes drilled in the vicinity of the project area indicated alternate layers of limestone, marly limestone, breccia and dolomite. The karst phenomenon is very common in the project area. From the geological map (Fig-3) these mesozoic rocks are locally classified as "calcare di Bari". From the tectonic stand-point, the cretaceous formations are found as monocline with a prevalent dip that varies from 5^{O} to 15^{O} to SSW. There are small faults with different almost vertical orientations. Two important faults are known as the "faults of Barletta" which cut at WNW the anticline of "Monte acute" and the faults are parallel to the Adraiatic sea. The discontinuity in strata due to these faults can also be observed. Some areas of cretaceous rocks (refer to geological map) are convered by sea deposits of the quaternary age consisting of calcarenites ("Tufi della Murgia") and more or less sandy clay.

According to investigations already carried out, these deposits have a thickness varying from 10 to 20 meters but in some cases near Barletta, their thickness reaches about 70 to 80 meters. The quarternary series is represented from the bottom to the top, by calcarenites, white or yellow in colour and more or less cemented that are stratigraphically in contact with limestone.

Over the calcarenites there are some layers of marly clay, blue grey in colour with silt particles. In some cases these are covered by sea deposits mainly of fine mostly quartzic sand yellowish-red in colour. Over these, we found the last stage of the geological series represented by sandy and gravelly alluvium deposits of the Holocene and Pleistocene age. In the Murgia, the aquifer flows are almost everywhere under pressure and generally below mean sea level, because upper rocky levels have low permeability owing to a low degree of fracturing and karst phenomena. The distribution of specific yield in the area, Trani-Barletta and Andria, shows very high values in comparison with the rest of the Murgia. In fact, in the area close to the sea, a value of more than 20 l/sec. m (Fig-4) has been encountered and in some locations values reach 50 l/sec: m, indicating high permeability. Moreover the hydraulic head is about 5 m. above mean sea level and the hydraulic gradient is about 1.5% near Andria. In this kind of aquifer the movement takes place in a concentrated manner due to the presence of impervious layers or because in some cases the fracturing or karst channels are filled by "Terra rosa".

Ground water flows in the aquifer under confined conditions. It is fed by autumn and winter rains, and the base level of ground water flow is the sea level. Run-off is mostly negligible and the rain water collected in depressions and low lying areas often evaporates. The major mobility of the ground water is in the zone of Andria Barletta and Trani. There are no large draining fronts along the coastal line. Most important karstic coastal springs are also found between Barletta and Trani and towards them the main preferential path of flow is directed as indicated by the iso-piezometiric plot (Fig-5).

Generally, salinity is greater near the coastal strip and it decreases going inland (Fig-6). A salinity value of 3g/l is found in the coastal strip. Good water with salinity of less than 2g/l is found at a distance of about 4 to 5 Km. from the coastal line.

Geophysical Investigations.

In order to have a broader view of the substrata and thickness of impervious layers, four representative sites were selected in the study area for geophysical survey through electrical soundings. These sites are marked on the geological map (Fig-3) as T_1 T_2 T_3 and T_4. The resulting information is that the substrata is uniform throughout with coarse sand layers over calcarenite. The calcarenite sometimes marly is resting on limestone rock which forms a deep aquifer.

2.6.2. When the calcarenite is marly, this strata is like an impervious level and it is possible to find a second aquifer discharging into the sea. A connection between the surface aquifer and deep aquifer is also recognized. These results were further verified by geological drilling completed in the nearby areas for the installation of some deep tubewells for irrigation purposes and some drilled and dug holes available in the project area.

3.0 HYDROGEOLOGICAL ASPECTS OF THE ZONE

3.1 General Description.

3.1.1 A study of the behaviour of the ground water table is of great importance in hydrogeological investigations since it provides valuable information on the properties of the aquifer. Drainage being the main interest of this study, the investigations have been limited to shallow ground water zone. The data collected has been particularly useful for identifying areas of easiest outflow, ascertaining the '"degree of homogenity"' of the aquifer, and the influence of virtually impermeable formations on flow patterns between ground waters and sea waters along the coast. A network of 30 observation wells was selected (Fig-7) among the large number of wells dug in the zone in order to establish the following objects:-

3.1.2 – The configuration of the water table and potentiometric surfaces.

– Direction of the ground water movement.

– Location of recharge and discharge areas.

– Variations of water table with time.

3.1.3 In the whole of the study area, the aquifer is divided and limestone rocks form a deep aquifer which extends to depth of about one thousand meters below sea level. Just below a thin fresh water zone salty sea water has intruded into the aquifer. The quality of this deeper aquifer in the upper layers is comparatively worse than that of the shallow aquifer found in post-cretaceous deposits. There is no scope for obtaining adequate discharges from this aquifer for irrigation purposes.

3.2 Shallow Aquifer.

The post-cretaceous deposits in a depth of 10-15 m form a shallow aquifer fed by rainfall and inland water from deep aquifer in the overlying high lands. cultivators have installed shallow wells of 3 to 4 l/sec: in this aquifer for irrigation during the summer period. The permeability being very low in this zone, the operation of wells results in a local drawdown of upto 5 meters.

3.3. **Description of Shallow Aquifer.**

As mentioned earlier, the lay out of the observation wells in this aquifer was made in accordance with topography, geology, hydrology, and soil conditions. Water depths were measured during the winter period of December to April. The observations were made twice a month. The typical iso-phreatic plot for 3.2.82 appears as (Fig-8) and the data collected regarding water levels salinity and temperature of water for the same date i.e. 3.2.82 appears as table-I. Generally the ground water flows sea-ward flow of ground water. In the central and southern part of the area, there is clear indication of flow below mean sea level through fissures and karst phenomena.

3.4 **Ground Water Table.**

3.4.1 The measurements made in a series of wells indicate that the water table for all practical purposes can be considered in a steady state condition. It is apparent from the iso-phreatic plot (Fig-7) that the average hydraulic gradient is 5 to $6^{o}/_{oo}$ with a minimum value of $1^{o}/_{oo}$. The water table is mostly influenced by the infiltration of the rain water into the sub soil. The contribution of rainfall amounts to 60-70% of its value. The topography of the area is such that run-off is negligible.

3.4.2 In certain parts the crop growth is endangered, both by the salinity of the soil and the quality of ground water. The combined action of seepage and the rainfall in the rainy season often causes the ground water table to rise to such levels that serious damage to crops results. The fluctuation of water table varies from 15 cm to 20 cm. The deepest ground water table is 0.11 m. near the sea. The main drainage area is central part. The sea level fluctuation effect is negligible on the ground water table as has been observed by a survey carried out for this purpose using automatic recording instruments. A change of about 40 cm. in sea level has not effected the water level in a well located about 200 m. from the coast.

3.5 **Ground Water Salinity.**

3.5.1 The Adriatic sea has a high salt content and near the project site a value of 40 g/1 was measured. The shallow water table in comparison to the sea is much less saline. The area lying on the right bank of the principal drain and enclosed between the sea and the river Camaggi has salinity values of 1.2 g/1 to 2.40 g/1. In the central part of the area salinity ranges from 2.30 g/1 to 3.80 g/1. These high values of salinity specially in the southern part, are attributed to the fact that ground water in this area is fed from seepage water coming from high overlying areas. It becomes the most important parameter to be established for the solution to the drainage problem of this area. Most of the seepage water coming in the study area, enters from the southern end.

3.5.2 The highest values of 6 to 7 g/1 were recorded just near the coast, the reason being a strong tidal effect on the ground water table near the coast. For the control of salt content in water about 500 cc. water samples were collected from each well and tested in the laboratory for electrical conductivity (mmho/cm) and TDS)g/1) were determined from a standard calibration curve (Fig-9), prepared starting from sea water samples and standard solutions of sodium chloride. Isosalinity lines were drawn for each observation data and one such observation is plotted in fig-6. The pattern of these lines remained the same throughout the period of study. There is considerable variation in the salt content of the ground water within the same aquifer, but generally speaking there are clear indications of an increase in salinity from the NORTH-West to the South-East and south corner of the study area. This fact is in accordance with higher premability in this part of the area which made sea contamination easier.

3.6 **Ground Water Temprature.**

3.6.1 Measurements of ground water temperature and air temperature for each well of the network were taken at the time of each observation and tabulated. The maximum temperature of ground water recorded is 17^{o} C in the case of well No. 13 and for most of the wells temperature ranged from 14^{o} to 16^{o}C. In the central part the mean horizontal temperature gradient is 2^{o}C/100 m. (Fig-10) and this low temperature gradient varifies the fact that ground water is comparatively mobile in this zone. The temperature of wells No. 1 and No.2 has a different pattern of variation when compared to the other wells and this is due to the influence of the sea and also to the fact that ground water is relatively less mobile in this zone.

3.6.2 The temperature of the group of wells No. 15, 16, 17 and 18 is high enough to show that ground water occupies the area not directly fed by infiltrating water.

3.6.3 As the study shows, ground water in this area is fed both by rainfall during the winter and spring seasons, and by inland seepage. The average temperature of rain-water varies from 9 to 10^{o}C and when this water percolates below and joins the ground water it reduces the average value of ground water temperature. The observations taken after heavy rainfall show a decline in temperature.

3.6.4 The iso-temperature lines (Fig-10) show that temperature increases from the sea, going inland. The reason for this, is the effect of the sea and the mobility of the groundwater in relation to the rock sides in contact with it. It was observed during the period of the observations that the temperature of some of the wells is influenced by air temperature because ground water is close to the surface. Such types of wells were excluded from the detailed study of salinity and temperature.

3.7 **Selection of Wells for Detailed Study.**

For selecting a system of wells unaffected by air temperature, the change of temperature of air and ground-water temperature(^{o}C) with respect to time (in days) was recorded and plotted for each well. Wells whose temperature change over the time was in full conformity with air temperature change, were rejected and the rest ten were selected for detailed study.

3.8 **Salinity Logging.**

Salinity logging performed in selected wells over different periods of time show that the salt content of ground water floating over the intruding sea water in certain portions varies little with depth. The observed value of resistivity was corrected and converted to T.D.S. by using the standard calibration curve (Fig-11). In well No. 24 where the thickness of the ground water is 12 m. The salinity ranges from 2.20 g/1 to 2.45 g/1. In well No. 28 the salinity value is very low; of the order of 1.20 g/1.

3.9 **Temperature Logging.**

Temperature logging performed at the same time as the salinity logging shows that this parameter can provide suitable information on ground water mobility. Where the ground water is not mobile, the increase in temperature down the column of water ranges from 0.10°C to 0.20°C per meter. It shows that in these wells the ground water is constantly fed from adjoining high lands. In the remaining cases, there is no rise in the temperature with the depth of the well. It is apparent from the data that surface temperature is higher along the coastal strip and lower further inland. In the case of well No. 10, flow takes place in the upper layers and the temperature remains constant showing the mobility of ground water.

3.10 Chemical Composition of Ground Water.

3.10.1 For determining the salinity components of the ground water, the concentration of the important ions (Ca^{++} Mg^{++} Na^{+} HCO_3- $Cl-$ $SO-$ $CO-$) were determined in typical samples. The result of these chemical analyses expressed in milliequivalents per litre are shown in Table-II.

3.10.2 A classification of the ground water which is more relevant for irrigation and drainage purposes is based upon the following characteristics:-

- Electrical conductivity (EC)
- Sodium adsorption ratio (S A R Value)

according to USDA (1954) falls under the cagegory of C_4S_4.

3.10.3 This classification reads as follows." This water very highly saline is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and highly tolerant crops shall be selected." The results of chemical composition are presented as SCHOELLER diagram (Fig-12).

3.11 Discharge of Existing Surface Drainage Channels.

3.11.1 The discharge of the existing general collector was measured at the north confluence and the south confluence and the same is compared with previous data available from 1926 to 1951 (Table III & IV).

3.11.2 The maximum discharge measured at the north confluence is 253 1/Sec: for the recorded period and for the south confluence it is 766 1/sec. Comparing these figures with the recent measured discharge, it is concluded that there is not much change in the discharge intensity of the existing main drainage channels.

3.11.3 To estimate the amount of seepage coming from high overlying lands to the study area, discharge of two existing seepage drains was measured alongwith the contributing area, and it was found that the specific discharge varies from 0.23 to 0.25 1/sec/Ha.

3.11.4 The discharge of collector No. 6 flowing towards the south confluence is measured as 262 1/sec. The discharge of collector No. 4 was of the order of 30 1/sec.

3.11.5 These high values of the discharges show, that the major portion of the foreign water coming in the study area is intercepted by these drains.

4.0 Soils.

4.1 **General.**

Soil is a dynamic natural body occurring on the surface of the earth. Its properties are due to climate and vegetation acting upon parent material over a period of time as conditioned by relief and it is capable of supporting plant life. It can be summarized in the following equation:

S= f (c,b,p,r,t)

Where
s= Soil
f= function
c= climate
b= biosphere
p= parent material
r= relief
t= time.

4.1.1 The soils of the project area although they show influences of climate and biosphere, donot show climax due to the role of relief and time. They are not strongly and deeply developed and about 50% of the project area has a water table within a depth of 60 cm. Thus the existance of poor natural drainage has adversely affected theprocess of soil formation. In general the soils of the area can be classified into order "Inceptisol" suborder "ochrepts" great group "xerochrep" and sub-groups "typic xerochrepts" and "aquic xerochrepts".

4.2 **Soil Characteristics**

The soils of the study area are developed in parent material derived mainly from limestone and dolomite, both sedimentary rocks. These are calcareous in nature. The epipedon is mainly "ochric" with "cambric" B horizons. They range from sandy loam to sandy clay loam. In some small patches it is more sandy. In a few places it is highly saline. The sub soil ranges from loam to sandy clay loam. The sub stratum is silt loam to silty clay loam with a greater percentage of silt (between 40 & 50 percent). This horizon is less permeable and bears a water saturation zone. The PH of the soil ranges between 7.5 and 8.5. The results of soil samples tested are given in table V.

4.3 **Soil Profile Characteristics.**

4.3.1 A description of soil profile observed near observation well No. 4 towards the sea site is given below:

Ap 0-12 cm. dark greyish brown loam, massive calcareous, common fine lime concretions, common fine roots, PH 8.1, clear smooth boundary.

B_2 12-38 cm. dark greysih brown loam, weak coarse sub-angular blocky structure, strongly calcareous, common to many fine lime concretions, PH-8.2, clear wavey boundary.

B_3 38-50 cm. greyish brown light loam, massive to weak coarse subangular blocky structure, strongly calcareous, common fine lime concretions, PH-9.5, clear wavy boundary.

A_1 b 80 cm.+ variegated colours sandy loam, common decayed roots.

