CS-94

Estimation of Hydrological Soil Properties for Design of Drainage System in Bulandshahr Area

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PREFACE

A prime requirement for successfull irrigated agriculture is the development and maintenance of a soil zone in which the moisture-oxygen-salt balance is favourable for plant growth. When a watertable rises or water gets stagnated in the fields and remains in the root-zone longer than 48 hours, agriculture production gets seriously affected. It gives rise to the need of drainage. A simple but comprehensible definition of drainage is the removal of excess water, From the soil at a rate which will permit normal plant growth. Drainage can be either natural or artificial.

Selection of the optimum drainage plan and the design and construction of adequate and successful drainage facilities depend upon the reliability and adequacy of the basic drainage data. The basic data must provide the knowledge of soil texture, saturated hydraulic conductivity of the soil and topography of the area under consideration.

Topography is of prime importance in drainage. Topography maps show land slopes, length of slopes, location and direction of natural drainage, potential outlets and other special conditions which affect drainage. Texture is important specially in subsurface drainage design because it is a soil characteristic which has a general relationship with hydraulic conductivity and water retention. It is diffficult to measure the saturated hydraulic conductivity of the soil in the fields when water table is present at large depth. If the soil classification of the area is available than the saturated hydraulic conductivity can be determined by the Johnson curves. In this study the field measurement of in situ saturated hydraulic conductivity was carried out by using the Guelph permeameter. The Guelph permeameter is a vary useful and reliable equipment fot the measurement of insitu saturated hydraulic conductivity of the soil both when water table is at shallow depth and at large depth. In this report soil hydrological properties such as texture, organic matter, and saturated hydraulic conductivity have been determined. Analysis of ground water table has also been carried out in this report.

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Director

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Abstract

High irrigation intensities or excess precipitation may cause drainage congestion on the surface of the soil or in the root zone of crops. If the top soil of such area is less permeable than the situation becomes alarmingly worse. Such a situation is found in the Bulandshahr district situated in the western part of Uttar Pradesh. The gross area of Bulandshahar district is 4568 sq.km. It has been reported that the area is suffering from waterlogging problem and drainage congestion. This study deals with the estimation of hydrological soil parameters needed for design of drainage system.

The eastern part of the Bulandshahr was selected as pilot area. The soil samples were collected from different locations and were analysed for textural classification. It was observed that the soil of the area is mostly sandy loam with sand content varying from 25 to 80%, silt content from 25 to 72% and clay content from 5 to 30%. The in situ measurement of saturated hydraulic conductivity was carried out by Guelph Permeameter at different locations. The chemical analysis of the soil of the area showed that the soil is containing carbonate.

The analysis of groundwater table data of the area revealed that in general the watertable of the area was fairly deep and as such there was no problem of waterlogging due to high watertable. Thus, in general from the study it could be ascertained that the Bulandshahr area is suffering from the problem of surface drainage. This is because of the presence of carbonate in the soil which reduces the hydraulic conductivity of the soil and increases surface runoff. The inadequate capacity of existing drainage system in the area is possiblly responsible for water stagnation in the field.

1.0 Introduction

The gross area of Bulandshahar district is 4588 sq.km. comprising of 17 blocks. 4250 sq.km. area falls within the command of Upper Gange canal (UGC) system. About 10% of the area of Sikandrabad block falls outside the command. Full area of rest of the blocks of the district is under UGC command. Groundwater table observations have been recorded on 54 observation wells by ground water department of U.P. district Bulandshahr. Bulandshar has boundary with district Ghaziabad and district Aligarh where as two other boundaries are formed by river Yamuna river Ganga. The UGC almost bisects the district Bulandshahr, the mat branch of UGC also passes through Bulandshahr upto Mathura.

Region has well integrated drainage system of river Ganga, almost all streams follow a NW-SE course concomitant with the regional slope of the land. The slope is extremely gentle and soil erosion is less. The near parallel courses and acute angle junctions of the tributories with master stream at most levels makes the region a pinnet drainage. River Kali and other most of the rivers are perennial with well defined courses. These are entirely the alluvial plain rivers originating from the depressions or lakes in Bhargava tracts (Kumar, S.1991).It has been reported that Bulandshar area is suffering from the waterlogging problem and drainage congestion. This study deals with the estimation of hydrological soil parameters needed for design system. the eastern part of Bulandshar was selected as pilot area (fig 1), the soil samples were collected from this area from 1 locations indicated on fig 1. The cropping pattern for the area indicates that rice, bajra and maize crops are grown in an area of 14, 22, 89 thousand hectares.

2.0 Methodology

2.1 Particle Size Distribution

2.1.1 Soil Texture

Soil texture is a term which refers to the size range of the particles present in the soil mass. The diameter of the particles present in the soil sample makes the soil to be coarse, medium and fine. Table 1 gives the textural class names of material larger than 2 mm in diameter. The traditional method of characterising particle sizes in the soils is to devide the particle sizes into gravel, sand, silt and clay. The soil texture is actually determined by seperating these fractions and measuring their proportion which is called the mechanical analysis. The soil texture triangle is then used to convert quantitative data from detailed gradation analysis of seperates less than 2 mm in diameter to textural class names of soils (tab 1). Soil texture is

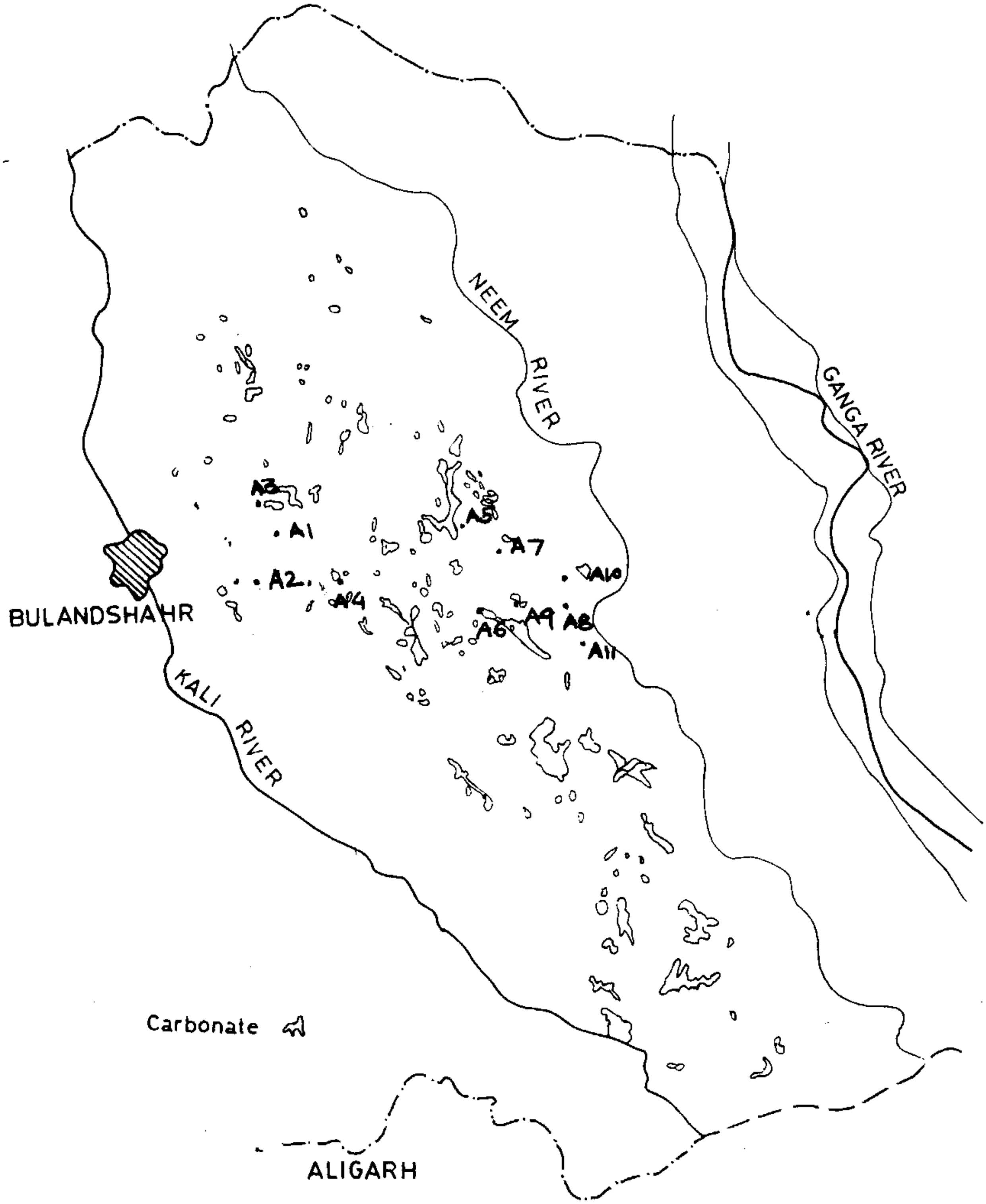


FIG. 1 - PLOT AREA

especially important in subsurface drainage as it has a direct relationship with hydraulic conductivity and water retention(David II, 1982).

Tab 1:

Material	Diameter
Stones	>10 inches
Cobbles	10 - 3 inches
Coarse gravel	3 - 0.5 inches
Fine gravel	0.5 - 2 mm
Very coarse sand	2 - 1 mm
Coarse sand	1 - 0.5 mm
Medium sand	0.5 - 0.25 mm
Fine sand	0.25 - 0.1 mm
Very fine sand	0.1 - 0.05 mm
Silt	0.005 - 0.002 mm
Clay	<0.002 mm

Fig 2 represents typical particle size distribution curves. The y-axis or the ordinate in the graph indicates the percentage of soil particles having the diameter finer than indicated on X-axis. Fig. 3 gives the chart showing the percentages of clay, silt and sand in the basic soil textural classes. The triangle of particle size distribution is shown in fig 3.

2.1.2 Soil Moisture Tension and PF values

The moisture contained in the pore spaces of a soil mass is subjected to the capillary forces. This capillary force causes a negative soil moisture tension which is also called suction. The suction is expressed as the height of water column (h) that will rise from the water table against the force of gravity. This height is inversely proportional to the diameter of the pores. Therefore, $h=0.3/d$, where d = equivalent pore diameter (EPD) of a cylindrical pore with the same capillary. The negative logarithm of soil moisture tension in centimeters of water is used to indicate the soil moisture tension. This negative log of soil moisture is referred to as pF. Tab below shows the characteristic figures of capillary soil moisture.

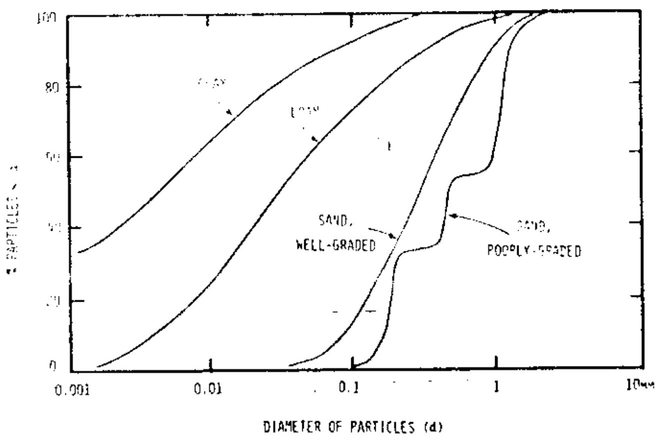
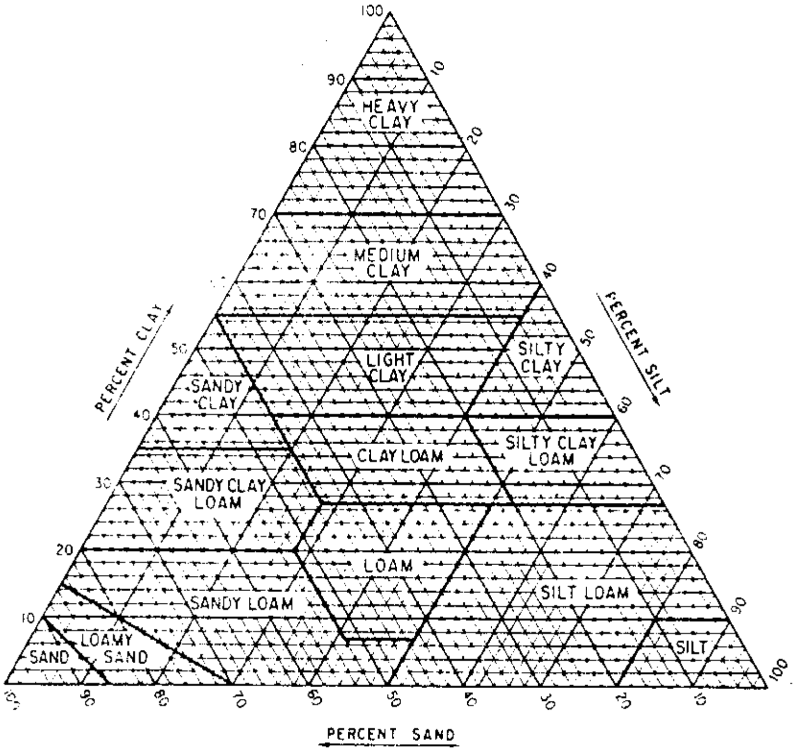