4.3.2 The soils of the study area are generally medium to moderately fine textured. The subsoil has a loamy feel but the substratum has a clay-like feel and it is this layer of the soil profile which is less permeable and is responsible for poor drainage. The percentage of moisture retained at field capacity and wilting point was determined as 28% and 15% respectively.

4.4 Infiltration Rate.

4.4.1 The general equation for cumulative infiltration can be written as:

$$I_{cum} = a\,t^{\,n}$$

where I_{cum} = cumulative infiltration (cm.)

t = time of infiltration (minutes)

a, n = constants depending upon soil type and the moisture contents of the soil.

The "n" constant is positive but less than unity. In very sandy soil the "n" value usually remains above 0.9 throughout the test. In moist soil "a" values are lower than in dry soil and "n" values vary conversely.

4.4.2 For the study area an infiltration test was performed near observation well No. 2 and the resultant infiltration rate curve appears as Fig: – 14.

4.4.3 The basic infiltration rate observed was 3.6 cm/hour. The reason for such a high infiltration rate may be the soil having a strongly developed crack system in the upper layers.

4.5 Hydraulic Conductivity.

4.5.1 The term hydraulic conductivity is the proportionality factor "K" in Darcy's law for the flow of water in the soil.

$$V = -K\,i$$

Where v = flow velocity

K = hydraulic conductivity

i = $\frac{dy}{dx}$ = hydraulic potential gradient (dimensionless)

4.5.2 The factor "K" usually stands for the hydraulic conductivity of a saturated soil. The hydraulic conductivity of a soil represents its average water transmitting properties, which depend mainly on the number and the diameter of the pores present.

4.5.3 For the study area, its value was determined by the auger hole method as the water table was close to the ground surface. The mean "K" value determined for 5 representative sites comes to 0.8 m./day. This hydraulic conductivity has been measured for the layer between 1.25m. to 1.75m. and corresponds to the saturated hydraulic conducivity.

4.6 Evapo-transpiration.

Data for average evapo-transpiration was collected from a nearby meteorological station and its distribution over the year is represented in Fig-15. The basic data gives the average figures of evaporation. These were converted into potential evapo-transpiration by using the formula:

E To	=	0.21 + 0.75 Ep
E o	=	Potential evapo-transpiration(mm/day)
Ep	=	Rate of evaporation(mm/day).

The minimum value during the winter period is 1 mm/day and the maximum value is of the order of 5.31 mm/day.

5.0 Drainage Aspects.

5.1 Selection of System and Type.

5.1.1 In this coastal area the irrigated lands are as originally formed and uneven in topography with low soil permeability. The natural drainage is rather inadequate and water-logging a serious problem. During the winter season (rainy season) generally, high water level prevails.

5.1.2 The area is already enclosed with open drainage channels to collect seepage water coming from high overlying lands but these have sufficient capacity to function also as collector drains.

5.1.3 As already mentioned earlier, the rainfall run-off is insignificant and can be safely accomodated by the existing surface drainage channels. Only the ground water seepage discharge is to be catered for, in the lands enclosed by these main drains. After considering all the pros and cons of the case a combination of surface and pipe drains system was selected and adopted.

5.2 Drainage Criteria.

5.2.1 In order to determine the drainage coefficient the water balance of the root zone for different critical periods was established. Keeping in view the drainage investigations conducted at site, there is a need to formulate the water balance for two season: the winter season (rainfall period) and the irrigation season (dry period).

5.2.2 In the project area, the distribution of winter rainfall is such that during this period crops can be grown without any additional application of water. This season extends from October to the end of March. Starting from the first week of April the application of irrigation water becomes necessary and continues till end of September.

5.3 Water Balance for Winter Period

5.3.1 During winter, when there is no irrigation, the ground water is recharged by rainfall and possible seepage from the adjacent slopes.The maximum monthly rainfall occuring in the period of the last 27 years is 163.6 mm. As per hydrogeological investigations 70% of this water percolates below the root zone. The seepage rate from the adjacent high lands can be estimated as 2mm. per day. The minimum rate of evapo-transpiration comes out as 1 mm/day from figure 15. so the water balance equation for the root zone in the project area can be written as follows:

$$Dr = P + S - E \pm \Delta M$$

where
- Dr = Rate of Drainage (mm./month)
- P = Precipitation (mm./month)
- S = Seepage from adjacenet slopes (mm./month)
- E = Evapo-transpiration (mm /month)
- ΔM = Vol. change in the storage of soil (mm./month)

Here we are given:–

- P = 114 mm/month
- S = 60 mm/month
- E = 30 mm/month

5.3.2 For long term equilibrium and soil moisture for most of the time at field capacity

$$\Delta M = 0$$

5.3.3 These values result in a drainage rate of 4.80 mm. per day which has been used for the design of the field laterals.

5.4 Water Balance for Irrigation Season.

5.4.1 The irrigation water losses percolating through the root zone may also cause a recharge of the ground water. In the study area during the irrigation season, cultivators apply water at the average rate of 10 mm. at each irrigation. The irrigation interval is 3 days., which gives the average daily application of 3.34 mm.

5.4.2 It has been established during the period of study that light showers do not cause deep percolation beyond the root zone, hence the effect of precipitation can be considered negligible on the water balance during the irrigation season.

5.4.3 The average evapo-transpiration rate during this period is 4.5 mm./day.

The water balance equation for this period on an average monthly basis can be written as follows:

5.4.3 The average evapo-transpiration rate during this period is 4.5 mm./day.

The water balance equation for this period on an average monthly basis can be written as follows:

$$Dr = P + S - E \pm \Delta M + I + C$$

Where
- I = Irrigation application (mm./month)
- C = Capillary rise (mm./month)

The rest of the terms are as explained in Section 5.3.1.

5.4.4 The amount of seepage contributing to the ground water table is assumed to be fairly constant during the year at 2mm./day.

5.4.5 For the calcuation of ΔM it is assumed that the soil-moisture content is at field capacity at the beginning and at the end of the period considered, and thus this term can be considered zero irrespective of any change in the water table height.

5.4.6 RIJTEMA (1969) presents a relationship between capillary flow velocity and depth of the water table for all soil types with a suction of 16 bar assumed at the surface. If the water table remains at a constant level as a result of seepage in-flow, which is true in the case of the study area, the capillary rise is considerable. Since the seepage water is saline this capillary rise means a severe increase in the salt content in the root zone, especially in the surface layers were the water evapporates.

5.4.7 The depth of the water table at which the capillary flow velocity reduces to 1 mm/day, is often defined as the critical depth, so for a sandy clay loam when the flow velocity is 0.3 mm/day, the capillary rise for a water table of 100 cm. (for surface without mulch). From some investigations (KOVDA 1961 GÅRDER 1960 WESSELING 1957) the following table has been composed giving the relation between maximum capillary rise and depth of ground water from the surface for different soil types.

5.4.8 **Maximum Capillary Rise as Related to Ground Water Depth.**

Distance to ground water (cm.)	Maximum capillary rise in mm. depth per day			
	Clay loam and clay	Loam	Sandy Loam	Medium Coarse Sand
25	10	high	very high	10
40	4	10	very high	2.5
50	2.5	3	high	1
75	1	1	high	0.5
100	0.5	–	10	0.2
150	0.2	–	1-4	–
200	–	–	0.5-1	–

5.4.9 From the figures in the table, it is clear that if the contribution of capillary water to the root zone is limited to 1 or 2 mm/day, the ground water depth will not be less than 75 to 100 cm. To be on the safe side the contribution of the capillary rise can be considered as 2 mm/day. So if we put the values of all these parameters in the water balance equation, the drainage requirement comes out to be 2.83 mm/day which is less than the drainage requirement of the winter season.

5.4.10 Thus, for the calculation for the field laterals, a drainage coefficient of 5 mm./day can be adopted.

5.5 **Depth of the Water Table.**

5.5.1 The depth of the water table below ground level for the design of subsurface drainage can be determined in the light of the following factors:–

- Soil
- Climate
- Crops
- Cropping intensity
- Water management.

5.5.2 Adequate crop production as well as the continuity is dependent on water table position with respect to crop root zone. It is theoretically 180 cm. or more whereas in practice it is generally between 90-180cm. The water table may even be less than 90 cm. for part of the year and may in fact even be level with the soil surface on rare occasions. Generally keeping in view the site conditions, it may be the best practice not to allow the water table and the capillary rise to occupy more than the lower one-third of the normal root zone of the crop. Although the yield of the crop will be reduced slightly by flooding one third of the root zone, this decrease is not high enough to justify further lowering of the water table with the increased drainage expenses. The following table shows the general variation of water table depth for different crop-groups:

5.5.3

Crop	Water table depth in m. below ground surface	
	fine-textured (permeable) soil	Light-textured soil
Field crops	1.2	1.0
Vegetables	1.1	1.0
Tree crops	1.6	1.2

5.5.4 In general the position of the water table at equilibrium depends on:–

- Rate of rainfall or applied irrigation water.
- Soil hydraulic conductivity.
- Depth and spacing of drains
- The depth to an impermeable layer.

5.5.5 Keeping in view all such considerations and the fact that the study area is reserved for vegetables, a water table depth in the centre of the drains is assumed as 0.75 m. and elsewhere it may be more than this value. The ground water table depth map (Fig. 16) also can be referred to in this regard.

In the project area, during the dry season the shallow water table may lead to excessive capillary rise if continuous downward flow is not maintained. It can only be avoided if the irrigation is done at the proper time. The annual crops grown in the area are only vegetables, so for these a water table depth of 0.75 m can safely be adopted. It is evident that in one way or other, the deep percolation beyond root zone is always there due to cropping of the whole area round the year. To some extent, the expected capillary rise of water table can be considered a favourable factor for subsurface irrigation. No gradual salinzation of root zone was observed in the fields.

5.6 Drain depth.

5.6.1 The drain depth depends on:

5.6.1 – The minimum depth is determined by the required ground water depth e.g. if it is one meter for irrigated periods and 1.5 meter for non irrigated periods the drain depth must be more than 1.5 meters.

5.6.2 – Permeability of the soil profile; drains must be cut into the good permeable layer practicable for maximum effect.

- Relation of drain depth to drain spacing; deeper the dra-in wider the drain, more expensive the drain.

5.6.3 The optimum depth for tne water table cannot be precisely determined with currently available criteria. The generally accepted practice of placing drains 2.5m. deep in arid areas and 1.5 m. deep in humid areas is considered to be a good guide. coarse-textured soils have a smaller capillary rise. Therefore the water table can generally be shallower in coarse-textured soils without causing a problem of soil surface salinization. Specifications used by the U.S. Bureau of Reclamation for arid and semi-arid areas do not allow a water table at a point midway between drains to rise closer to the soil surface than 1.3 m. at any time during the year.

5.6.4 The desired drain depth is that which meets the criteria for water table control at a minimum cost. In practice, the shallowest possible drain depth is the optimum water table depth plus the range over which water table fluctuates and it is generally in the range of 1.5 m. -2.0 m. below ground surface.

5.6.5 The drain depth to be selected may be deeper than the minimum depth obtained above. How much deeper depends upon the cost factors and on specific local conditions. Cost factors include the installation of field drains as well as work needed on collectors mains, pumps and related structures. Deep drains cost more per unit length but can be spaced further apart due to high available working head, increased storage capacity and a resultant lower rate. Therefore the net cost per unit area is likely to be less. The other factors affecting choice of drain depth is the capacity of the available digging machinery and availability of barrier depth. Areas of high and continuous seepage may further add to the drain depth. Keeping in view all these factors and assuming hydraulic head of 0.75 m. alongwith maximum fluctuation in ground water table of 0.30 m a drain depth of 1.5 m. can be safely adopted.

5.7 **Drain Spacing Computations.**

A pipe or tube drainage system is designed for steady flow conditions or non steady flow conditions depending upon the nature of the problem

5.8 **Steady State Drainage Equation.**

5.8.1 Steady state conditions are considered to occur, when over a sufficiently long period of time, the water table does not change position. The general equation for drain design given by HOOGHOUDT (1940) is:

$$q = \frac{8\,K\,d\,h}{S^2} + \frac{4\,K\,h^2}{S^2}$$

where q = Discharge rate per unit surface area (m/day)

h = Hydraulic head(m) or water table elevation above drain level midway between the drains.

K = Hydraulic conductivity (m/day)

S = Drain spacing(m)

d = Thickness of the so-called equivalent layer which depends on the distance D_o from drain depth to impervious base the drain spacing S(m) and wet perimeter(P) of the drain.

5.8.2 The equation is applicable to a single layer. For two layers of different hydraulic conductivity

ERNST (1956 1962) gave the following equations for drain spacing:–

$$h = q\frac{Dv}{Kv} + q\frac{s^2}{8\Sigma(KD)_h} + q\frac{L}{\pi K_r}\ \ln\frac{a\,Dr}{u}$$

where = h = total hydraulic head or water table height above drain level at mid point(m)

- q = discharge rate per unit surface area(m/day)
- s = drain spacing(m)
- Kr = hydraulic conductivity of layer with radial flow (m/day)
- Kv = hydraulic conductivity for vertical flow (m./day)
- Dv = thickness of layer over which vertical flow is considered(m).
- Dr = thickness of layer in which radial flow is considered(m)
- $\Sigma(KD)_h$ = transmissivity of the soil layers through which horizontal flow is considered (M2/day)
- u = wetted perimeter of drain(m)
- a = geometry factor for radial flow depending on flow conditions

5.8.3 The value for Dv, $\Sigma(KD)_h$, Dr, a and u are to be determined in accordance with the soil profile and the relative position and size of drain.

5.9 **Non-steady Drainage Equation.**

5.9.1 GLOVER-DUMM (1954 1960) gave the following equation for the solution of a non-steady flow pattern

$$s = \pi\left[\frac{KDt}{u}\right]^{1/2}\left[\ln 1.16\,\frac{ho}{ht}\right]^{-1/2}$$

where s = spacing of drains(m)

- K = hydraulic conductivity (m/day)
- D = thickness of soil layers through which flow takes place(m)
- t = drainage time(days)
- u = drainable pore space
- ho = initial depth of water table(m)
- ht = final depth of water table after time t(m)

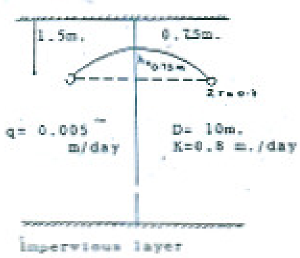
5.9.2 As already mentioned earlier steady state conditions prevail in our area and so Hooghoudt's steady state equation for single layer has been used as we are handling only the shallow aquifer. The equation reads:–

$$q = \frac{8\,K\,d\,h}{s} + \frac{4\,K\,h}{s}$$

$$D/h = \frac{10}{0.75} = 13.33$$

$$\frac{h}{\pi} = \frac{0.75}{\pi.0.1} = 2.38$$

$$K/q = \frac{0.8}{0.005} = 160$$



From Graph (Fig-17)

S/h = 100

S = 100x0.75 = 75 m.