Fig No. 2: Particle size distribution curves for different types of soil



TEXTURAL CLASSES

TEXTURE		SAND %	SILT %	CLAY %
SAND	(S)	85 to 100	0 to 15	0 to 10
LOAMY SAND	(LS)	70 to 90	0 to 20	0 to 15
SANDY LOAM	(SL)	43 to 85	0 to 50	0 to 20
LOAM	(L)	23 to 52	28 to 50	7 to 27
SILT LOAM	(SiL)	0 to 50	50 to 100	0 to 27
SANDY CLAY LOAM	(SCL)	45 to 80	0 to 28	20 to 35
CLAY LOAM	(CL)	20 to 45	15 to 53	27 to 40
SILTY CLAY LOAM	(SiCL)	0 to 20	40 to 73	27 to 40
SANDY CLAY	(SC)	45 to 65	0 to 20	35 to 55
SILT	(Si)	0 to 20	80 to 100	0 to 12
SILTY CLAY	(SiC)	0 to 20	40 to 60	40 to 60
CLAY	(C)	0 to 46	0 to 40	40 to 100

BASIC TEXTURAL CLASS MODIFYING TERMS

SAND Diameter, millimeter	U S Standard sieve numbers	Term		GRAVEL Content, Percent	Term	
0.05 to 0.10	300 to 140	Very fine sand	(VFS)	20 to 50	Gravelly	(Gr)
0.10 to 0.25	140 to 60	Fine sand	(FS)	50 to 90	Very Gravelly	(VGr)
0.25 to 0.50	60 to 35	Medium sand	(S)			
0.50 to 1.00	35 to 18	Coarse sand	(CsS)			
1.00 to 2.00	18 to 10	Very coarse sand	(VCsS)			

Coarse sand 25% or more VCsS and less than 50% of any other grade of sand
Sand 25% or more VCsS, CsS, and S, and less than 50% of F or VFS
Fine sand 50% or more FS and less than 25% of VCsS, CsS, and S and less than 50% of VFS
Very fine sand 50% or more VFS.

Fig No. 3: Soil triangle

Tab 2:

Equivalent pore diameter (m)	SMT (cm)	pF value
3,000	1	0
1,200	2.5	0.4
1,000	3.0	0.34
300	10	1.0
30	100	2.0
20	150	2.20 FC
15	200	2.30
9	340	2.51 ME
3	1,000	3.00
0.3	10,000	4.00
0.2	15,000	4.18 wp
0.03	10^5	5.00
0.003	10^7	7.00 oven dry

2.1.3 Field Capacity

The water present in a saturated soil is allowed to drain out, the water quickly leaves the soil via largest paves and air is pulled into the soil. This movement of water is mainly due to the gravitational potential difference.When the rapidly moving water in the unsaturated soil ceases to move then the soil is said to be at Field capacity. Field capacity occurs when soil retains the maximum amount of water with little or no further loss of water by drainage or loss of gravitational water. A soil water matrix potential of about -1/3 bars has been found to correspond to the field capacity (fig 4).A bar is equal to 10^6 dynes. A dyne is equal to the force that imparts to a mass of 1 gram an acceleration of 1 cm/sec^2. A bar is also equal to 1,020 cm water column or 1,020 gm/cm^2.

2.1.4 Wilting Point

As soil becomes drier, the conductivity rapidly decreases and movement and uptake of water becomes slower. Therefore, if no additional water is added to the soil, the plant will absorb water slower than water is lost by transpiration. Thus a water deficit develops in the plant. This point is called wiling point. A soil water matrix potential of about -15 bars has been found to correspond to wilt point (Fig.4) (Henry, 1984).

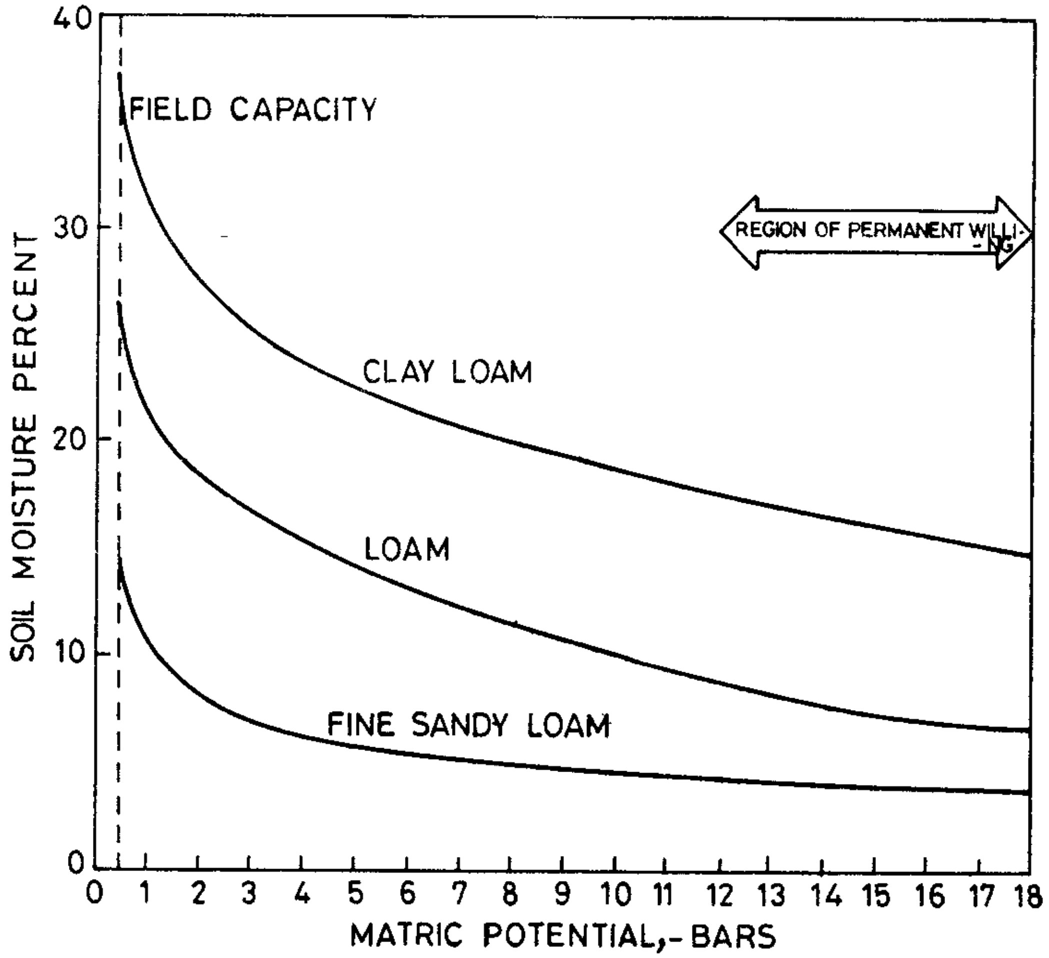


FIG. 4 SOIL MOISTURE CHARACTERISTIC CURVES FOR THREE SOILS. THE WATER BETWEEN THE MATRIC POTENTIAL OF -0·3 AND -15·0 BARS IS GENERALLY CONSIDERED AVAILABLE FOR PLANT USE.

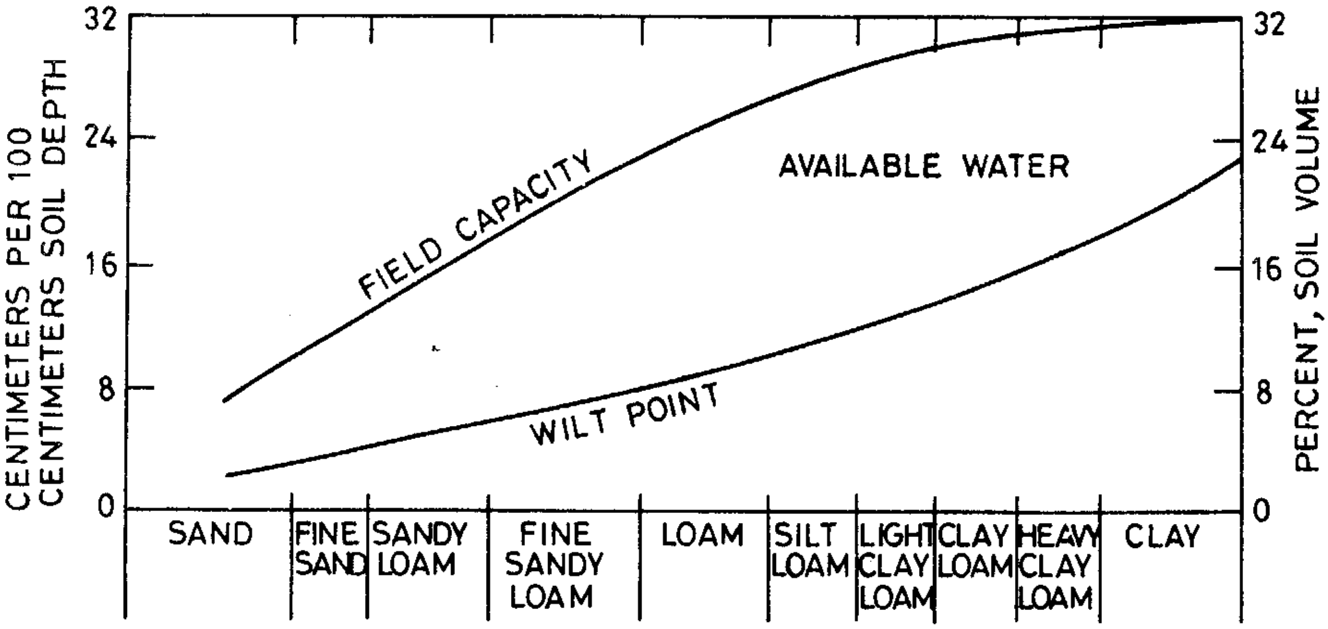


FIG. 5 RELATIONSHIP OF SOIL TEXTURE TO AVAILABLE WATER-HOLDING (BETWEEN FIELD CAPACITY AND WILT POINT) CAPACITY OF SOILS.

2.1.5 Available Water

The water present in the soil between field capacity and wilting point is known as available water. It is generally considered to be matrix potential in the range of -0.3 to -15 bars (fig 4).

2.1.6 Effect of texture on Available water

The capacity of soil to hold water is related to surface area as well as pore space volume. Hence, water holding capacity is related to both structure and texture of the soil. In general fine textured soils have the maximum total water holding capacity, but maximum available water is held in medium-textured soils. As depicted in Fig.5 (Henry, 1984). Several researchers have indicated that available water in many soils is closely correlated with content of silt and very fine sand. It is well known that sandy soils are more droughty than clayey soils, because fine-textured soils are able to retain more available water. Also, there is a difference in the soil of soil-moisture characteristic curves of sand and clay (fig.4). The flatness of the curve for fine sandy loam at water matrix potential is less than -4 bars which means that must of the available water in the sandy soils have a high potential. Therefore, plants can readily use this water in sandy soils. Since in clay or clay loam soils the water is available at lower potential therefore it can be rapidly used by the plants.

2.3 Sieve Analysis

In the Indian Standard (IS: 460-1962), the sieves are designated by the size of apperture in mm, whereas in BS (410-1962) and ASTM (E11-1961) standards, the sieve sizes are given in terms of the number of openings per inch. These are described in the following table 3 (Seth, 1990). The mechanical analysis of soil is performed by sieve analysis and sedimentation analysis. The sieve analysis is basically carried out in two parts i.e. coarse analysis and fine analysis.