So for the design of field laterals, a spacing of 75 m can be adopted.

5.9.3 If the hydraulic head is kept as 1m. then in the same fashion from the nomogram the calculated spacing comes out as 50 m. Bearing practical considerations in mind a drain spacing 60 m. can safely be adopted for the area.

5.9.4 If the impervious barrier is available at a depth of 4 m. below drain level the spacing works out to be 56 m. which is quite near to the adopted design spacing of 60 m.

6.0 Design of Field Laterals.

6.1 Either smooth clay pipes or corrugated PVC pipes can be used as field laterals taking the length of the field lateral as 200 m.

The hydraulic design of the smooth clay pipes can be done with the Wesseling equation and that of the corrugated PVC pipes with the Manning equation.

$$QL = q \quad SL = 89 \quad d^{2.714} \quad i^{-0.572}$$ (Weseling equation)

$$Al = q \quad SL = 38 \quad d^{2.667} \quad i^{-0.5}$$ (Manning equation)

where Q = Discharge rate (m^3./day)
q = Discharge rate per unit surface area(m./day)
S x L = Drainable area (m^2)
L = Drain length (m)
d = Drain internal diameter (m)
i = Hydraulic gradient = Drain slope

6.1.1 If the maximum specific discharge of 5 mm./day prevails and the drainable area is of 12000 m^2. (S= 60 M. L=200m.) an internal diameter of 8 cm. with a drain slope of 0.1% is sufficient for both clay and PVC pipes (figs: 18 and 19). The reduction factor of 60% has been assumed in calculations for the safety margin depending upon the quality of the installation work,the expected rate of deposition and the proposed intensity of maintenance operations.

6.2 Design of Collector and Main Drain.

6.2.1 The study area is surrounded by a system of open drainage channels and these shall serve the purpose of collector and main drains. The depth of the existing collector drains (> 2m.) is sufficient to allow a safety margin (> 30 cm.) between lateral outlet and water level in the drains.

6.2.2 The present condition of the existing drains is very bad from the technical point of view and they require a large-scale cleaning operation to bring them up to design conditions. This work has to be completed first, before the installation of the subsurface network.

6.2.3 The typical cross-sections of the existing network are shown in figure-20. The existing drains are trapezoidal in section. The bed width varies from 8.65 m. to 2.00 m. and depth ranges from 3 0m. to 2.0m. The side slopes vary from 1: 1¼ to 1 : 1. The net flow area has been reduced due to weed growth.

6.3 Drainage Outlets.

6.3.1 Drainage water can be disposed into the Adriatic Sea through two outfalls, one at the north and the other at the south confluence.

6.3.2 The existing conditions are such that ample working head is available for the free outflow of water. With the construction of outfall improvement works the conditions would also improve.

6.4 Lay out of Pipe Drainage System.

A tentative layout of the field laterals is shown in figure-21. The laterals discharge directly into the existing drainage channels to save the construction of new collectors. In some places the length of the lateral comes to as much as 300 m., but this can-be easily accomodated by selecting a diameter of one step larger in the design of laterals. A 200 m. - wide coastal strip can directly outfall into the Adriatic Sea.

6.5 Design of Gravel Envelope for Laterals.

6.5.1 A properly designed gravel envelope for the laterals should fulfil two requirements:

- It should be more permeable to water than the surrounding soil or base materials and hence allow water to move freely into the drain.
- It should hold or keep the base material from moving into the drain or into the filter.

6.5.2 The U.S. Bureau of Reclamation proposes the criteria given below for the design of a gravel filter-

Uniform material $\dfrac{D_{50}\text{ filter}}{D_{50}\text{ base}}$ = 5 to 10

Graded material $\dfrac{D_{50}\text{ filter}}{D_{50}\text{ base}}$ = 12 to 58

6.5.3 For providing gravel material to the laterals, based upon the above criteria the thickness of envelope to be provided is 8 cm.

7.0 VERTICAL DRAINAGE.

7.1. Selection of Pumping Capacity.

7.1.1 The geophysical study has indicated that deep aquifer and shallow aquifer are separated from each other in some places by thin layers of the semi-impervious type. The thickness of the water column in the shallow aquifer ranges from 10 to 15 meters. So one possibility for vertical drainage is to install water table wells also sometimes known as gravity wells, in a grid system, and to use the water for irrigation purposes as is being done by the cultivators of the land. For the design of such vertical wells, the following data can be assumed:

7.1.2
- Average depth of water column (h_c) = 15 m
- Average water table slope (i_n) = $6^{o}/00$

- Average value of hydraulic conductivity K=lm./day = 1.15 x 10 m/sec.
- Radius of well = 0.6 m.
- Drawdon = 10 m.

7.1.3 Then we can apply the following formula for the uniformly sloping water table:

$$\frac{Q}{Kh_?^2} = \frac{\pi\left[1-\left(\frac{hw}{\ }\right)^2\right]}{2.303 \log\left[\frac{1}{2}\left(\frac{Q}{Khe^2}\right)\left(\frac{he/rw}{\ln}\right)\right]}$$

7.1.4 which gives a small discharge of 2-3 1/sec. This is due to the low permeability of the upper layers. It is an uneconomical discharge. Another solution for vertical drainage is to install artesian wells in a semi-confined aquifer, considering flow towards the well as steady. In this case the following equation by DEGLEE (1930) is used:

$$\Delta h = \frac{Q}{2\pi KD} K_o \frac{r}{\sqrt{KDc}}$$

where
- Δh = Drawdon (m.)
- Q = Discharge (m^3/sec)
- KD = Transmissiveity constant (m^2/day)
- r = Radius of the well(m.)
- K_o = Modified Bassel function of first kind and zero order.
- c = Hydraulic resistance (days)

7.1.5 Based on the data of deep wells installed in the near vicinity of the area, with a diameter of 290/300 mm. and drawdown of 1.5 m. a similar well can yield a discharge of about 45-50 1/sec. This value of discharge can be considered economical from the point of view of vertical pumpage.

Four wells of such a type may be required for the area. Their pumping schedule may be such that these wells are run only during the winter period. To get some idea about the performance of such wells and for verification of the aquifer characteristics, it would be advisable to first install one well and check its performance carefully.

7.2 Pump Cost

7.2.1 The pump cost may be calculated by keeping in view the following cost factors:

- Costs for selection of site
- Cost of drilling
- Cost of strainer blind pipe etc.
- Cost of complete pumping set with electric motor
- Cost of starting the well.
- Cost of shrouding material.
- Cost of pump-house including delivery tanks.
- Cost of developing the well.

7.2.2 Drilling costs in the area are about 50,000 Italian Lire per metre. The cost of blind pipe is 40,000 Lire/m. and an additional 50% can be added for the strainer.

7.2.3 The cost of the pumping set is about 1,5000,000 Lire. Taking all these costs into consider tion vertical drainage may cost about 300,000 Lire per Hectare.

7.3 **Technical and Social Aspects of Both Solutions.**

7.3.1 Both horizontal and vertical drinage solutions seem to be feasible, but the former solution has relatively more merits, due to very low energy costs involved in the operation of the system. The shallow pumpage for drainage purposes has limited success as compared with deep pumpage with nominal drawdown. For vertical drainage, good skilled labour, together with a co-operative society of the cultivators is a must for its operation and maintenance. But in the project area no such co-operative society exists.

7.3.2 For horizontal drainage, the only problem which may arise during the execution of works is the further sub division of small plots to which the land owners may object.

7.3.3 The cost of the horizontal drainage is about 700,000 Lire/Ha. against the vertical drainage cost of about 300,000 Lire/Ha.

7.3.4 It is known that financial and technical assistance is available from the State. Labour is also available in abundance at a reasonable wage rate. The lands are usually highly fertile; Good roads, power and service industries abound. So this considerable expenditure is justified to enable the land to produce at its optimum capacity. The whole of the drainage project can be carried out as a development project and the farmers involved would have to pay the operation and maintenance charges only.

8.0 CONCLUSIONS

8.1 The following conclusions are drawn:–

1. From the hydrogeological study it is clear that the study area lies in a karstic zone in the presence of post cretaceous rocks wherein. a deep aquifer is present.
2. The impervious barrier lies at a depth of 13 to 15 m. below the ground surface in almost the whole area.
3. From a practical point of view the shallow aquifer is unconfined but the deep aquifer is of a semi-confined type.
4. The ground water table mainly varies between 0.30m. and 1.0 m. below the surface of the land. Its height ranges from 1 m. to 5m. above mean sea level.
5. The rise and fall of the ground water table has no connection with the fluctuation of the sea level.
6. The highest ground water table is found in the rainy season (October-March). In some places it rises to the ground surface.
7. The rise and fall of the ground water table is such that it constitutes steady state flow conditions and the variation in the water table was found to be 15 – 20 cm.
8. The results of the investigations and the preliminary processing of the field data make it possible to gain a more detailed knowledge of the geological structure

flow hydrodynamics and to estimate the hydrogeological para-meters required for the design of the drainagse network.

9. The main direction of ground water flow was found to be from South-West to North-East.

10. The ground water is highly saline and the increasing salt content is a matter of concern for agriculture. The total salt concentration varies from 2-3 g/1.

11. The seepage flow is sufficient to contribute towards consumptive use of crops but the quality of seepage water may put the whole area under threat of complete salinization.

12. The capacity of the existing network of draninage channels is sufficient for the installation of sub surface drainage and these can serve the useful purpose of collectors and main drains.

13. The working head available at the outfall into the sea can be considered as sufficient, provided the necessary sea-wave breakers are maintained at the points of outfall.

14. Maintenance measures were originally not given importance, which made the system of the existing network inefficient.

15. In the project area the high values of salinity show that natural drainage in the area is one of the major limitations for increasing agricultural production.

16. The water table is continuously fed by foreign water coming from high lands but in future this amount of seepage is going to be decreased with the installation of irrigation wells in the upper.

17. The important and critical period of drainage is December to February when the highest intensity of rainfall is experienced.

18. In such an area the steady state equations can be safely applied for the design of a subsurface drainage network.

19. The drainage criteria are related to excess drainage.

20. Based on the geological hydrogeological and soil conditions of the area, as well as the crop water requirements, for the determination of drain spacing, the design depth of field drains was taken as 1.5 m.

8.2 RECOMMENDATIONS

1. Keeping in view the salinity of ground water, it is recommended to grow only highly tolerant crops.

2. A suitable crop rotation in future may also help in keeping soil fertility at a reasonable level.

3. The drainage solution has to be implemented in the following two phases:–

   (i) Clearing of the existing collector drains along with construction of outfall works-Phase- I

   (ii) Construction of a subsurface drainage network Phase-II

4. Collectors No. 5 and 6 require deepening of bed by at least 0.5 m. for good outfall of the field drains.

5. Measures may be taken to introduce fresh water in the project area from outside. If this seems impossible, then water for the irrigation season could be transported from the zone enclosed between the river Camaggi and the right bank of the general collector. A good water belt is available near tubewell No. 24.

6. An automatic control valve should be installed near the outfall to avoid entry of sea water into the outfall channels during exceptionally high tides.

7. There is need for pumping ; immediately after the heavy rainfalls if a vertical pumpage system is adopted.

8. Observations on water table, salinity and alkalinity of soils and ground water should be checked every two years with the help of an extensive network of control points

9. No fallow areas specially during summer.

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Observation data 3/2/82

Table: 1

Well No.	R.L. of measuring point from G.L. (m)	Bottom depth of well (m)	Depth of water table from G.L. (m)	W.L.	TDS g/l	Temperature	
						Air °C	Water °C
1.	0.84	2.	0.60	0.24	6.00	5	4
2.	0.06	1.5	0.49	0.43	4.2	3	8
3.	1.39	5	1.28	0.11	2.85	4	13
4.	2.10	5	0.94	1.16	2.40	6	15
5.	2.65	5	0.56	2.09	2.60	5.8	13
6.	2.18	5	0.50	1.68	2.40	4.8	14
7.	3.38	6	1.20	2.18	2.50	5	14
8.	2.10	1.0	0.80	1.30	2.80	6	13
9.	2.46	5.5	0.92	1.54	2.50	6	14
10.	2.30	8	0.74	1.56	3	7	15
11.	2.33	4.50	0.78	1.55	3.80	7.8	10
12.	2	5	0.60	1.40	3.2	6	16
13.	4.31	6.00	2.0	2.31	2.50	10	17
14.	3.76	5	1.45	2.31	2.70	10	16
15.	3	2.5	0.47	2.53	3.40	9	15
16.	3.10	2.5	0.72	2.38	3.20	10	16
17.	5.28	3	0.30	4.98	3.0	9.5	15
18.	5.15	4	0.30	4.85	2.70	9	16
19.	4.57	5	0.62	3.95	3.30	9	9
20.	4.01	5.5	0.93	3.08	3.60	10	9
21.	4.00	3	1.66	2.34	2.40	7	13
22.	3.57	2	1.24	2.33	2.40	5	11
23.	4.17	4	1.72	2.45	2.40	4	14
24.	5.10	15	2.70	2.40	2.40	4	14
25.	4.60	5	2.18	2.42	2.40	13	16
26.	4.50	6	2.00	2.50	2.50	5	13
27.	4.97	1.5	0.73	4.24	3.11	8	5
28.	4.90	4	1.30	3.60	1.20	9.7	6
29.	4.80	4	1.26	3.54	2.40	8.5	8.5
30.	6.30	5	2.54	3.76	2.40	9	7

Chemical composition of ground water Table 2

Sample No.	PH	E.C. mmhos/cm at 25°C (TDS g/l)	Cations (meg/l) Na^+	K^+	Ca^{++}	Mg^{++}	Anions $CO3^{--}$	HCO_3^-	SO_4^{--}	Cl^-	SAR
w 10	7.4 (3.0 g/1)	6.00	45.97	2.05	4.80	10.2	0	12.4	5.20	45.4	16.77
w 13	7.5 (2.50 g/l	5.00	33.26	1.03	4.80	9.2	0	8.8	2.60	36.0	12.55

Discharge of collector general at north confluence

Table 3

Date	Discharge (1/see)
26/10/1926	161
19/3/1927	192
10/12/1927	253
28/3/1928	176
1/6/1929	101
20/12/1932	176
2/2/1933	181
19/11/1948	184
23/9/1951	132
1/4/1982	120

Discharge of collector general at south confluence

Table 4

Date	Discharge (1/see)
22/12/1926	544
9/4/ 1927	376
17/10/1927	392
28/3/ 1928	400
4/6/ 1929	401
20/12/1932	571
10/1/ 1933	527
21/3/ 1934	589
18/5/ 1935	536
29/6/ 1936	536
23/6/ 1937	452
23/4/ 1938	562
30/5/ 1939	572
16/3/ 1940	658
6/5/ 1941	586
30/7/ 1942	555
29/12/1945	597
30/1/ 1946	766
2/4/ 1947	729
12/4/ 1948	599
7/2/ 1949	558
13/7/ 1951	455
1/4/ 1982	720