The soil sample for which the sieve analysis is to be carried out is first dried in the oven. The dried sample is then sieved through 4.75 mm sieve (Indian Standard). The portion retained on the sieve is known as the gravel portion. The portion which passes through the 4.75 mm sieve is used for finer sieve analysis. The sieves used for fine sieve analysis are: 2mm, 600, 425, 300. 212, 150 and 75 micron is sieves. In order to carry out the sieve analysis the sieves are arranged in one over another in the lowering order of mash openings. The cover is placed on the

TABLE-3 SIEVES DESIGNATION AND THEIR SIZES

IS Sieves IS : 460—1962		*BS Sieves BS : 410—1962*		*ASTM Sieves ASTM E 11—1961*	
Designation	*Aperture (mm)*	*Designation*	*Aperture (mm)*	*Designation*	*Aperture (mm)*
50 mm	50·0	2-in.	50·80	2-in.	50·80
40 mm	40·0	1½-in.	38·10	1½-in.	38·10
20 mm	20·0	3/4-in.	19·05	3/4-in.	19·00
10 mm	10·0	3/8-in.	9·52	3/8-in.	9·51
*5·60 mm	5·60	—	—	3½	5·66
4·75 mm	4·75	3/16-in.	4·76	4	4·76
*4·00 mm	4·00	—	—	5	4·00
*2·80 mm	2·80	6	2·80	7	2·83
2·36 mm	2·36	7	2·40	8	2·38
*2·00 mm	2·00	8	2·00	10	2·00
*1·40 mm	1·40	12	1·40	14	1·41
1·18 mm	1·18	14	2·00	16	1·19
*1·00 mm	1·00	16	1·00	18	1·00
710-micron	0·710	22	0·710	25	0·707
600-micron	0·600	25	0·600	30	0·595
*500-micron	0·500	30	0·500	35	0·500
425-micron	0·425	36	0·420	40	0·420
*355-micron	0·355	44	0·355	45	0·354
300-micron	0·300	52	0·300	50	0·297
250-micron	0·250	60	0·250	60	0·250
212-micron	0·212	72	0·210	70	0·210
*180-micron	0·180	85	0·180	80	0·177
150-micron	0·150	100	0·150	100	0·149
*125-micron	0·125	120	0·125	120	0·125
*90-micron	0·090	170	0·090	170	0·088
75-micron	0·075	200	0·075	200	0·074
*63-micron	0·063	240	0·063	230	0·063
*45-micron	0·045	350	0·045	325	0·044

*Sieves marked with *have been proposed as an International (ISO) Standard. It is recommended to include, if possible, these sieves in all sieve analysis data or reports.

top of assembly and a container is kept at bottom. The entire assembly is shaken by sieve shaker. Shaking of the sample is performed for nearly 10 minutes. The soil sample which is to be analysed and which is passing through 4.75 mm sieve is washed with distilled water. The washing is done to dislodge the silt and clay particles sticking on sand particles. For providing good dispersion of different particles two grams of sodium hexametaphosphate is added per litre of water used. Washing is done till water coming out through 75 micron sieve is perfectly clean. The portion retained on the 75 micron sieve is then dried in oven. The sample is then placed on the top sieve of sieve assembly and sieve is shaked.

At the end the portion retained on each sieve is collected and weighted. The percentage of soil sample retained on each sieve on the basis of total weight of soil sample and the percentage of weight passing through each sieve was calculated (Bowles ,1986). The calculations were started with 100 percent and subtracting the percentage retained on each sieve as a cumulative procedure as given by

Percentage passing = Percentage arriving - percentage retained

A plot on semilogrithmic paper of grain size versus percent finer was plotted and are given in fig 11 for all the samples.

2.4 Wet Mechanical analysis

The soil fraction which is finer than 75 micron size is used for sedimentation analysis. This analysis is based on the stokes law which states that all other factors being constant the velocity at which grains settle out of suspension is dependent upon the weight, shape and size of grains. Assumptions are made for the analysis that the soil particles are spherical and all the particles have some specific gravity. This assumption leads to the fact that coarser particles settle more quickly than finer ones. The terminal velocity of a particle in suspension is given by following formula:

$$v = \frac{D^2}{18} \frac{\gamma_s - \gamma_w}{\eta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, v = Terminal velocity,
r = Radius of spherical particle (cm),
D = Diameter of particle (cm),
γ_s = density (unit wt.) of particles (g/cm^3),

γ_w = density of water/liquid (g/cm^3)

η = viscosity of water/liquid ($g\text{-}sec/cm^2$)

η = μ /g

μ = viscosity in absolute units of dynes-sec/sq.cm,

and g = acceleration due to gravity (cm/sec)

If water is used as a medium for suspension, $\gamma_s = G\,\gamma_w$ = G as γ = 1 g/cu.cm. Therefore from eq. (1)

$$v = \frac{G-1}{1800\eta} D^2 \quad \text{.......(2)}$$

At 20^{o}c viscosity of distilled water is approximately 0.01 poise. For G = 2.68, the equation (2) reduces to

$$v = 91.5\ D^2 \quad \text{.......(3)}$$

Equation (3) is an approximate solution of stokes law and is used for estimation of diameter of soil particles (Seth, 1990).

2.5 Hydrometer Method

In the hydrometer analysis the weight Wd per ml of suspension is found by reading the density of soil suspension at a depth He at various time intervals. This height He goes on increasing as the particles settle with the increase in time interval. Therefore, it is necessary to calibrate the hydrometer and sedimentation jar before the start of the sedimentation test. This calibration will provide the relation between He and the density readings of the hydrometer.

2.5.1 Calibration of Hydrometer

The stem of the hydrometer has horizontal markings which gives the density of the soil suspension situated at the centre of the bulb at any time. For the sake of convenience the hydrometer readings are substrated by one and the remainder is multiplied by one thousand to give a reduced reading indicated as Rh (Fig 6). Hydrometer readings increase in the downward direction towards hydrometer bulb. Refering to fig. 6 when hydrometer is immorsed in the jar water level increases, the level aa rises to a1a1 and bb to b1b1. At this point time b1b1 corresponds to the centre of hydrometer at which density measurements are taken.

$$He = (H + h/2 + Vh/2A) - Vh/A$$
$$He = H + 0.5(h - Vh/A)$$

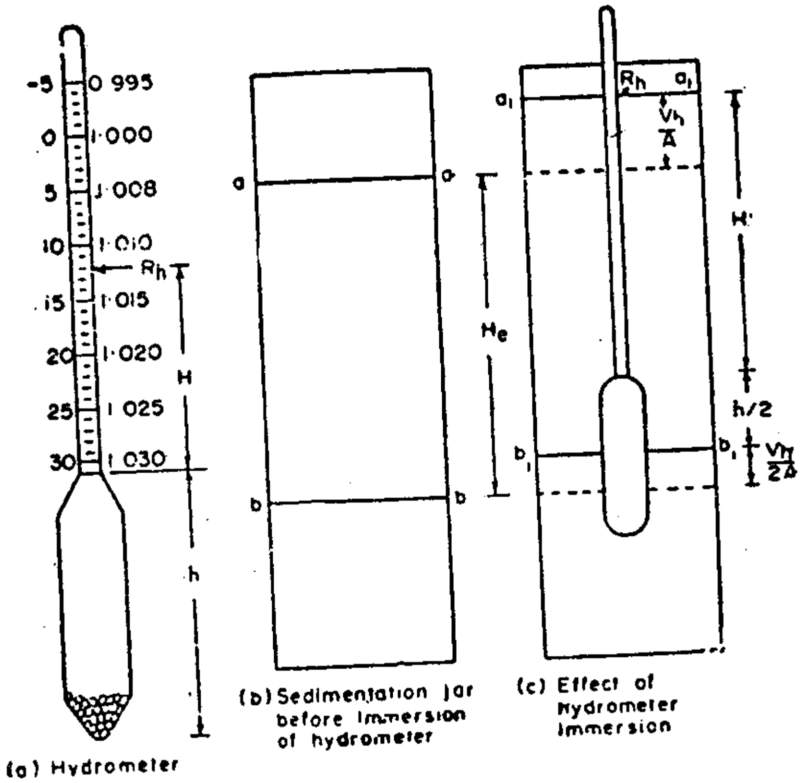


Fig No. 6: Hydrometer analysis

Above equation have two variable He and H which depends upon the hydrometer reading (Rh). By selecting various hydrometer readings the depth H can be measured with the help of an scale and corresponding effective depths (He) can be found as Vh, A and h are constant for a given hydrometer.

2.5.2 Test procedure

2.5.2.1 Soil Suspension Preparation

About 24 to 60 gm of oven dried sample (depending upon the type of soil) is taken and is weighed accurately. The sample is placed in a beaker and distilled water is added to form a smooth thin paste. A deflocculating agent (e.g. sodium oxalate, sodium silicate and sodium polyphosphate compound such as tetra sodium petrophosphate, sodium hexametaphosphate (calgon) and sodium tripolyphosphate) is also added to get a proper dispersion of soil. IS:2720 (Part IV)-1965 recommends the use of dispersing solution containing 33 g of sodium hexametaphosphate and 7g of sodium carbonate in distilled water to make one litre of solution. 50 ml of this solution is added to beaker containing soil sample, this mixture is warmed gently for about 10 minutes. The contents are then transferred to the cup of mechanical mixture. The soil sample is stirred well for about 15 minutes and is then washed through 75 micron sieve using distilled water. Now the sample is ready for analysis and is transferred to measuring cylinder care should be taken that the volume of suspension should be 1000 ml for analysis.

The sedimentation jar is shaken vigorously and is kept verticle over solid bases. The hydrometer is inserted and readings are taken at definite time interval (1/2, 1, 2, 4, 8, 5, 30 mins and 1,2,4 hours etc.). To take reading, hydrometer is inserted 30 seconds before the given time interval so that it is stable at the time when reading is taken. The reading is taken for upper level of meniseus. A suitable meniscus correction is then applied to the hydrometer readings.

2.5.2.2 Correction for hydrometer reading

Hydrometers are generally calibrated at $27^{o}C$, if the temperature of soil suspension is not $27^{o}C$, a temperature correction (Ct) should be applied to the observed hydrometer reading. If temperature is more than $27^{o}C$ the reading of hydrometer will be less hence temperature correction will be positive and viceversa. Other corrections to be applied are meniscus correction and dispersing agent correction. As reading of hydrometer is taken at the top of meniscus, actual reading at water level is higher. Hence meniscus correction (Cm) is always positive. It is found by immersing the hydrometer in clean water. The dispersing agent correction (Cd) is always negative as it increases the density of water.

Therefore corrected hydrometer reading

$$R = Rn + Cm + Ct - Cd$$

where, Rn = observed hydrometer reading at the top of meniscus

Cm, Ct and Cd can be combined into C which is called composite correction.

$$R = Rn + C$$

2.5.2.3 Determination of composite correction

To calculate 'C' an identical cylinder with 1000 ml capacity is taken and filled with distilled water and same quantity of dispersing agent as is used in sedimentation analysis. The temperature of both cylinders being same the hydrometer is immersed in this comparison cylinder. The reading of hydrometer is taken at the top of meniscus. The negative of this reading so obtained gives the composite correction. Composite correction is found before the test and also at time interval more than 30 minutes.

2.5.2.4. Computation of D and N

The observed hydrometer readings were corrected suitably as per the calculated meniscus and temperature corrections and from the corrected hydrometer reading the He was calculated for the corresponding time and Rh. The particle size diameter was calculated by

$$D = 10^{-5} M (He/t)^{0.5} \quad \text{.................................(4)}$$

The over all percentage finer was calculated as below

$$N = N' \frac{W1}{W}$$

where, $N' = \frac{100\ G}{Wd\ (G - 1)}$

N = over all percentage finer,
N' = percentage finer based on Wd,
G = specific gravity of soil particles,

Wl = Cumulative weight passing through 2mm.
Wd = weight per ml of suspension, and
W = total dry weight of soil
t = time to fall through a height He

The grain size was plotted against percentage finer on semi log paper and are given in fig 11 for all the samples.

Similar analysis was also carried out for the soil samples after the carbonate was removed from them. The carbonate from these samples was removed by adding sufficient quantity of 10 N of HCL solution. These samples were then washed with distilled water and HCL was added again. The process was repeated till the bubbles stopped coming out from the soil sample.

2.6 Measurement of Field Saturated Hydraulic Conductivity by Guelph Permeameter

Hydraulic conductivity is the measure of the ability of a soil to conduct water under a unit hydraulic gradient. Field saturated hydraulic conductivity (Ks) refer to the saturated hydraulic conductivity of soil containing entrapped air. Field saturated hydraulic conductivity is more appropriate than the truely saturated hydraulic conductivity for unsaturated zone investigations because by definition, positive pressure heads do not persist in unsaturated conditions long enough for entrapped air to dissolve. In the presence of the water table, the auger hole method is a simple and reliable technique for measuring saturated hydraulic conductivity in relatively uniform soils. However this method cannot be used if the water table is not present in the region of interest. The methods for measuring hydraulic conductivity in the absence of the water table are more complicated. The shallow well permeameter method, also known as the dry auger hole method and the bore hole permeameter method are the techniques for measuring hydraulic conductivity. Hydraulic conductivity decreases as the soil water suction increases. This relationship is called the conductivity pressure head relationship. The Guelph permeameter is used to determine Ks for a particular soil. Once the soil water suction is measured, the hydraulic conductivity for that soil at that soil water suction can be readily estimated.

2.6.1 Guelph Permeameter Apparatus

The Guelph Permeameter is essentially an "in hole" Mariotte bottle constructed of concentric transparent plastic tubes. The apparatus comprises the following sections. The two models of Guelph Permeameter are shown in Fig 7.

(i) Tripod Assembly

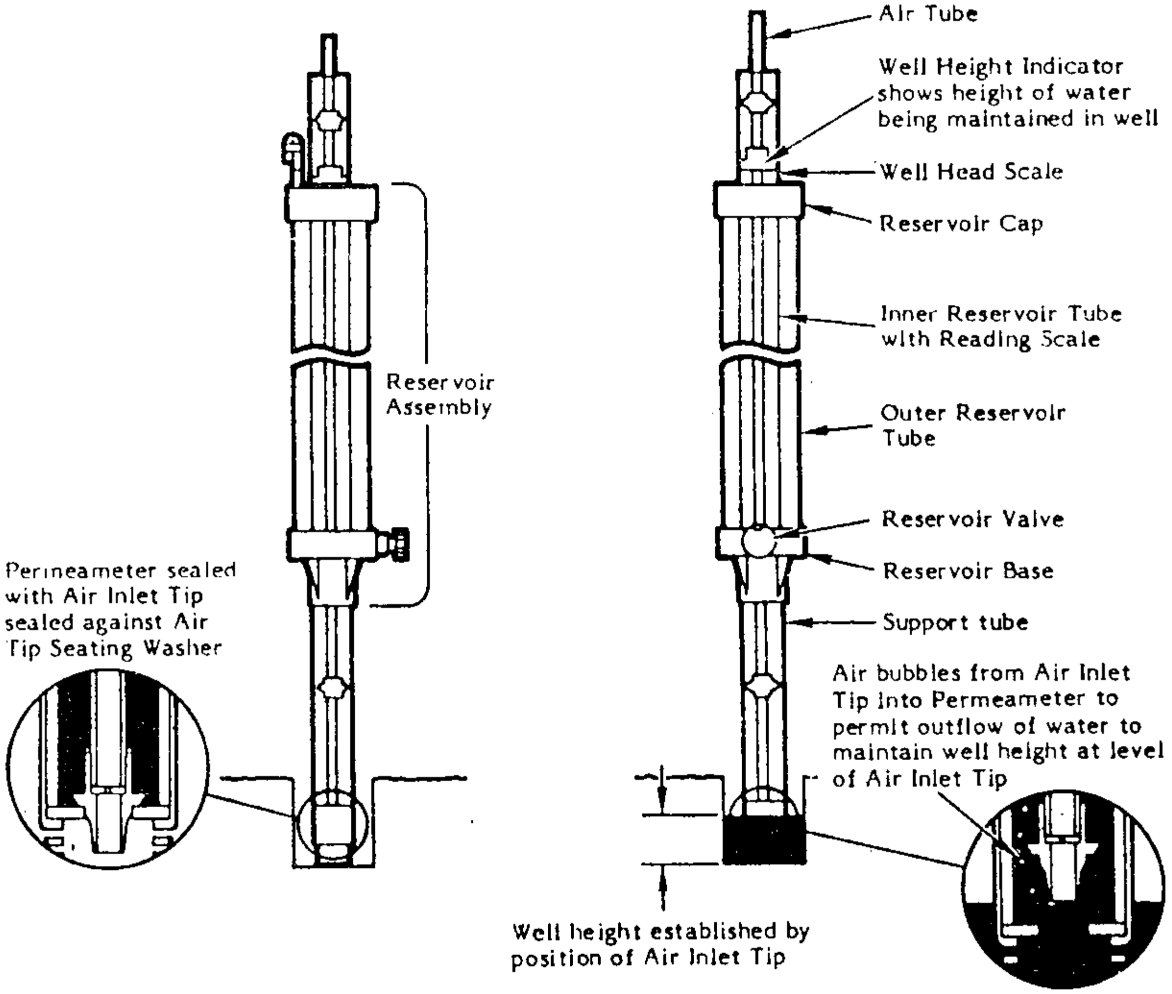


Fig No. 7: Guelph permeameter models

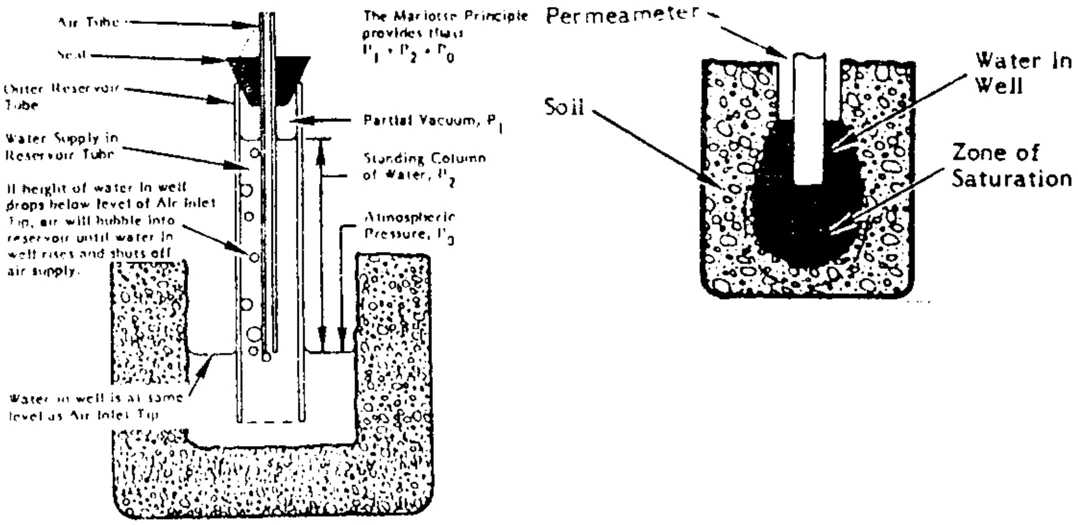


Fig No. 8: Permeameter in operation

(ii) Support Tubes and lower air tube fittings
(iii) Reservoir Assembly
(iv) Well Head Scale and upper air tube fittings
(v) Auxiliary tools

(i) Tripod Assembly:

The tripod assembly consists of a tripod based with moveable tripod bushing and three detachable tripod legs complete with end tips. The flexible tripod base has three leg sockets into which the tripod legs are inserted. Tripod chain is used for firm placement and support of tripod legs.

(ii) Support Tube and Lower Air tube fittings:

These are the fittings which conduct water from the reservoir assembly into the well hole and provide the means for establishing and maintaining a constant head in the well hole. The support tube supports the reservoir assembly over the well hole and transports water from the reservoir to the water outlet. The water outlet tip serves as a base for the permeameter and disperses the energy of the outflowing water through the ribbed vents at the bottom to the tip to minimize erosion of the soil in the well hole. The air tip seating washer rests on the inside step of the water outlet tip and is the seat for the Air Inlet tip when the air inlet is fully seated against the air tip seating washer, air cannot move up through the support tube and there is no flow of water out of the reservoir. The air inlet tip is connected to the bottom of the lower air tube and is used to regulate the well head height. The air restriction washer is located inside the air inlet tip and regulates air flow to provide a constant, non fluctuating head in the well.

(iii) Reservoir Assembly:

The reservoir assembly provides a means of storing water and measuring the outflow rate while the Guelph Permeameter is in use. It consists of inner reservoir tube, outer reservoir tube, reservoir valve, base and reservoir cap. For studies in very low permeability soils, for example clay soil, use of the inner reservoir alone is required to provide adequate outflow rate. When working in moderate to high permeable soils, for example sands and loamy soils, the reservoir combination is used. The inner reservoir tube is graduated in centimeters for measuring the rate of fall of water out of the reservoir in both situations. The Guelph permeameter (fig 7) shows the closed or sealed state with air inlet tip sealed against air tip seating washer. When air tube is uplifted, with accompanying air inlet tip and well height indicator, water flows from the reservoir down the inside of the support tube through the water outlet tip and into the well. The water height in the well is established by the height of the air inlet tip. This water height in the well can be set and read using well height indicator in conjunction with the well head scale.

The reservoir base includes the reservoir valve. The base connects and seats the inner and outer reservoir tubes to the support tube. Water flow is controlled by the position of the reservoir valve. When the valve position is up, both reservoirs supply water to the well hole. When it is pointing straight down, only the inner reservoir supplies water to the well hole. The reservoir cap provides an airtight cover for the top of the reservoir, the seal of the air tube and supports the well head scale. The middle air tube is located inside the inner reservoir tube. Two ports are located in the reservoir cap namely Fill port and Fill plug. The vacuum port consists of an Access tube, Neoprene tube and clamping ring. The vacuum port facilitates pulling a vacuum when the reservoirs are not initially compietely filled.

(iv) Well Head Scale and Upper Air Tube Fittings:

The upper air tube is connected to be Middle air tube with an air tube coupling. It serves as an extension to facilitate setting the well head after the well head scale is put in place.

(v) Auxiliary Tools

The Guelph permeameter kit includes a soil auger for excavating a well, a sizing auger, a well prep brush, a vacuum hand pump for pulling a vacuum in the reservoir and a collapsible water container for carrying water to the field. The well prep brush meant for removing any smear layer that exists in the augered well hole that may create a barrier to the natural flow of water out of the well into surrounding soil.

2.6.2 Procedure

The Guelph permeameter method (Reynold et.al. 1985) measures the steady state liquid recharge necessary to maintain a constant depth of liquid in an uncased cylindrical well finished above the water table. Constant head level in the well hole is establiswhed and maintained by regulating the level of the bottom of the air tube which is located in the centre of the permeameter. As the water level in the reservoir falls, a vacuum is created in the air space above water. When the permeameter is operating, an equilibrium is established. The reduced pressure in the air above the water in the reservoir together with the pressure of the water column extending from the surface of the well to the surface of the water in the reservoir which is always equal to the atmospheric pressure.

When a constant well height of water is established in a cored hole in a soil, a bulb of saturated soil with specific dimension is rather quickly established. The bulb is very stable and its shape depends on the type of soil, the radius of the well and the head of water in the well (fig 8). The shape of the bulb is numerically described by the C factor used in the calculations. Once the bulb shape is established, the outflow of water from the well reaches a steady state flow rate which can be measured. The rate of this constant outflow of water, together with the diameter of the well and height of water in the well can be used to determine the field saturated hydraulic conductivity of the soil.

The Richard analysis of steady state discharge from a cylindrical well in unsaturated soil, as measured by the Guelph permeameter technique accounts for all the forces that contribute to three dimensional flow of water into soils, the hydraulic push of water into soil, the gravitational pull of liquid out through bottom of the well and the capillary pull of water out of the well into the surrounding soil. The Richard analysis is the basis for the calculation of field saturated hydraulic conductivity. The C factor is a numerically derived shape factor which is dependent on the well radius and head of water in the well. Fig 9 shows the curves for three classes of soil.