Soil analysis

Table 5

Soil sample	pH	E.C. mmhos/cm	Particle size distribution Silt %	Sand %	Clay %	Texture
4 I	8.1	10.5	20	60	20	Sandy loam
4 II	8.2	4	9	61	30	Sandy clay loam
4 III	8.5	2.6	12	58	30	Sandy clay loam
4 IV	8.2	2.4	14	66	20	Sandy clay loam
16 I	7.5					
16 II	8.4	2.5	12	60	28	Sandy clay loam
16 III	8.3	2.6	10	60	30	Sandy clay loam
19	7.9	2.4	6	88	6	Loamy sand
1	8.1	6.5	12	68	20	Sandy loam
11	8	3.4	1	64	24	Sandy clay loam
2	7.8	2.5	6	88	6	Loamy sand

LOCATION PLAN

SCALE. 1 : 25000

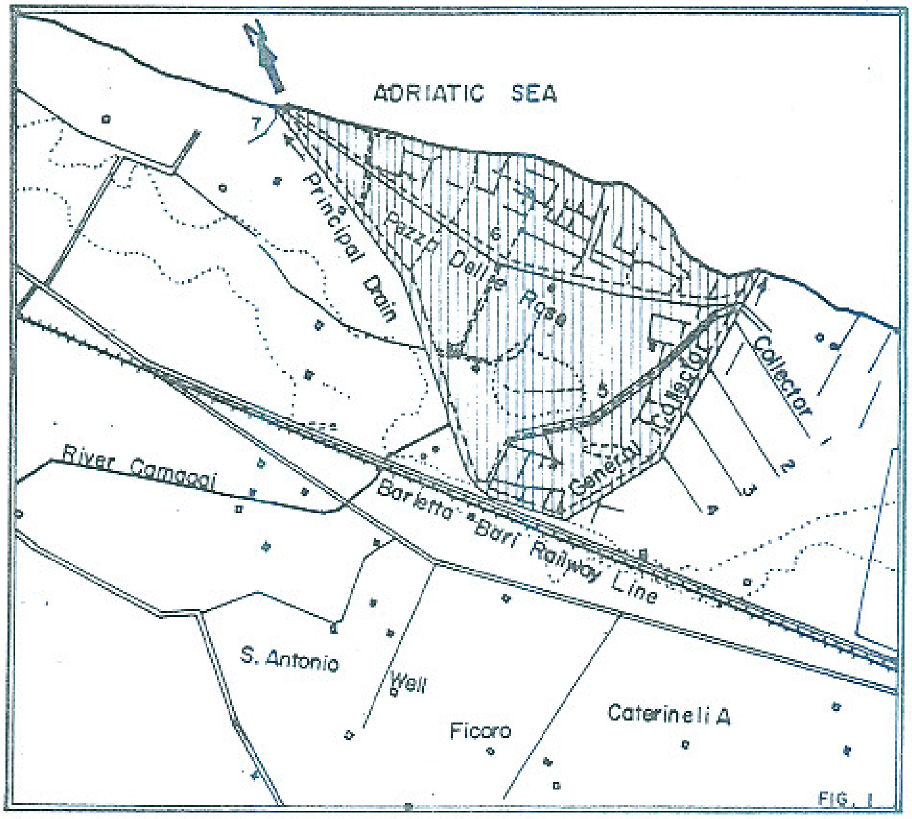


FIG. 1

Study Area Shown thus

S. MANSOOR.

Paper No. 485

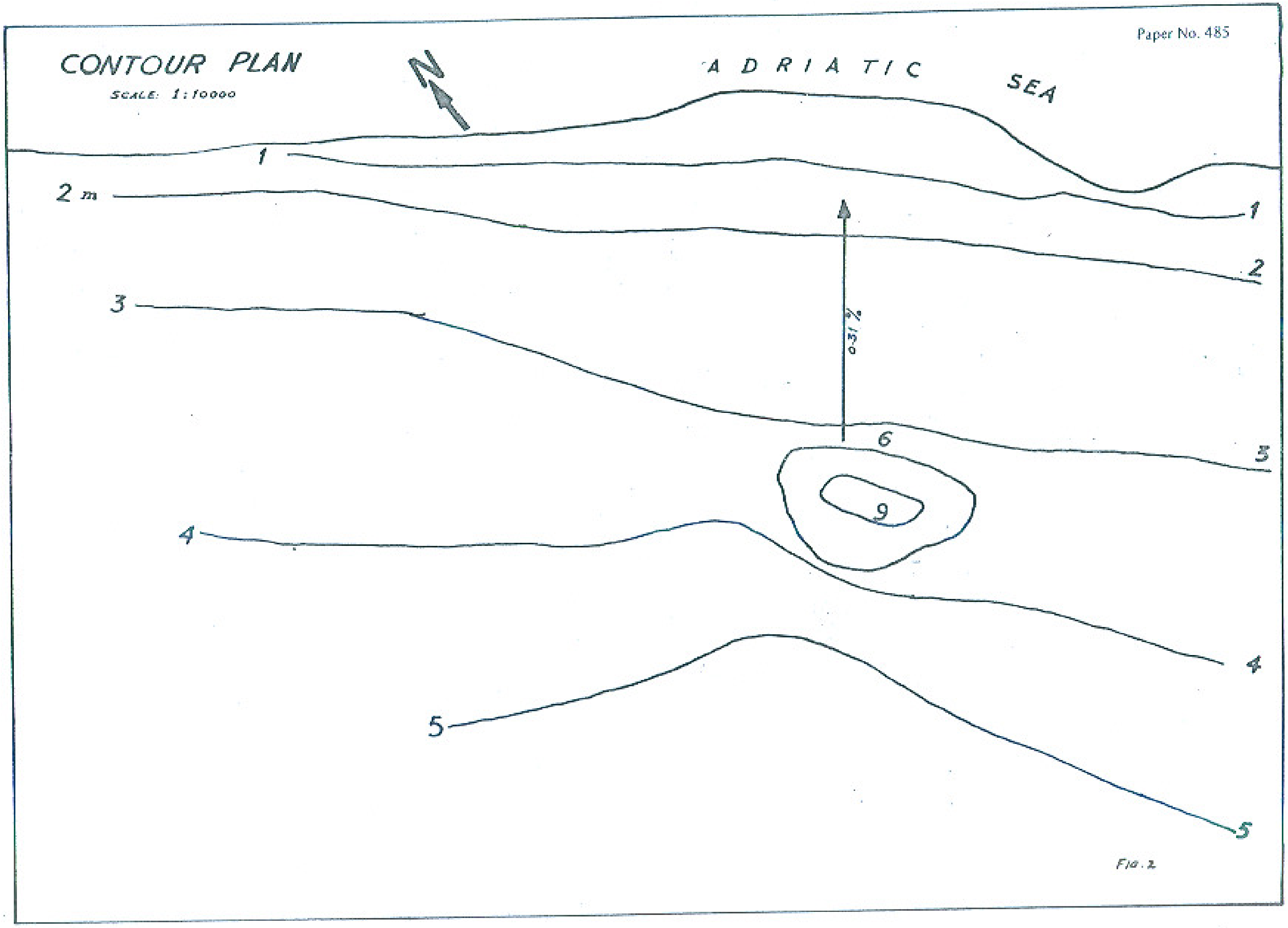
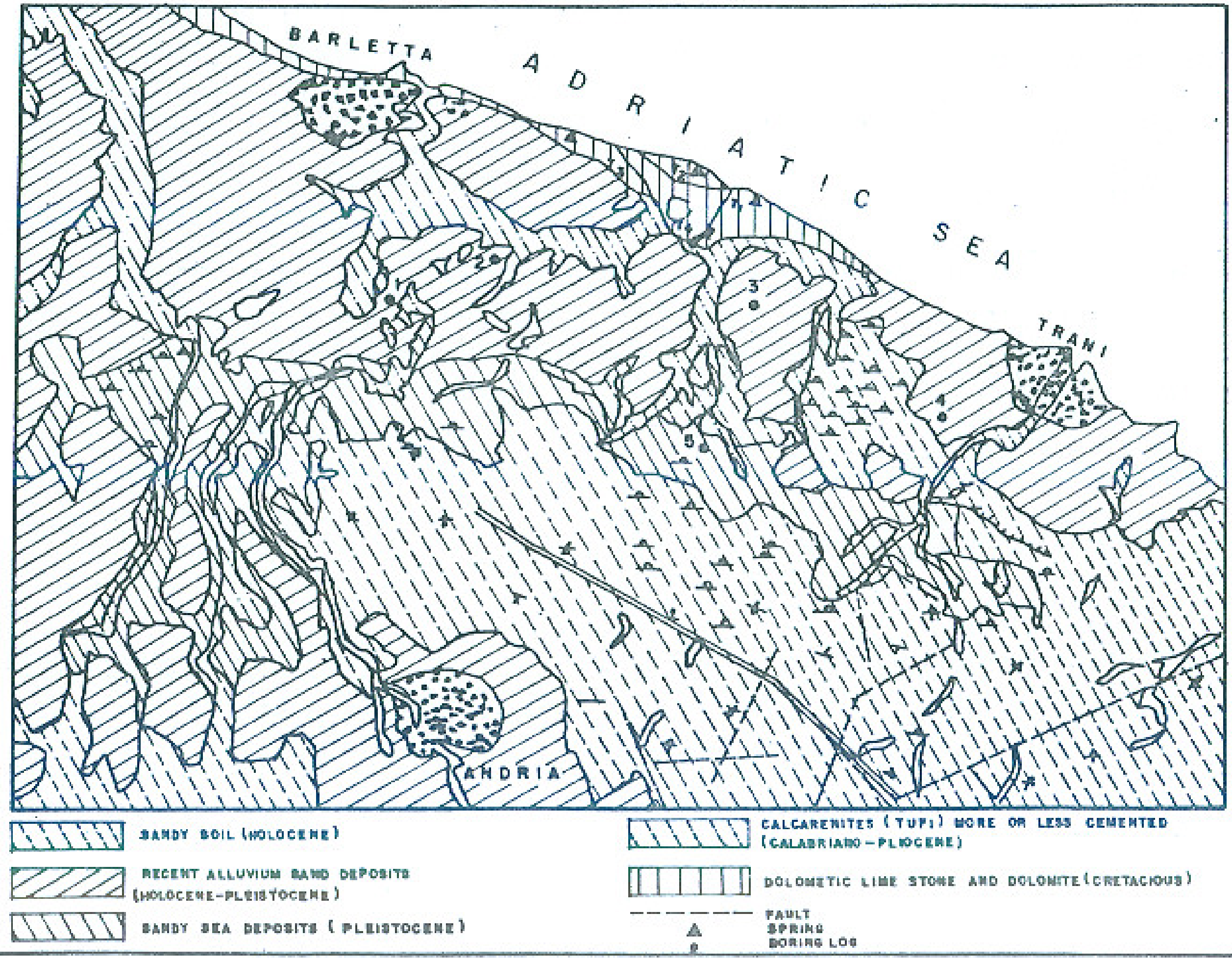