2.6.3 Procedures for Field Use

Before making a measurement with the Guelph permeameter in the field, it is necessary to perform a site and soil evaluation, prepare a well hole, assemble the permeameter, fill the reservoirs, and place the permeameter in the well hole (fig 10)

2.6.4 Well preparation

The instruments needed for excavating and preparing a well bore hole are soil auger and sizing auger. The soil auger and sizing auger. The soil auger is used to remove bulk amounts of soil and rock. The sizing auger is used as a finishing tool to produce a proper sized well hole of uniform geometry and to clean debris off the bottom of the well hole. The sizing auger is designed to produce a hole that is uniformly 6 cm in diameter with a flat bottom. Generally, the procedure is to use the soil auger to excavate the well hole down to a depth 15 cm less than that desired for the final well hole. The last 15 cm can than be excavated using the sizing auger to produce a debris

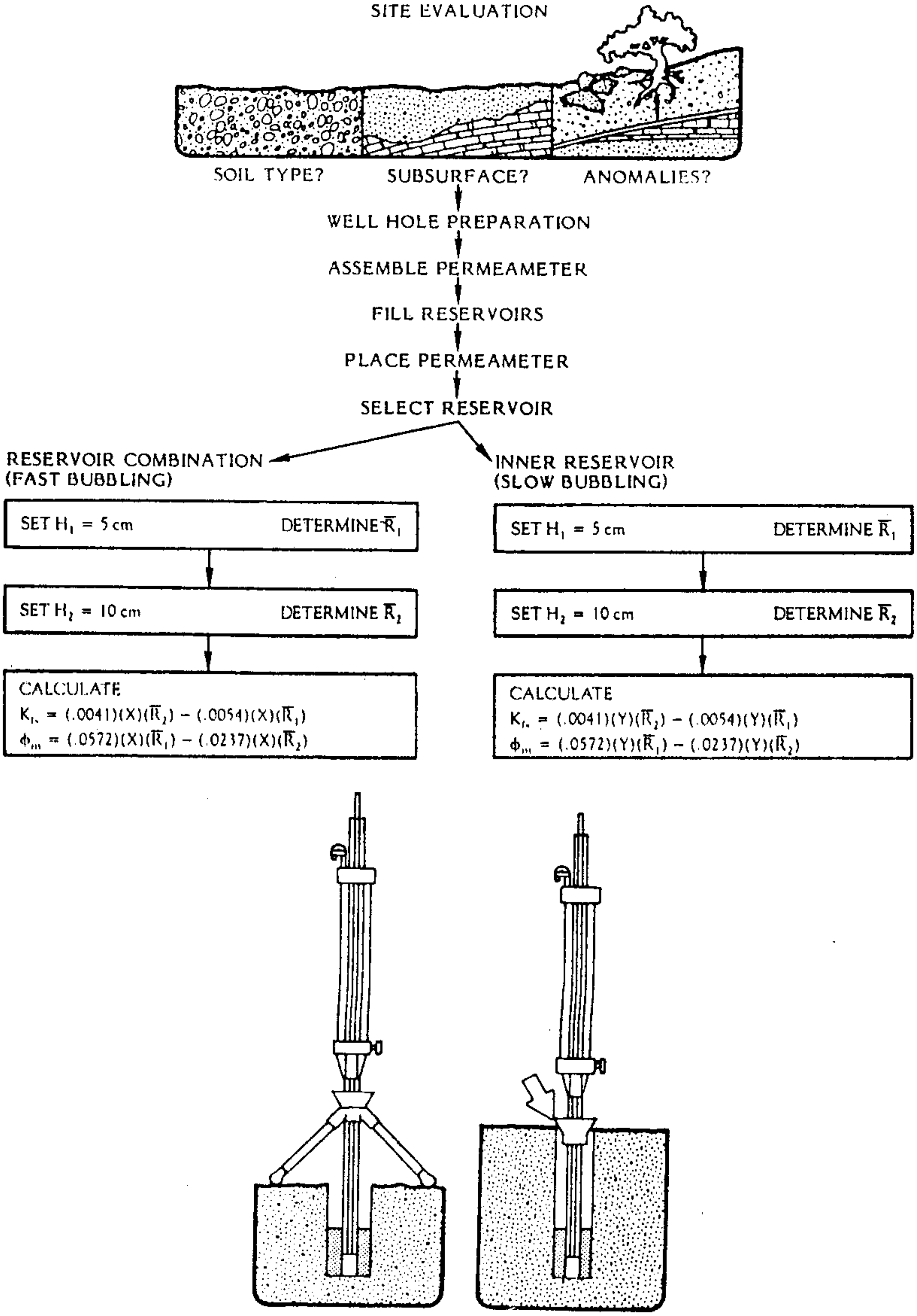


Fig No. 10: Flow chart of procedure and permeameter placement

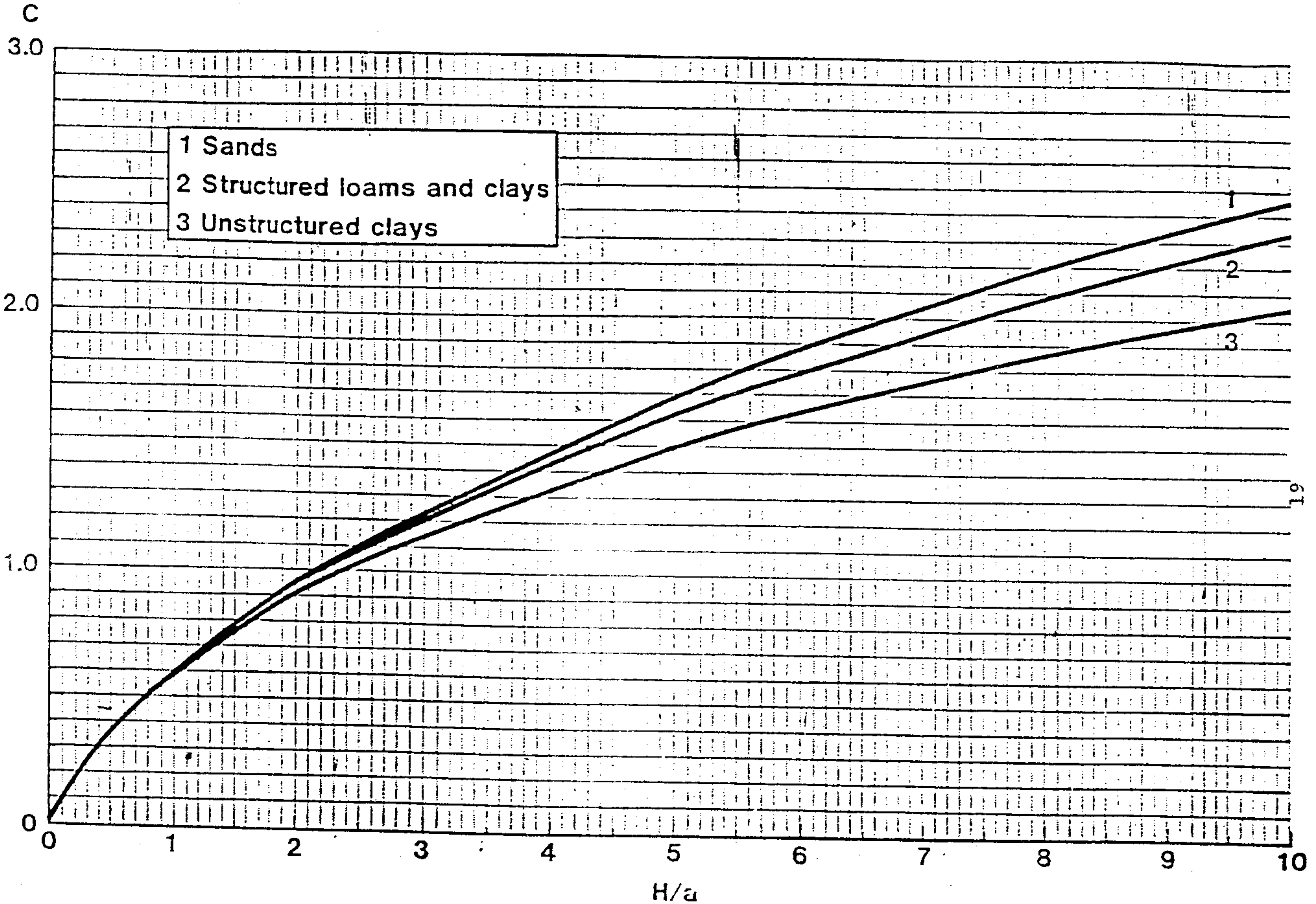


Fig No. 9: C - Factor

free well hole of uniform geometry.

In the moist soils or in medium to fine textured soils, the process of augering a hole may create a smear layer which can block the natural flow of water out of the well into the surrounding soil. In order to obtain reliable and representative results using the Guelph Permeameter, the smear layer must be removed. The well prep brush is designed to use in the standard 6 cm diameter well hole.

2.6.5 Permeameter Placement

Tripod is centered over the well hole (as shown in Fig 10) and slowly the permeameter is lowered so that the support tube enters into the well hole. The tripod is used to support the permeameter in well down to approximately 38 cm in depth. For use in wells deeper that 38 cm, the tripod bushing alone provides the functions of centering and stabilizing the permeameter. After the permeameter is placed, it can be easily filled with water. The following standard procedure should be followed for making measurements.

(i) Verify that both the reservoirs are connected. The reservoirs are connected when the notch on the reservoir valve is pointing up.

(ii) Establishe a 5 cm well Head Height (H1). Slowly raise the air inlet tip to establish the 5 cm well head height. Raising the air tube too quickly can cause turbulence and erosion in the well.

iii) Observe the rate of fall of the water level in the reservoir. If it is too slow, then turn the reservoir valve so that the notch is pointing down. Water will then be supplied, only from the small diameter inner reservoir which will result in a much greater drop in water level between readings.

(iv) Measure permeameter outflow. This is indicated by the rate of fall of water in the reservoir. Readings should be made at regular time intervals, usually 2 minute intervals are used. The difference of readings at consecutive interval divided by the time interval equals the rate of fall of water, R1 in the reservoir. Continue monitoring the rate of fall of water in the reservoir untill the rate of fall does not significantly change in three consecutive time intervals. This rate is called R1 and is defined as the "Steady state rate of fall" of water in the reservoir at height H1 which is the first well height established and is always 5cm in the standardized procedure.

(v) Establish 10 cm Well head height (H2). Slowly raise the air inlet tip to establish the second well head height of 10 cm. Monitor the rate of fall of water, R2, in the reservoir until a stable value of R2 is measured.

(vi) The field saturated hydraulic conductivity, Ks can be calculated using the following equation:

$$Ks = 0.0041 \times R2 - 0.0054 \times R1 \quad \ldots\ldots(5)$$

where,

X = Reservoir constant, equal to 35.39 where reservoir combination is used and 2.14 when only inner reservoir is used

R2 = Steady rate of fall of water in the reservoir for a head of 10 cm.

R1 = Steady rate of fall of water in the reservoir for a well head of 5 cm.

2.7 Ground Water table analysis

The groundwater table data for pre monsoon and post monsoon for Bulandshahr district was provided by the ground water department, Roorkee. The ground water table data for post monsoon & premonsoon was available for year 1971 to 1991. The data of depth to water table from soil surface as well as the reduced level of the ground surface or measuring point is available. The ground water table data for the Bulandshahr was analysed for the premonsoon and post monsoon for year 1987, 88, 89, 90 and 91 and depth to water table contours for the area were plotted (fig 13).

3.0 Procedure

3.1 Soil Sampling

A pilot area shown in fig 1 was selected for the estimation of soil hydrological properties of the area. The soil sampling was carried out from this area. Samples have been collected from 11 locations indicated in the fig 1. Measurement of field saturated hydraulic conductivity was also carried out in these locations.