FIG. 2

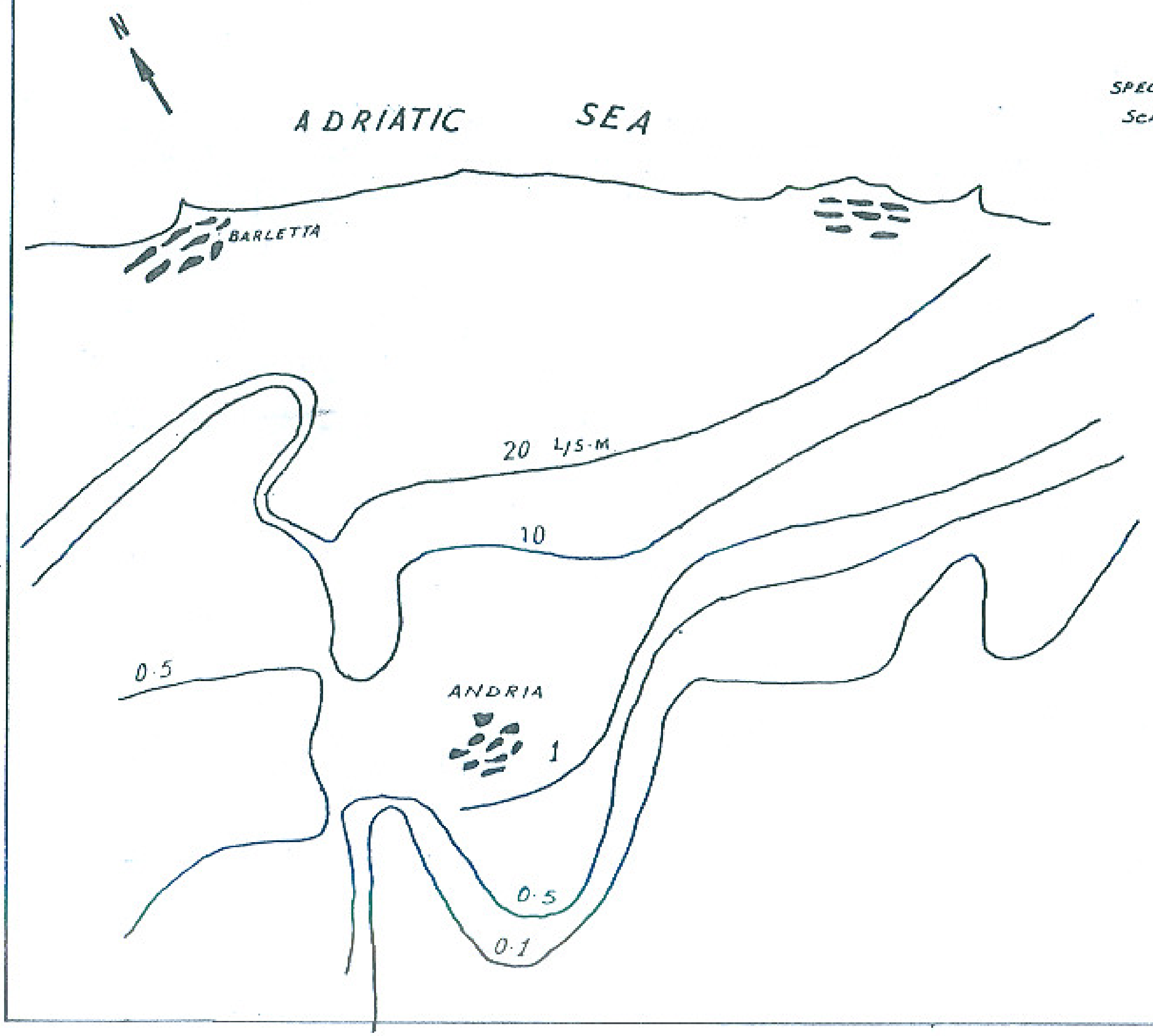
FIG. 3

GEOLOGICAL MAP

SCALE. 1 : 100000



SPECIFIC YIELD MAM
SCALE 1/100000



FIG·4

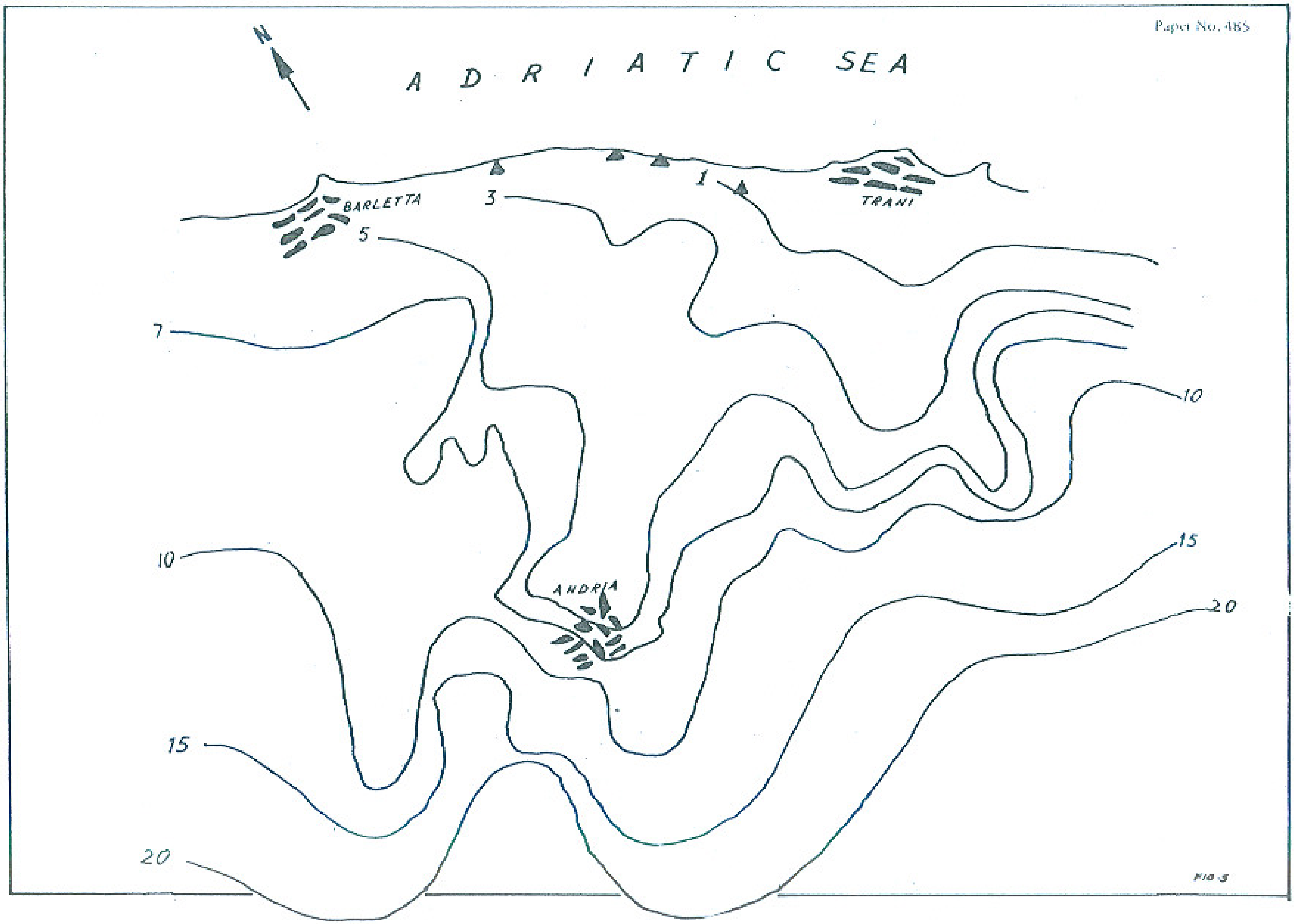


FIG 5

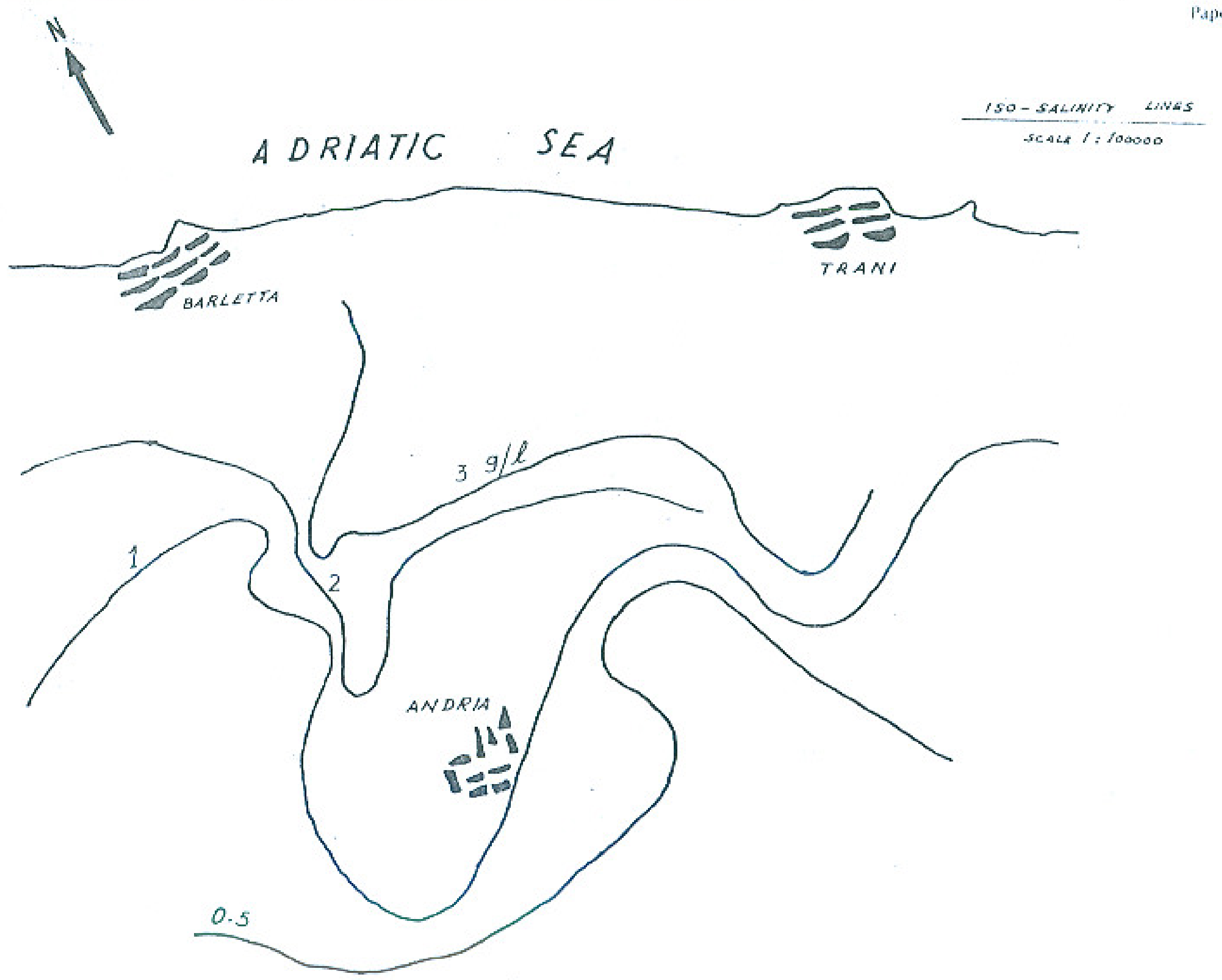
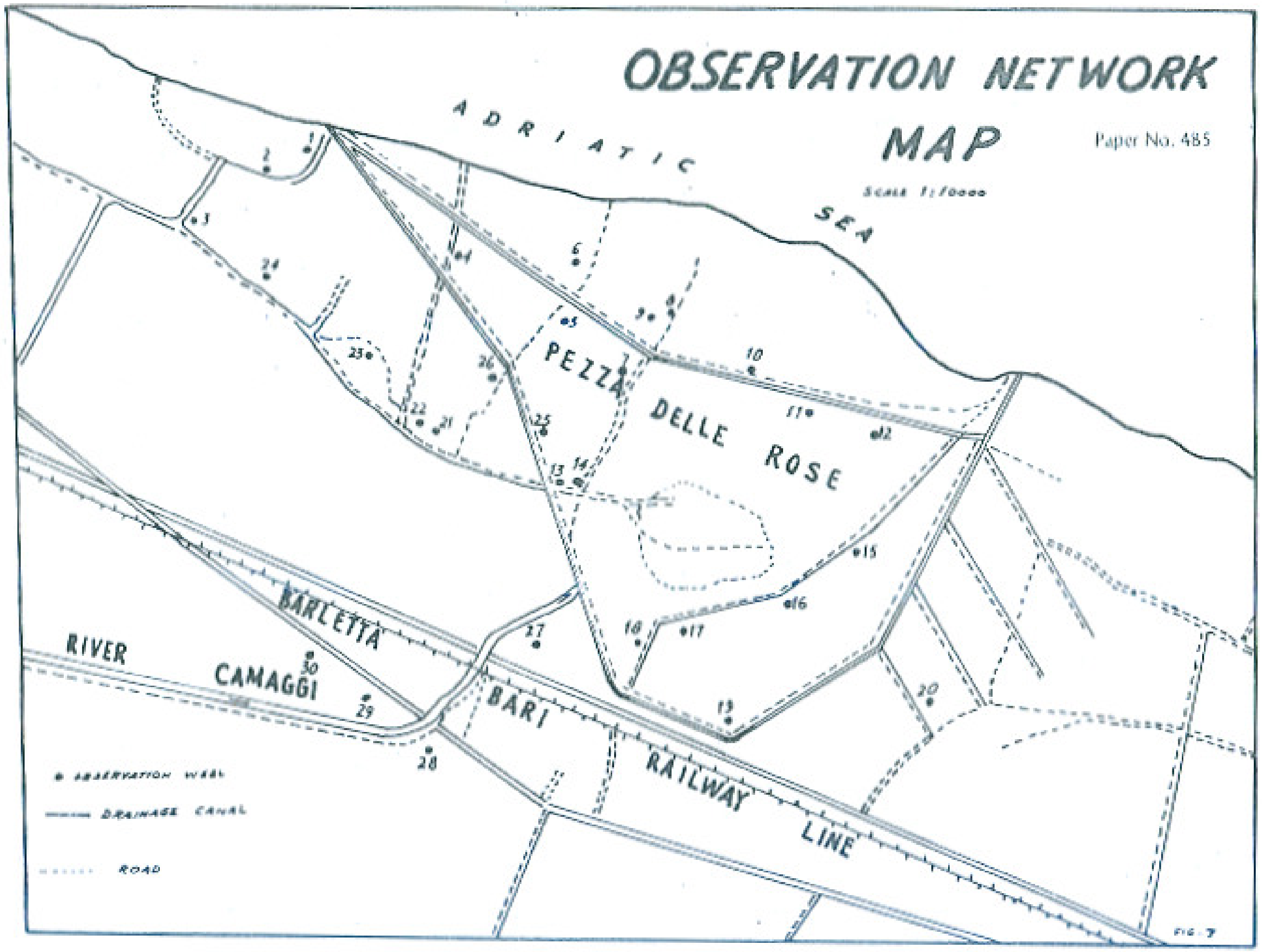
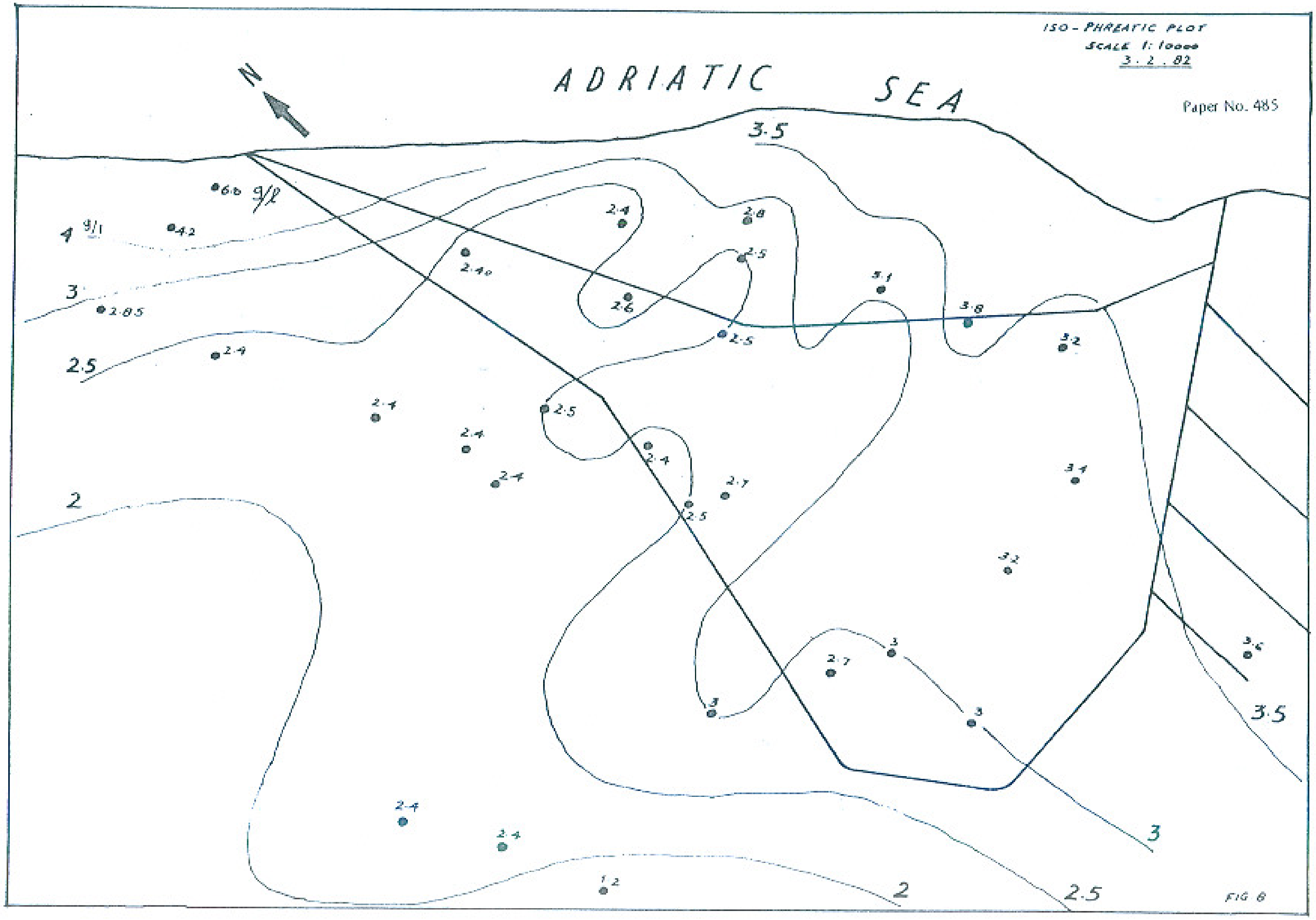

ISO - SALINITY LINES
SCALE 1 : 100000
N
ADRIATIC SEA
BARLETTA
TRANI
ANDRIA
3 g/l
2
1
0.5

FIG. 6


OBSERVATION NETWORK MAP
Paper No. 485
SCALE 1:10000
ADRIATIC SEA
PEZZA DELLE ROSE
RIVER CAMAGGI
BARLETTA BARI RAILWAY LINE
OBSERVATION WELL
DRAINAGE CANAL
ROAD
FIG. 7


ISO - PHREATIC PLOT
SCALE 1: 10000
3 . 2 . 82
Paper No. 485
ADRIATIC SEA
N
FIG 8

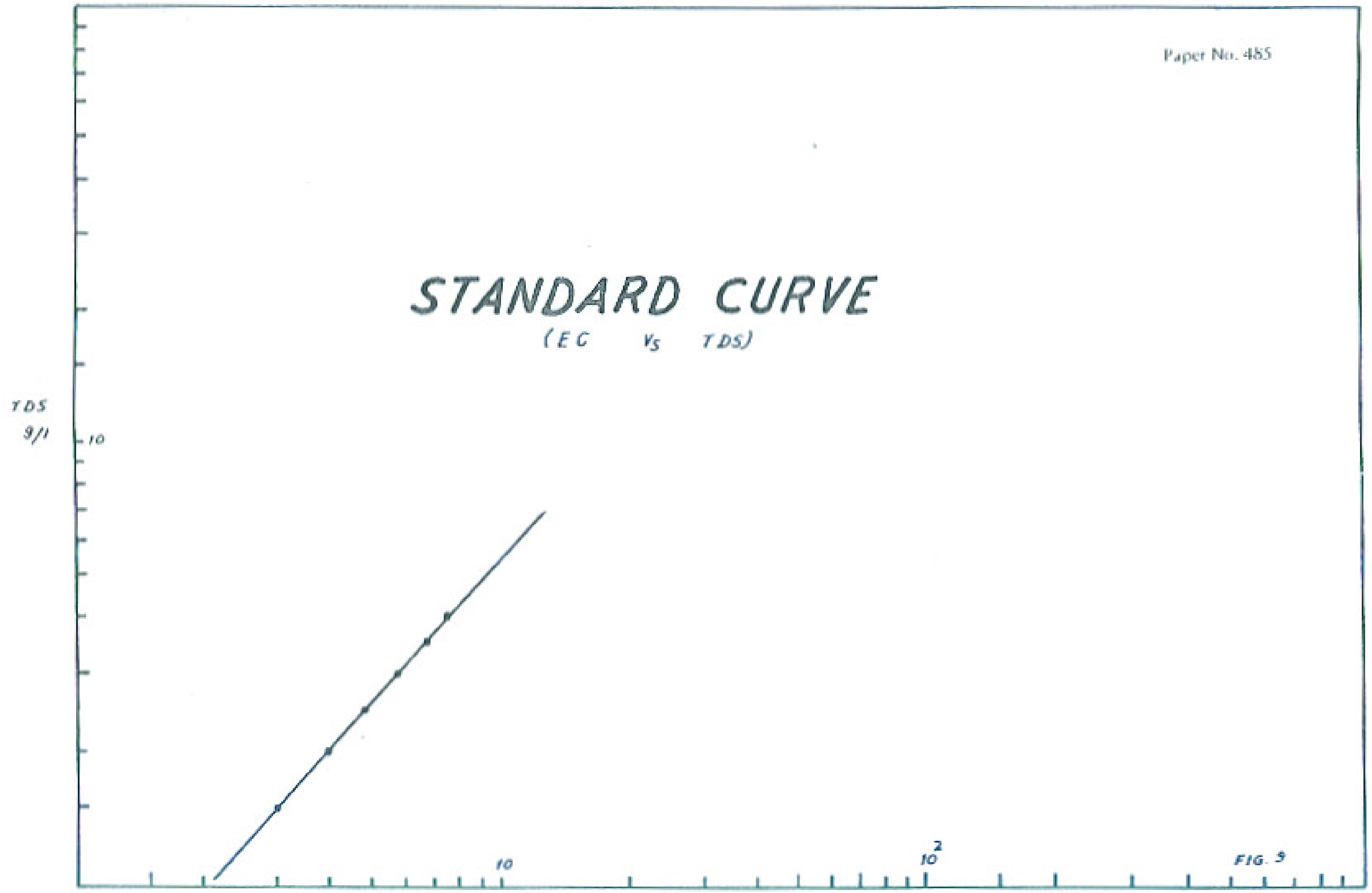


FIG. 9

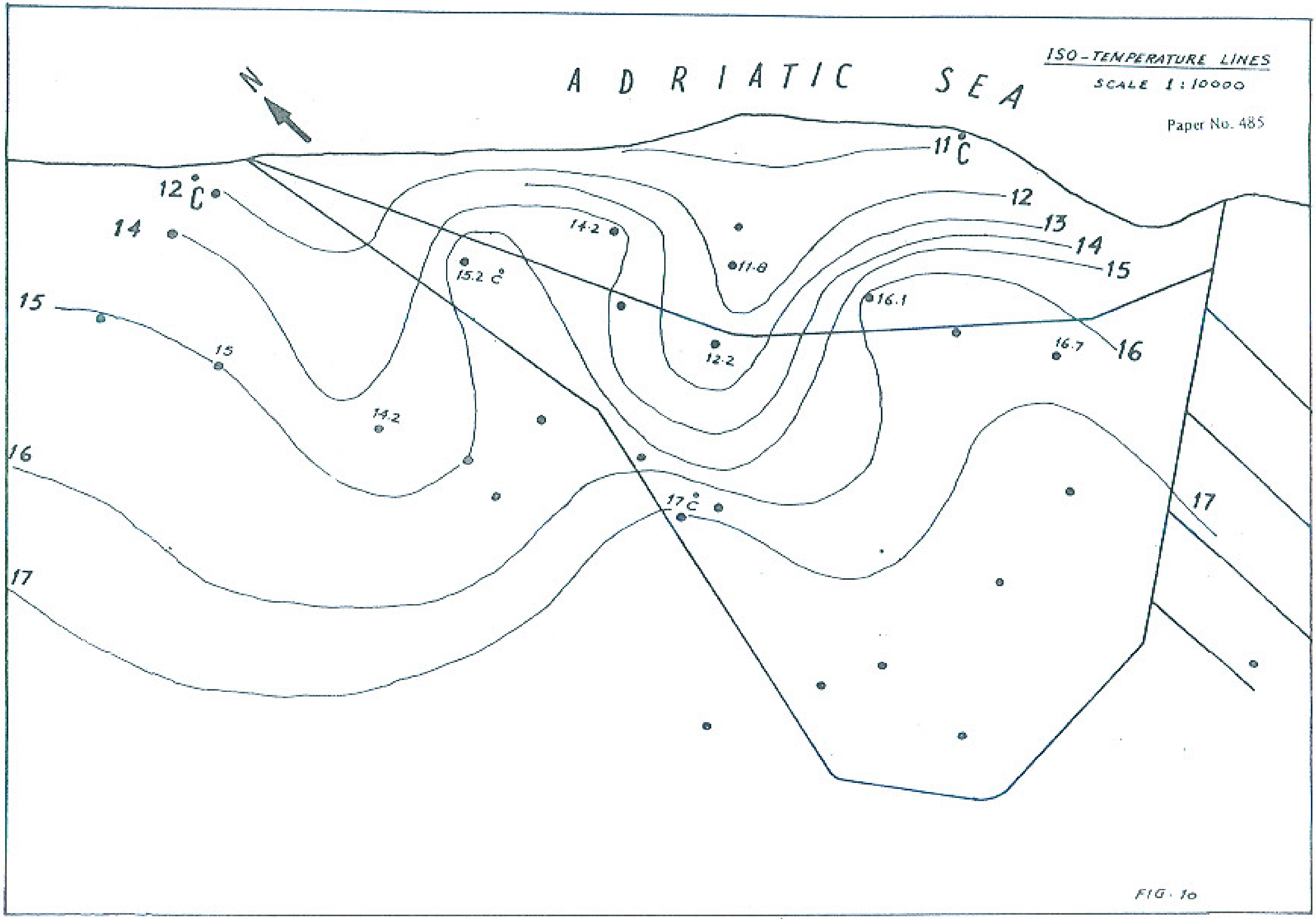

ADRIATIC SEA
ISO-TEMPERATURE LINES
SCALE 1:10000
Paper No. 485
N
11°C
12°C
12
13
14
15
16
17
14.2
11.8
15.2°C
16.1
12.2
16.7
15
17°C

FIG. 10

Paper No. 485

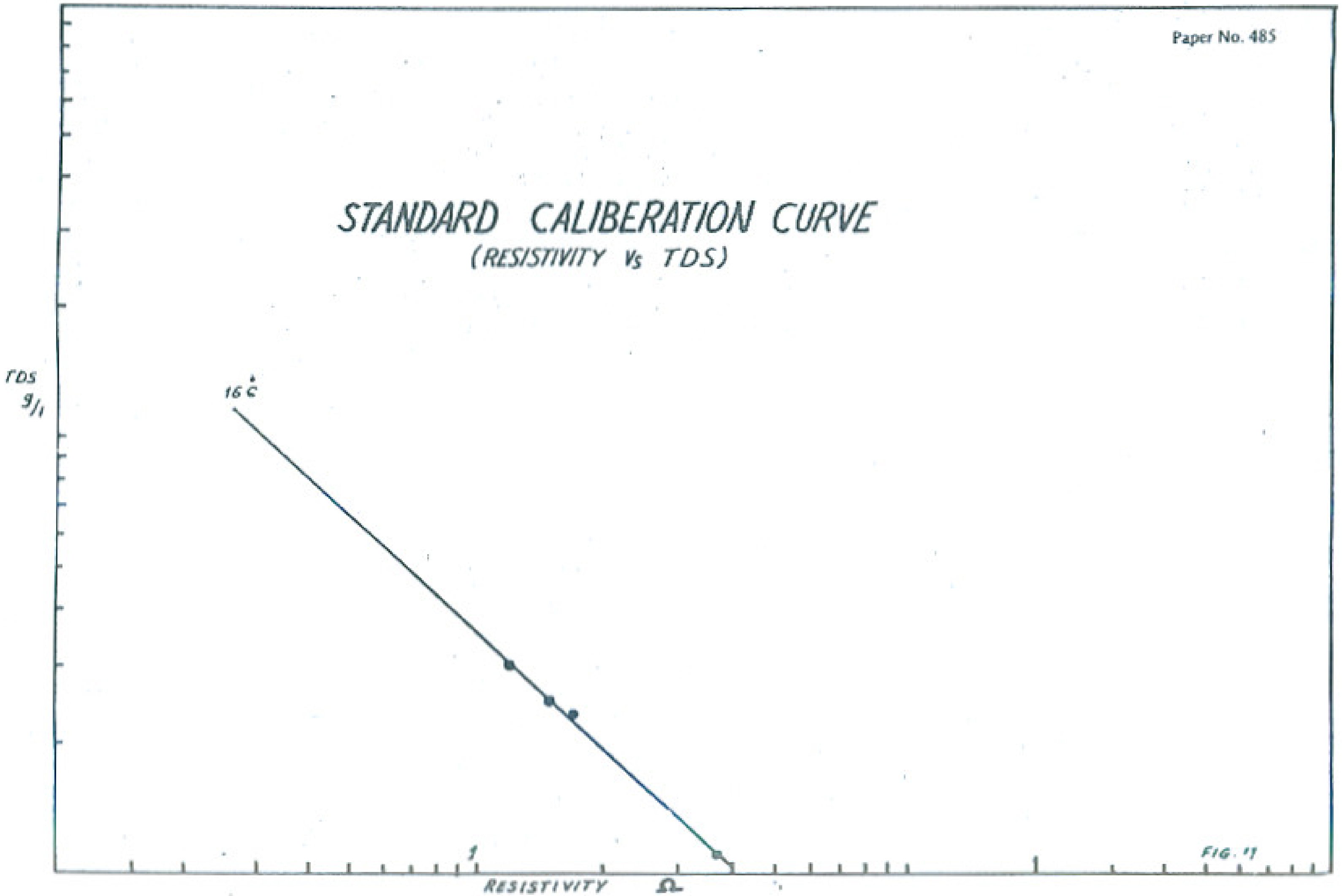
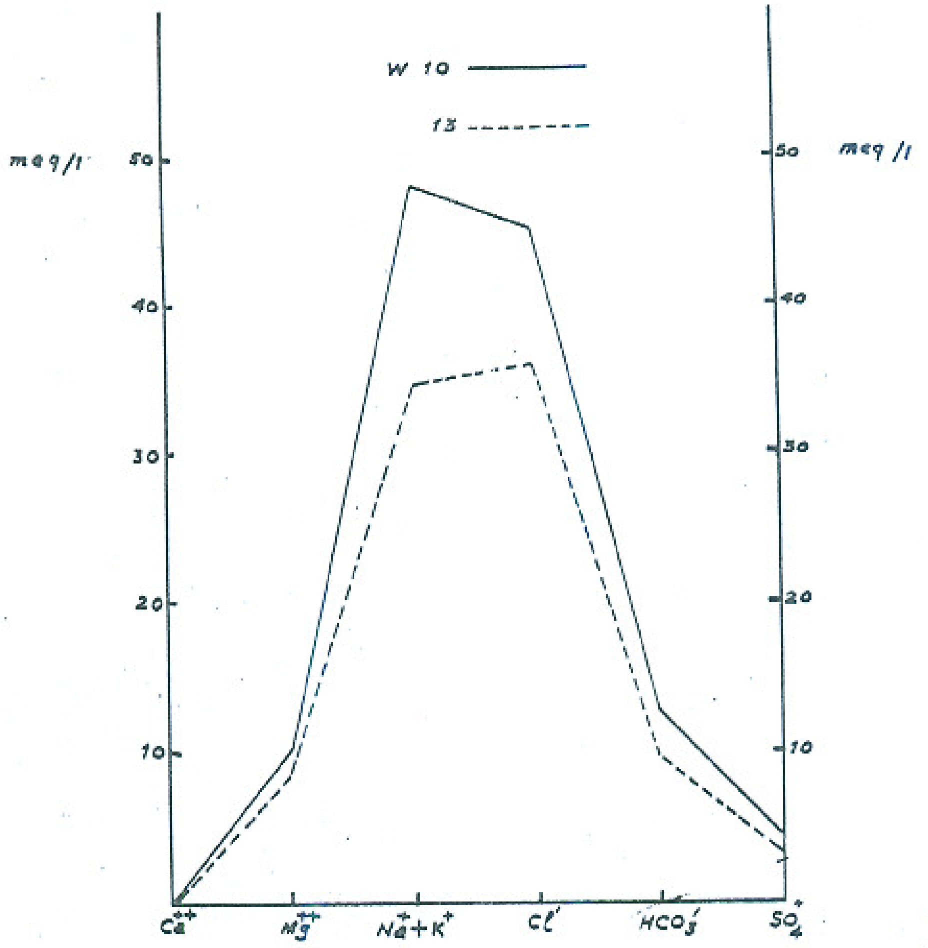