3.2 Grain Size Analysis

1. Oven dried sample weighing 500 gm was taken and soaked with water.
2. This sample was washed through no. 200 sieve. The washing was carried out carefully using distilled water.
3. Two group of soils, one passing through the sieve and another retained on the sieve were collected seperately.
4. Both the groups of soil were then oven dried. The group retained on sieve was subjected to sieve analysis and the group passing through the sieve was subjected to sedimentation

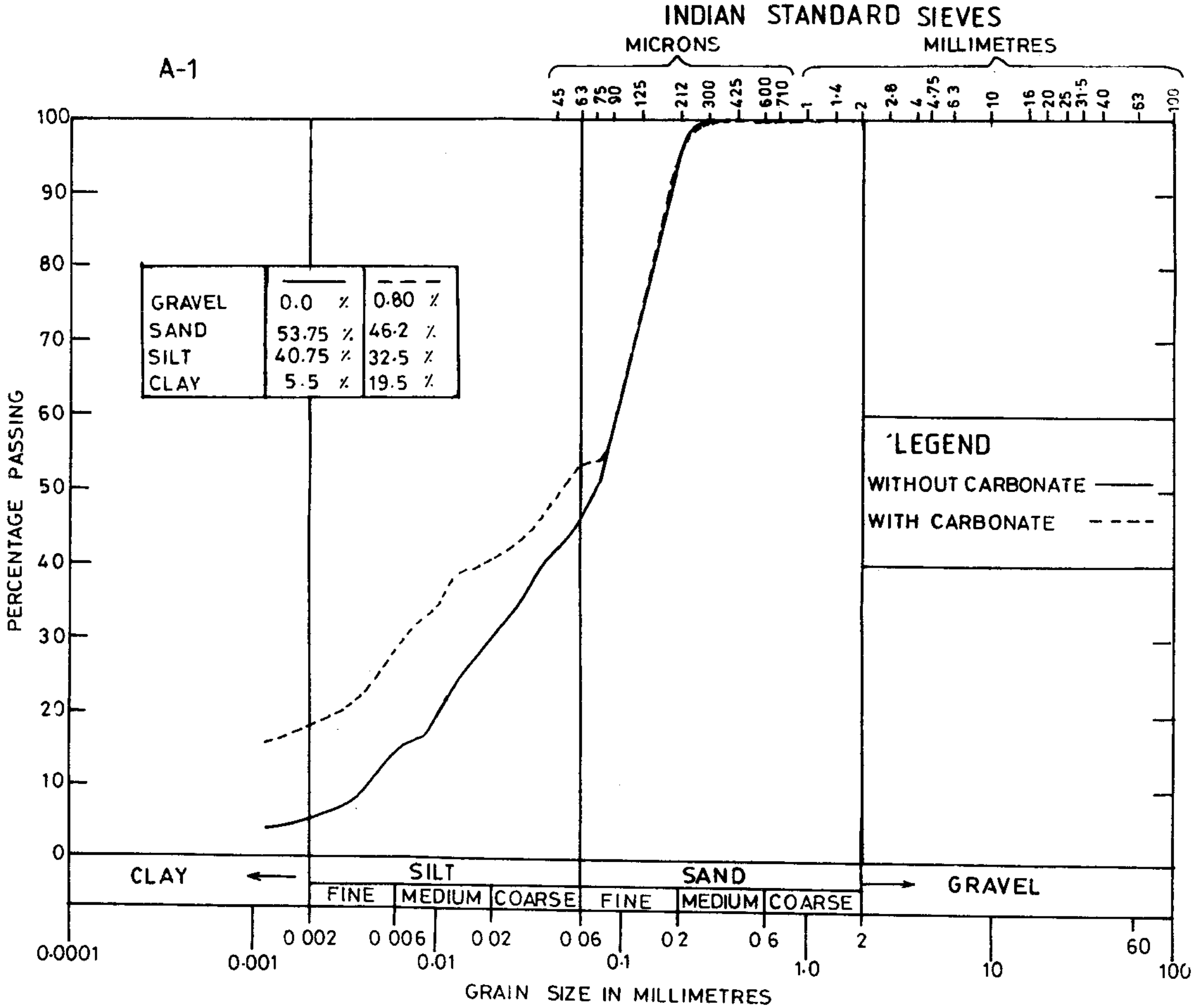
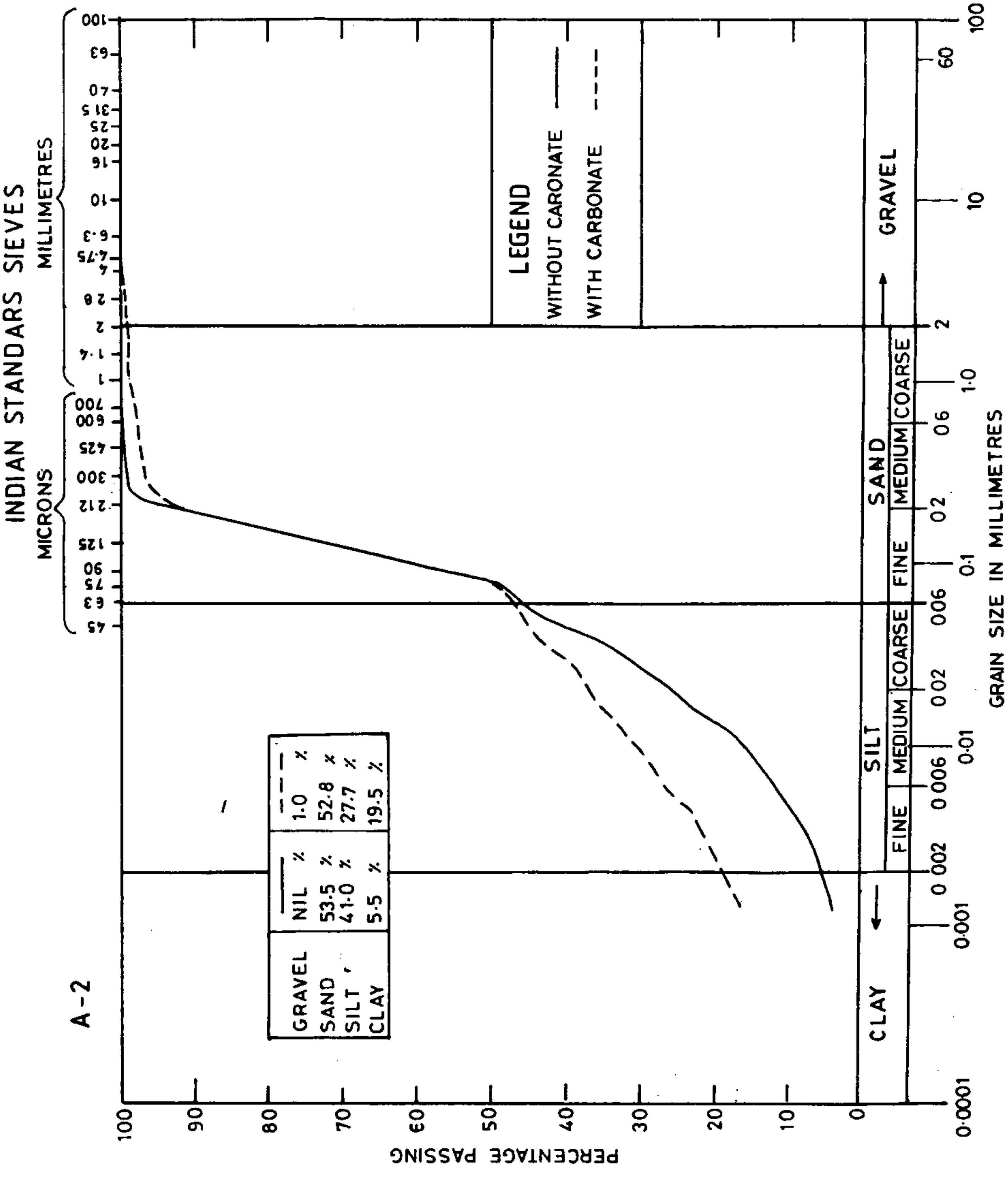
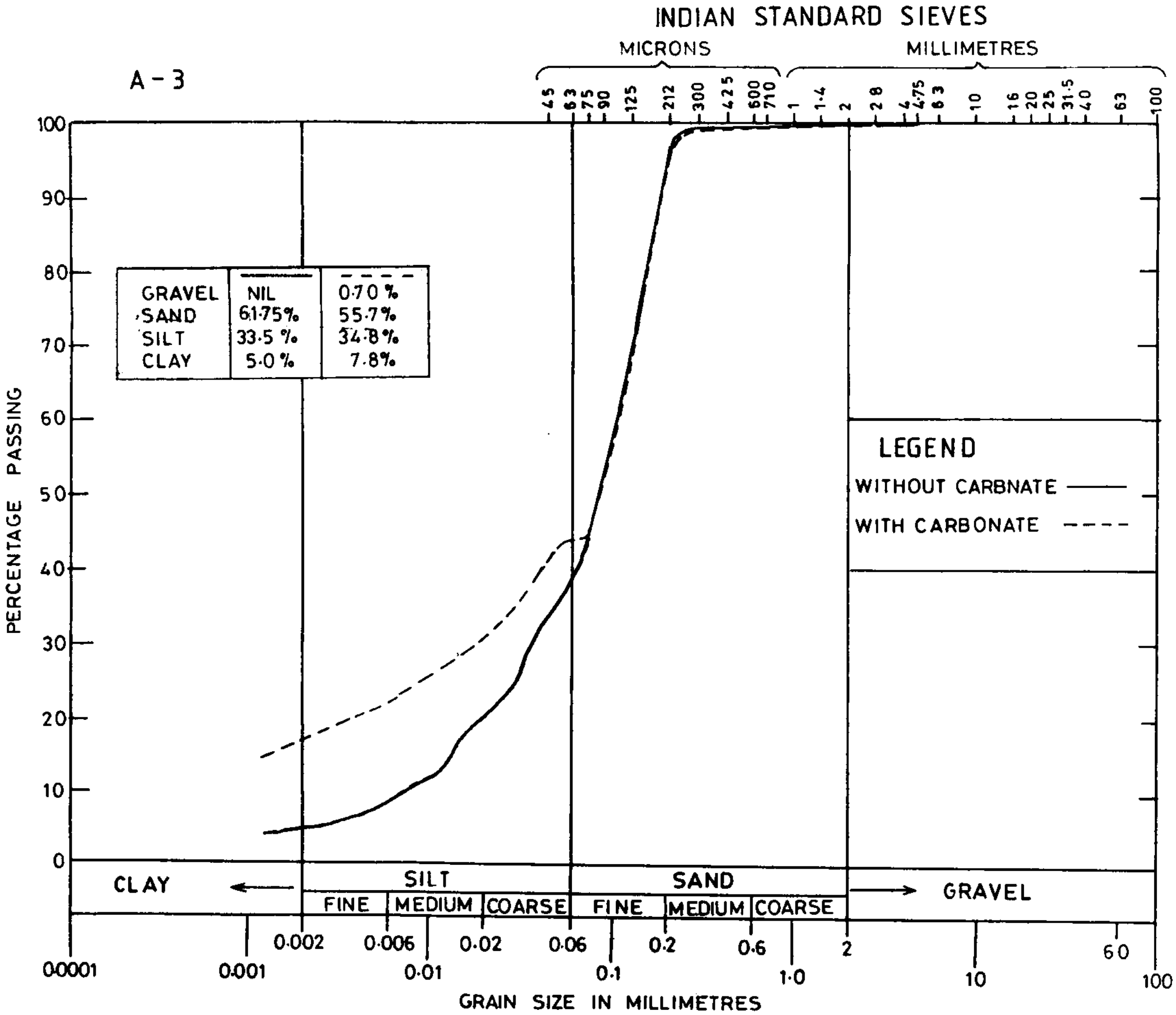
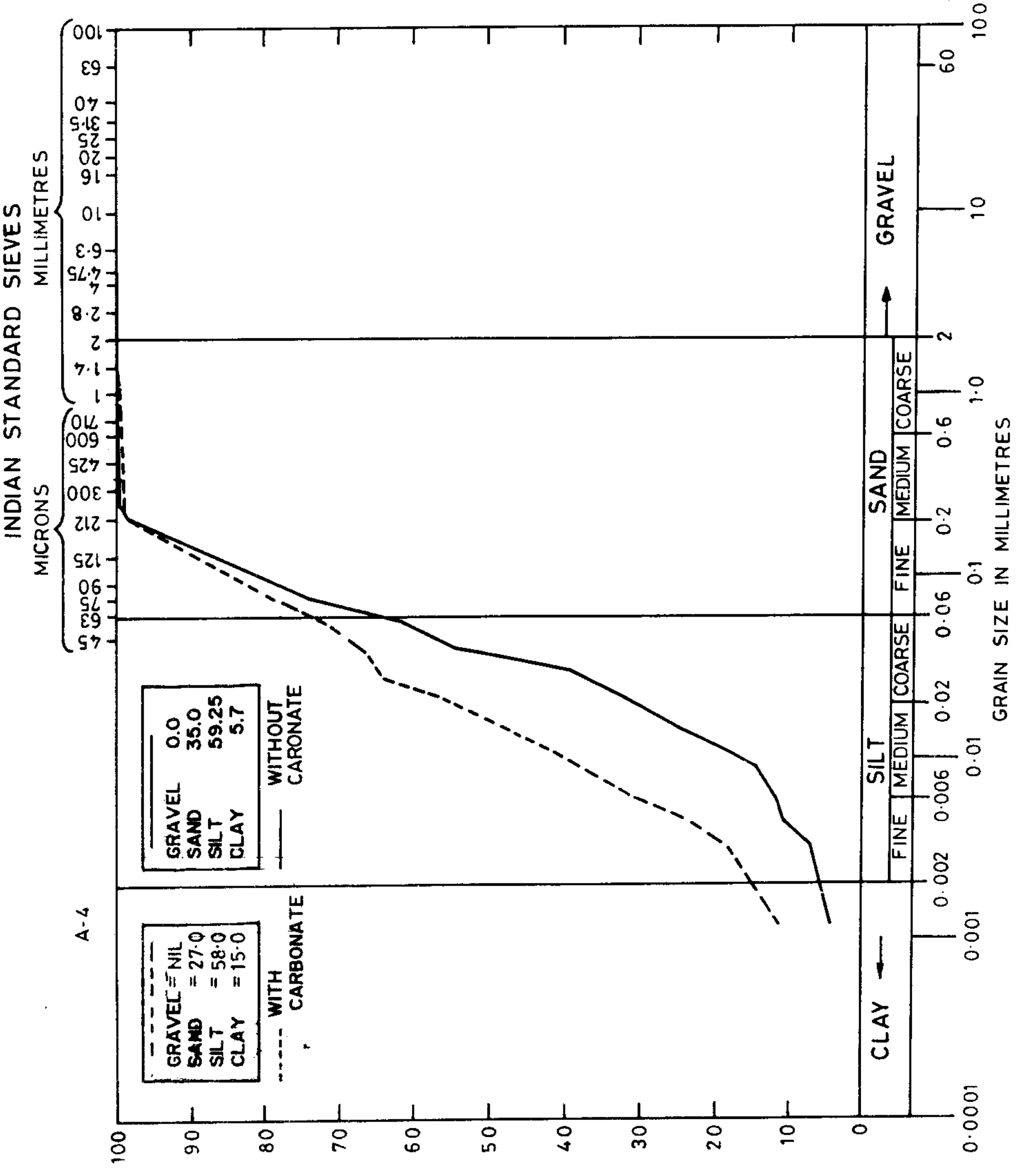
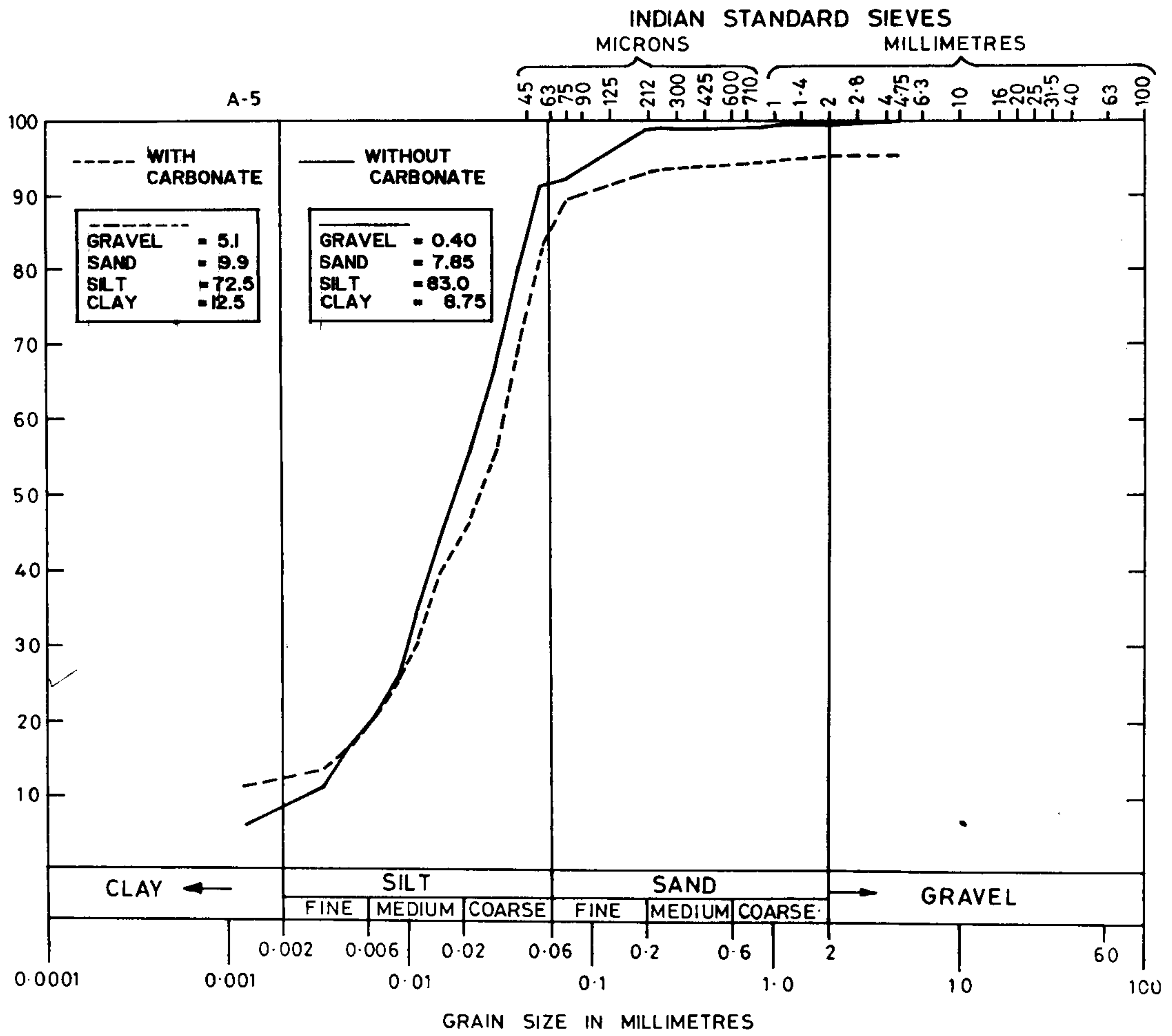


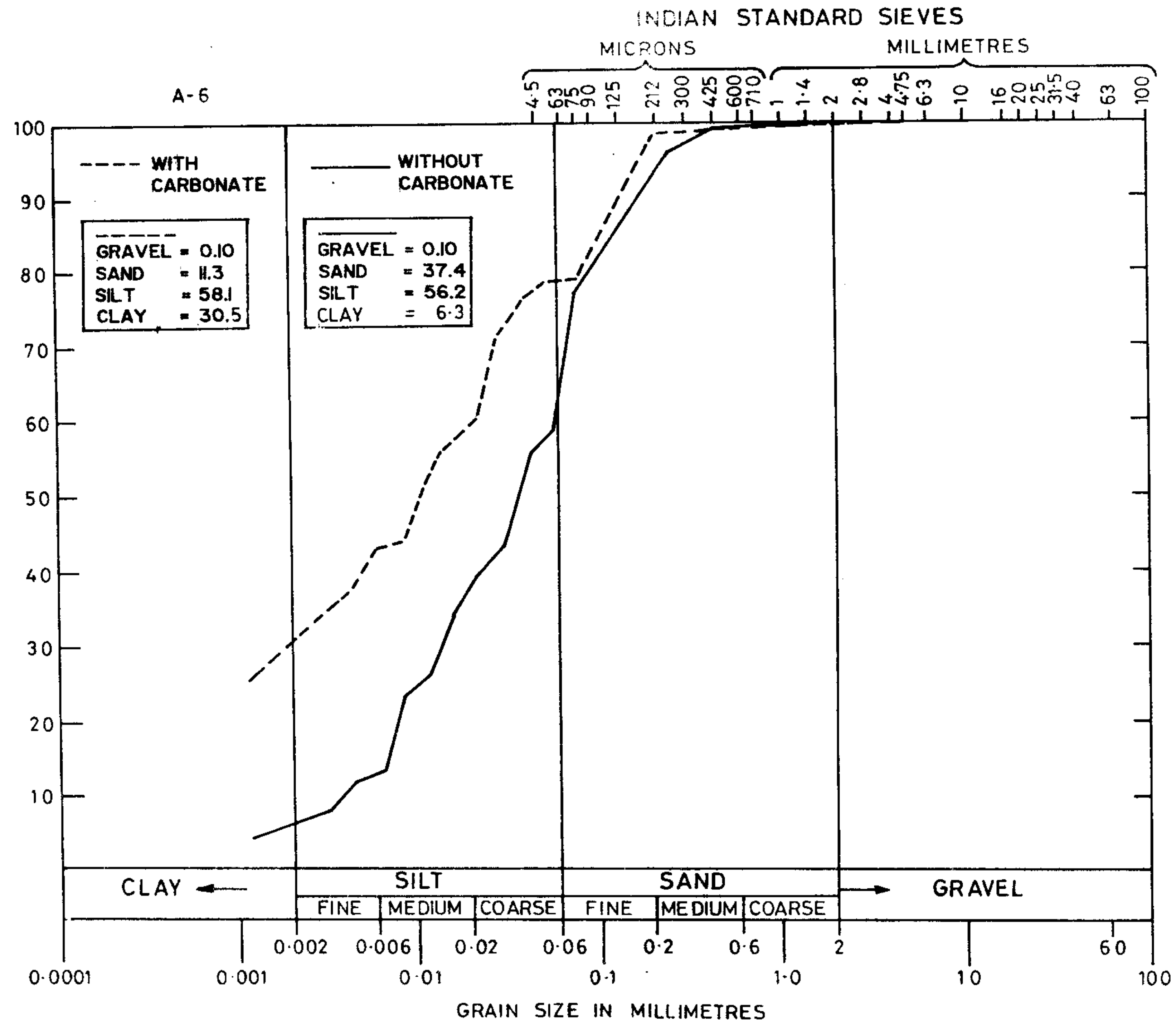
FIG.11- PARTICLE SIZE DISTRIBUTION CURVES (A 1 TO A 11)


A-2
INDIAN STANDARS SIEVES
MICRONS
MILLIMETRES
45 63 75 90 125 212 300 425 600 700
1 1·4 2 2 8 4 4·75 6·3 10 16 20 25 31 5 40 63 100
LEGEND
WITHOUT CARONATE
WITH CARBONATE
GRAVEL NIL % 1.0 %
SAND 53.5 % 52.8 %
SILT 41.0 % 27.7 %
CLAY 5.5 % 19.5 %
PERCENTAGE PASSING
100 90 80 70 60 50 40 30 20 10 0
CLAY
SILT
FINE MEDIUM COARSE
SAND
FINE MEDIUM COARSE
GRAVEL
0·0001 0·001 0 002 0 006 0·01 0 02 0 06 0·1 0 2 0 6 1·0 2 10 60 100
GRAIN SIZE IN MILLIMETRES