FIG. 11

Paper No. 485



CHOELLER DIAGRAM

FIG. 12

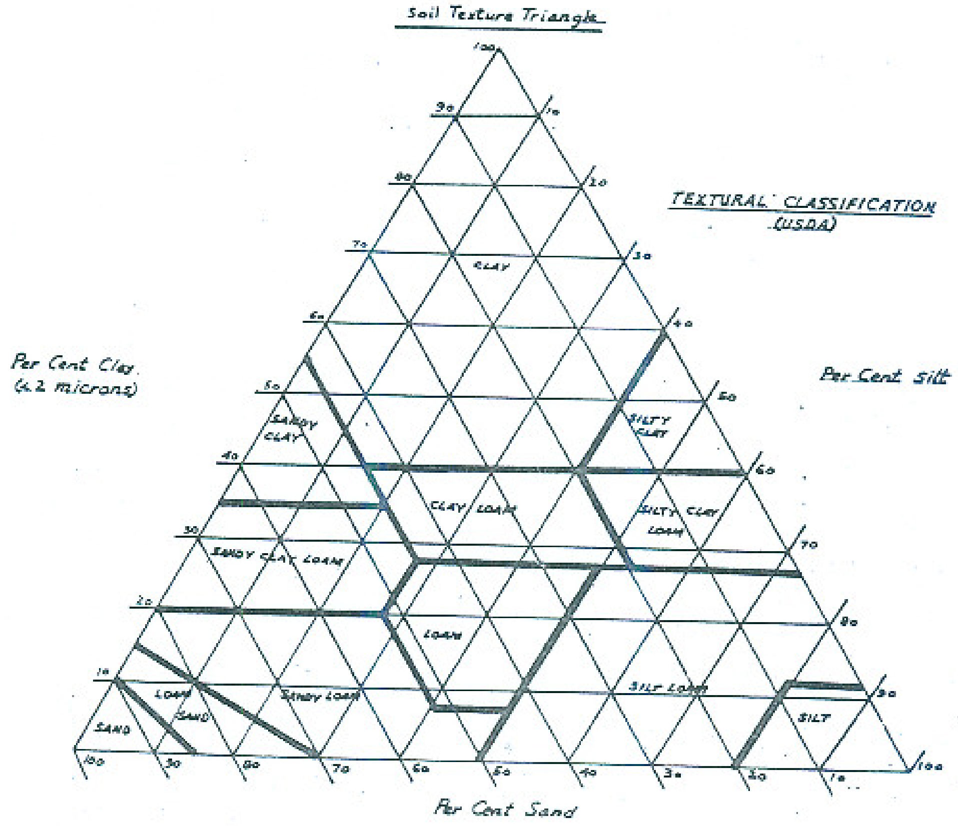

Soil Texture Triangle
TEXTURAL CLASSIFICATION (USDA)
Per Cent Clay (<2 microns)
Per Cent Silt
Per Cent Sand
CLAY
SANDY CLAY
SILTY CLAY
CLAY LOAM
SILTY CLAY LOAM
SANDY CLAY LOAM
LOAM
SANDY LOAM
SILT LOAM
SILT
LOAMY SAND
SAND

Fig-13

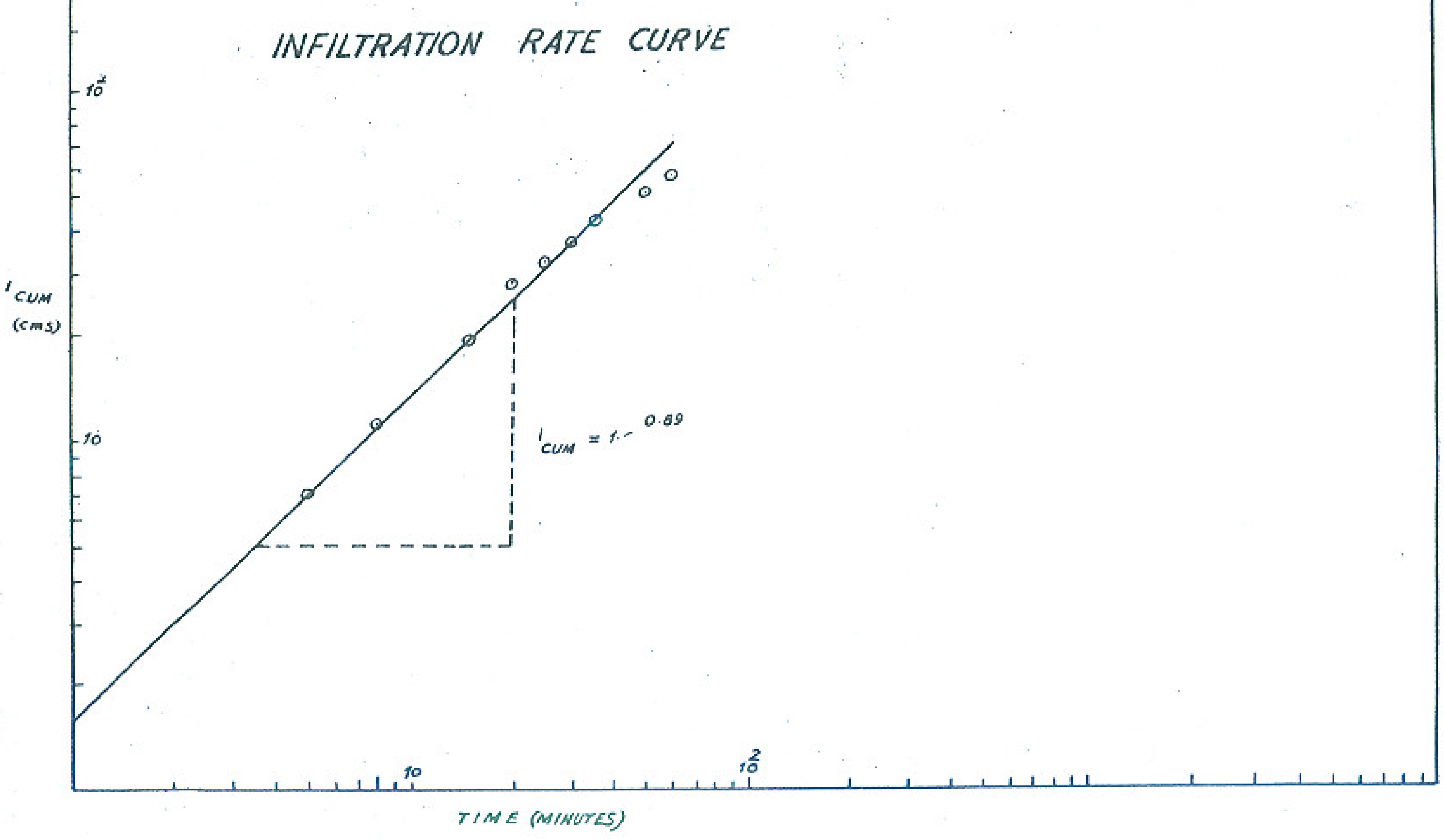

INFILTRATION RATE CURVE
10^2
I_{CUM} (cms)
10
$I_{CUM} = 1.{-}^{0.89}$
10
10^2
TIME (MINUTES)

FIG. 14

MEAN DAILY POTENTIAL EVAPO-TRANSPIRATION CURVE

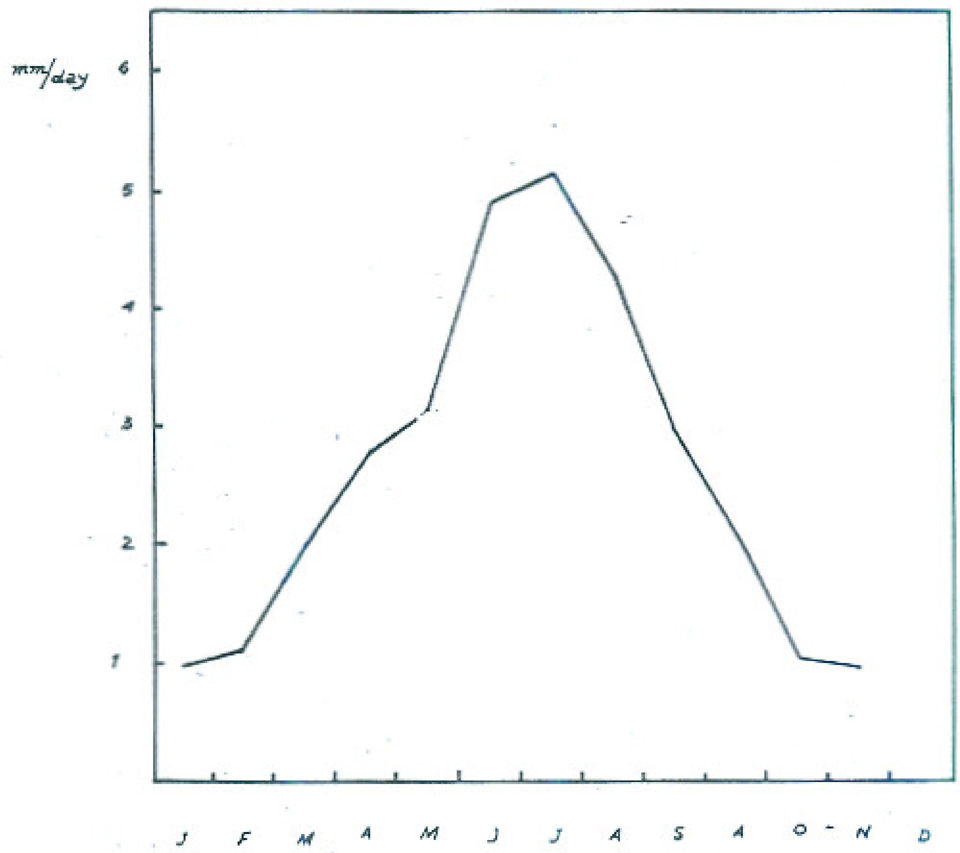
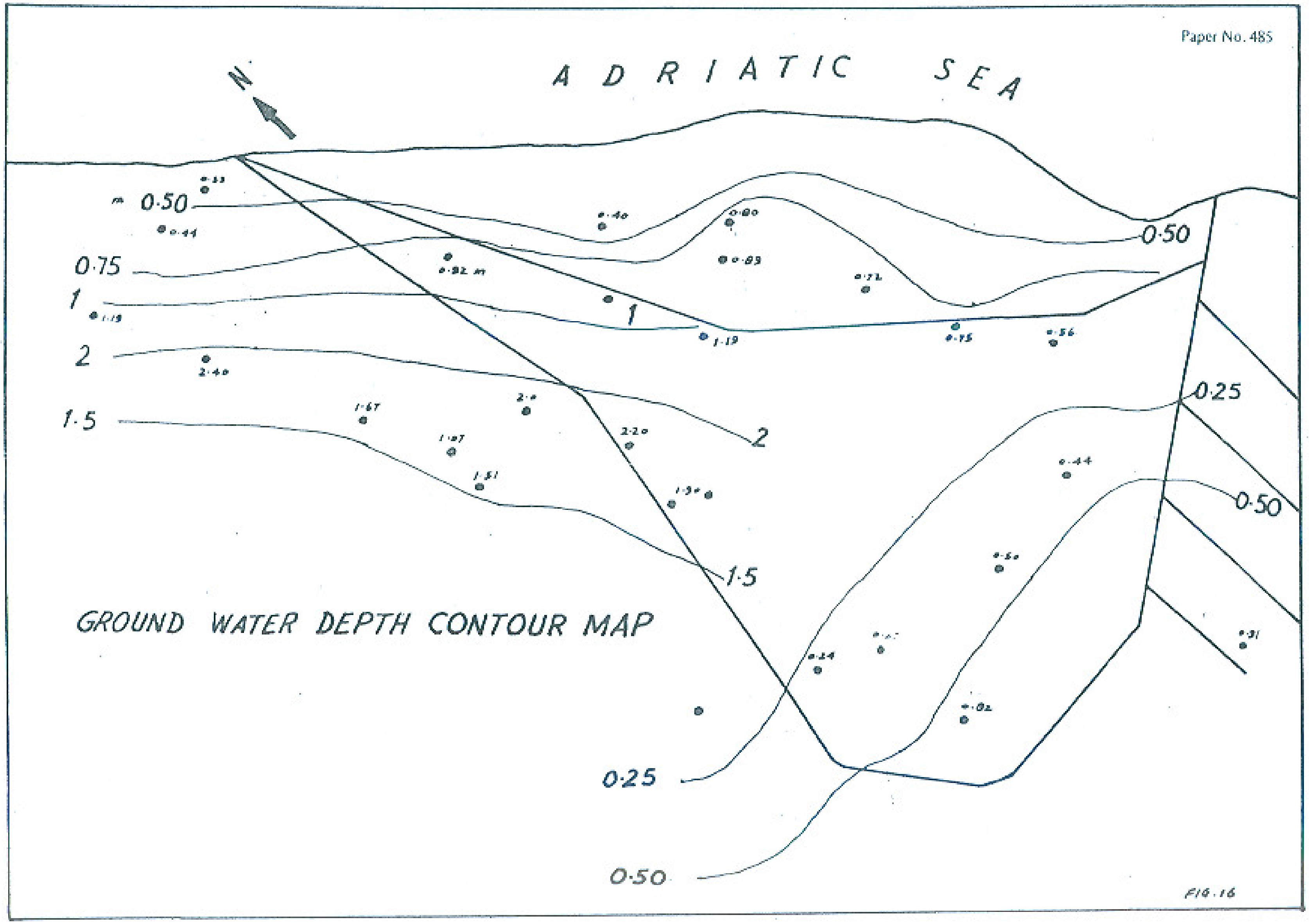


FIG. 15

Paper No. 485



GROUND WATER DEPTH CONTOUR MAP

FIG.16

HOOGHOUT'S NOMOGRAPH

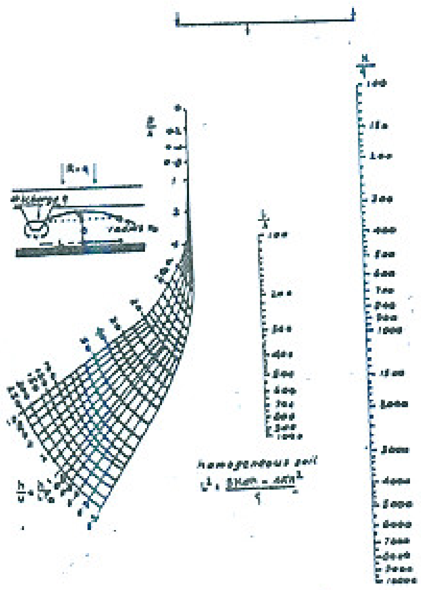


FIG. 17

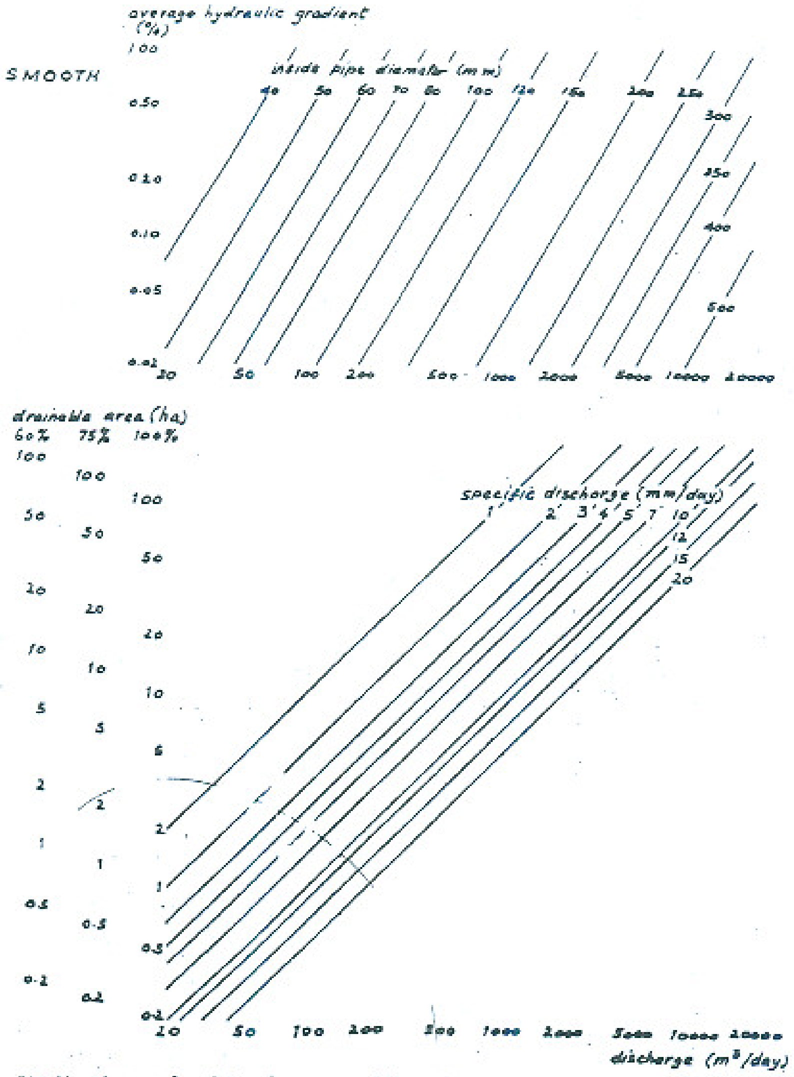


Fig. 11. Diagram for determining capacities of smooth, dewatering, and full-flowing drain pipes, based on Wesseling's equation $Q_L = qA = qBL = 89\ d^{2.714}\ i^{0.572}$

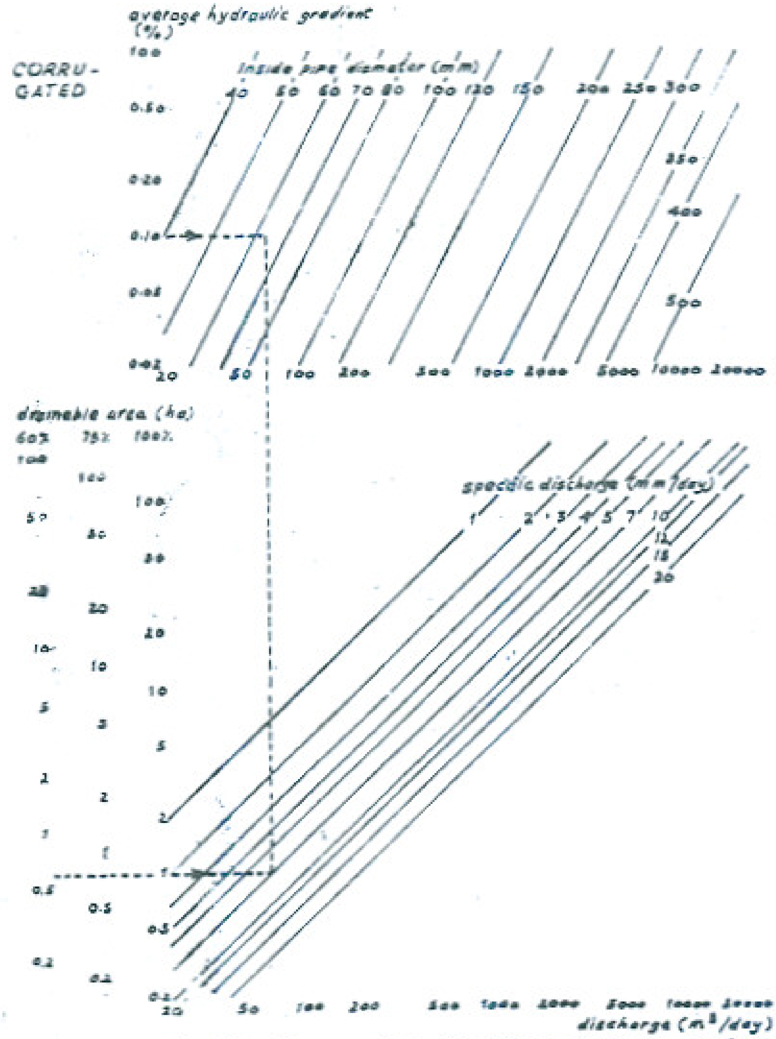


Fig. 12. Diagram for determining capacities of corrugated, dewatering, and full-flowing pipes, based on Manning's equation $Q_L = qA = qBL = 30\ d^{2.667}\ i^{0.5}$

FIG. 13

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TYPICAL X-SECTIONS OF EXISTING DRAINS

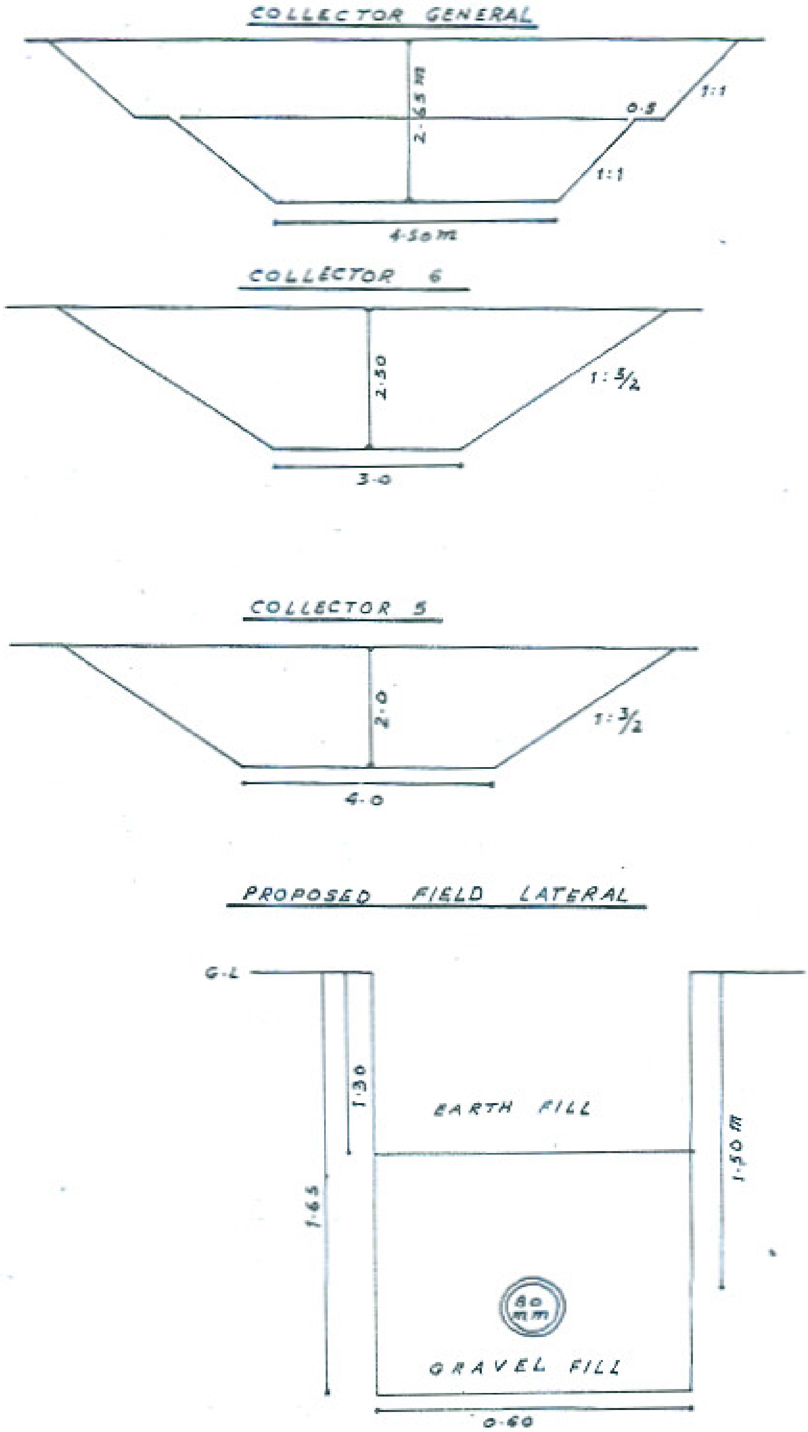

FIG. 20

Paper No. 485

LAYOUT PLAN - PIPE DRAINAGE NETWORK

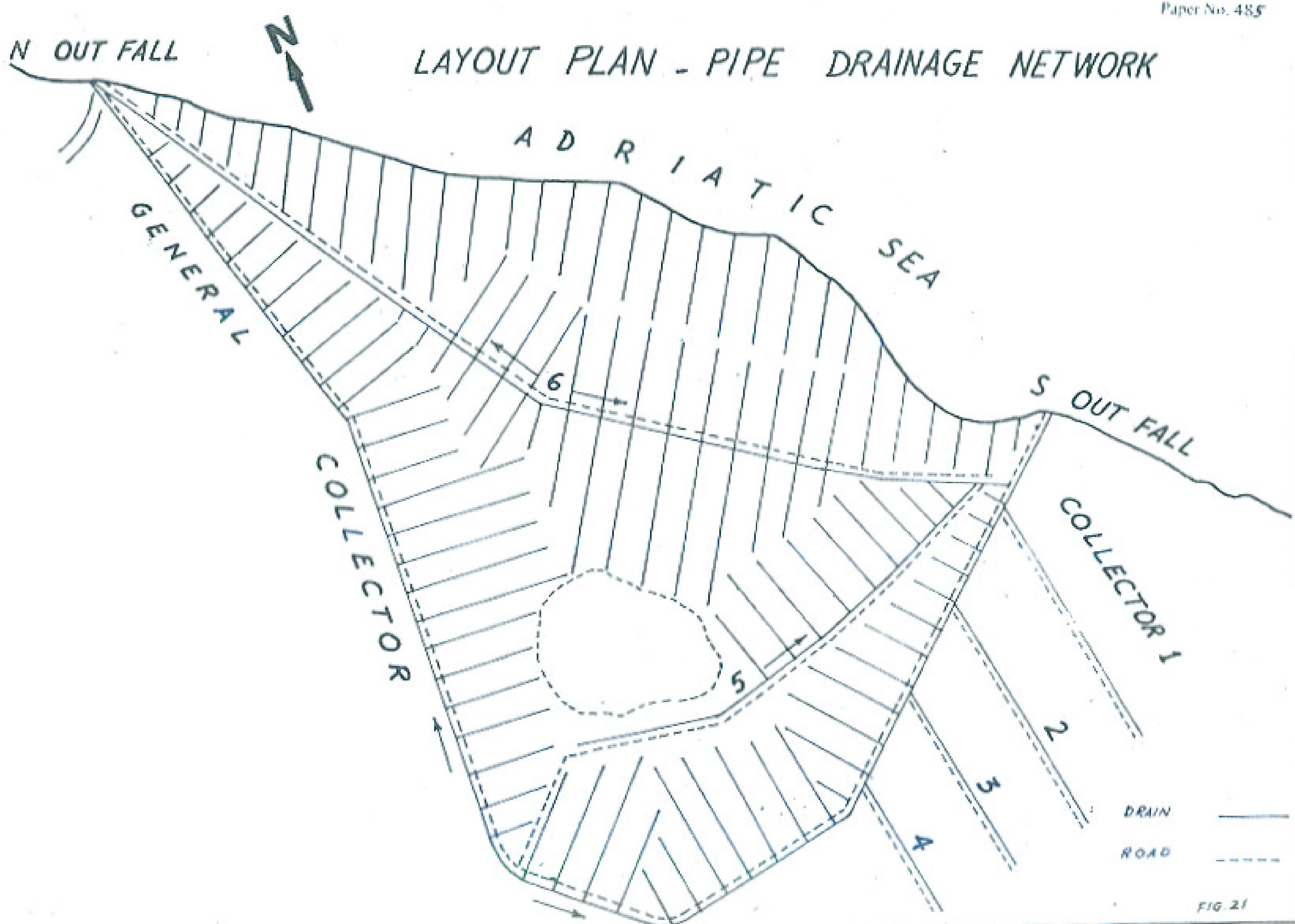

FIG. 21