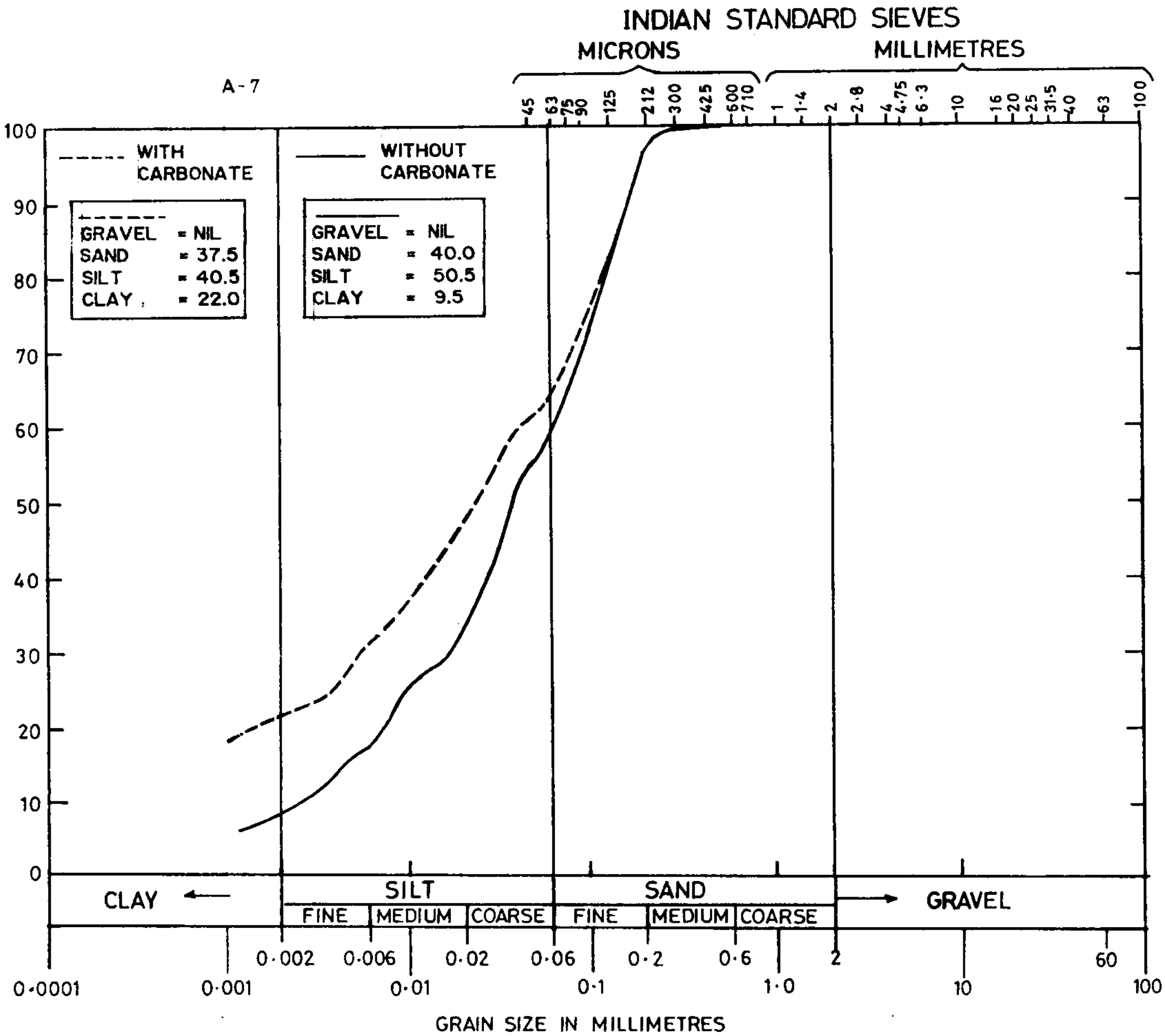

INDIAN STANDARD SIEVES
MICRONS
MILLIMETRES
45 63 75 90 125 212 300 425 600 710
1 1.4 2 2.8 4 4.75 6.3 10 16 20 25 31.5 40 63 100
A - 3
GRAVEL NIL 0.70 %
SAND 61.75% 55.7%
SILT 33.5 % 34.8%
CLAY 5.0 % 7.8%
LEGEND
WITHOUT CARBNATE
WITH CARBONATE
PERCENTAGE PASSING
100 90 80 70 60 50 40 30 20 10 0
CLAY
SILT
FINE MEDIUM COARSE
SAND
FINE MEDIUM COARSE
GRAVEL
0.0001 0.001 0.002 0.006 0.01 0.02 0.06 0.1 0.2 0.6 1.0 2 10 60 100
GRAIN SIZE IN MILLIMETRES


INDIAN STANDARD SIEVES
MICRONS
MILLIMETRES
45 63 75 90 125 212 300 425 600 710
1 1·4 2 2·8 4 4·75 6·3 10 16 20 25 31·5 40 63 100
A-4
GRAVEL = NIL
SAND = 27·0
SILT = 58·0
CLAY = 15·0
WITH CARBONATE
GRAVEL 0.0
SAND 35.0
SILT 59.25
CLAY 5.7
WITHOUT CARONATE
100 90 80 70 60 50 40 30 20 10 0
CLAY
SILT
SAND
GRAVEL
FINE MEDIUM COARSE
FINE MEDIUM COARSE
0·0001 0·001 0·002 0·006 0·01 0·02 0·06 0·1 0·2 0·6 1·0 2 10 60 100
GRAIN SIZE IN MILLIMETRES

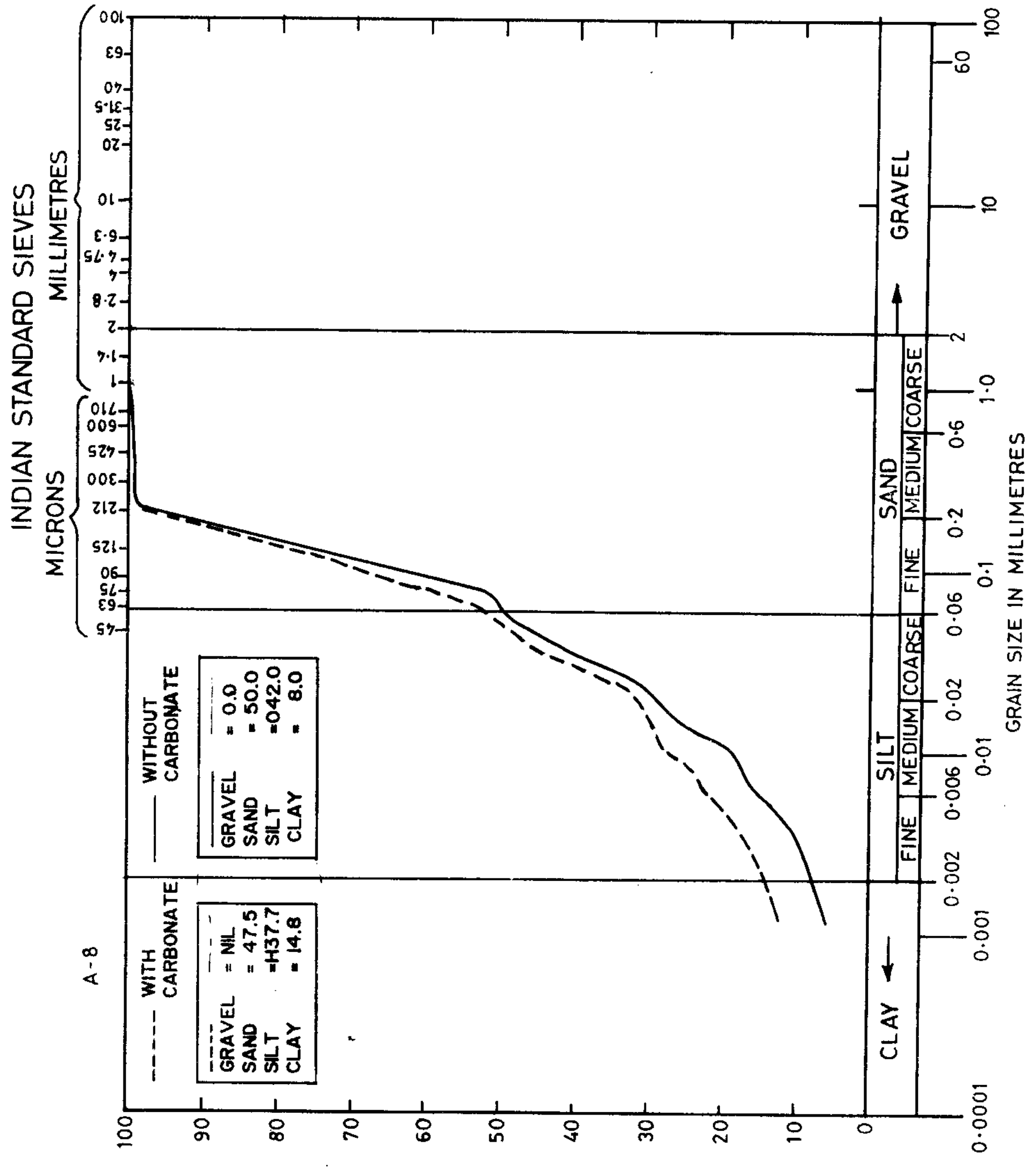

INDIAN STANDARD SIEVES
MICRONS
MILLIMETRES
45 63 75 90 125 212 300 425 600 710
1 1·4 2 2·8 4 4·75 6·3 10 16 20 25 31·5 40 63 100
A-5
WITH CARBONATE
GRAVEL = 5.1
SAND = 9.9
SILT = 72.5
CLAY = 12.5
WITHOUT CARBONATE
GRAVEL = 0.40
SAND = 7.85
SILT = 83.0
CLAY = 8.75
100 90 80 70 60 50 40 30 20 10
CLAY
SILT
FINE MEDIUM COARSE
SAND
FINE MEDIUM COARSE
GRAVEL
0·0001 0·001 0·002 0·006 0·01 0·02 0·06 0·1 0·2 0·6 1·0 2 10 60 100
GRAIN SIZE IN MILLIMETRES



INDIAN STANDARD SIEVES
MICRONS
MILLIMETRES
4·5 63 75 90 125 212 300 425 600 710
1 1·4 2 2·8 4 4·75 6·3 10 16 20 25 31·5 40 63 100
A-6
100
90
80
70
60
50
40
30
20
10
---- WITH CARBONATE
GRAVEL = 0.10
SAND = 11.3
SILT = 58.1
CLAY = 30.5
—— WITHOUT CARBONATE
GRAVEL = 0.10
SAND = 37.4
SILT = 56.2
CLAY = 6·3
CLAY
SILT
FINE
MEDIUM
COARSE
SAND
FINE
MEDIUM
COARSE
GRAVEL
0·002 0·006 0·02 0·06 0·2 0·6 2 60
0·0001 0·001 0·01 0·1 1·0 10 100
GRAIN SIZE IN MILLIMETRES

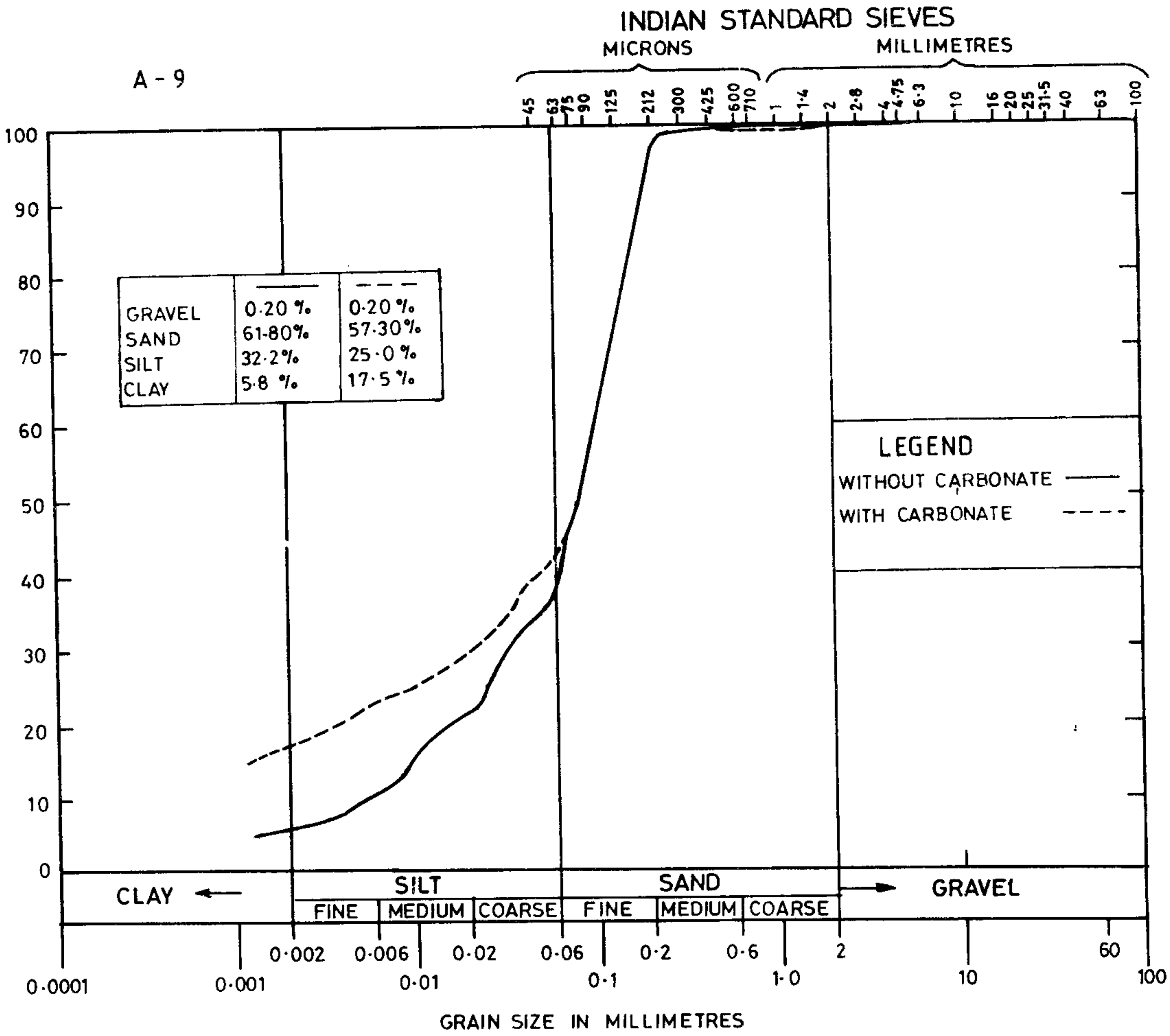


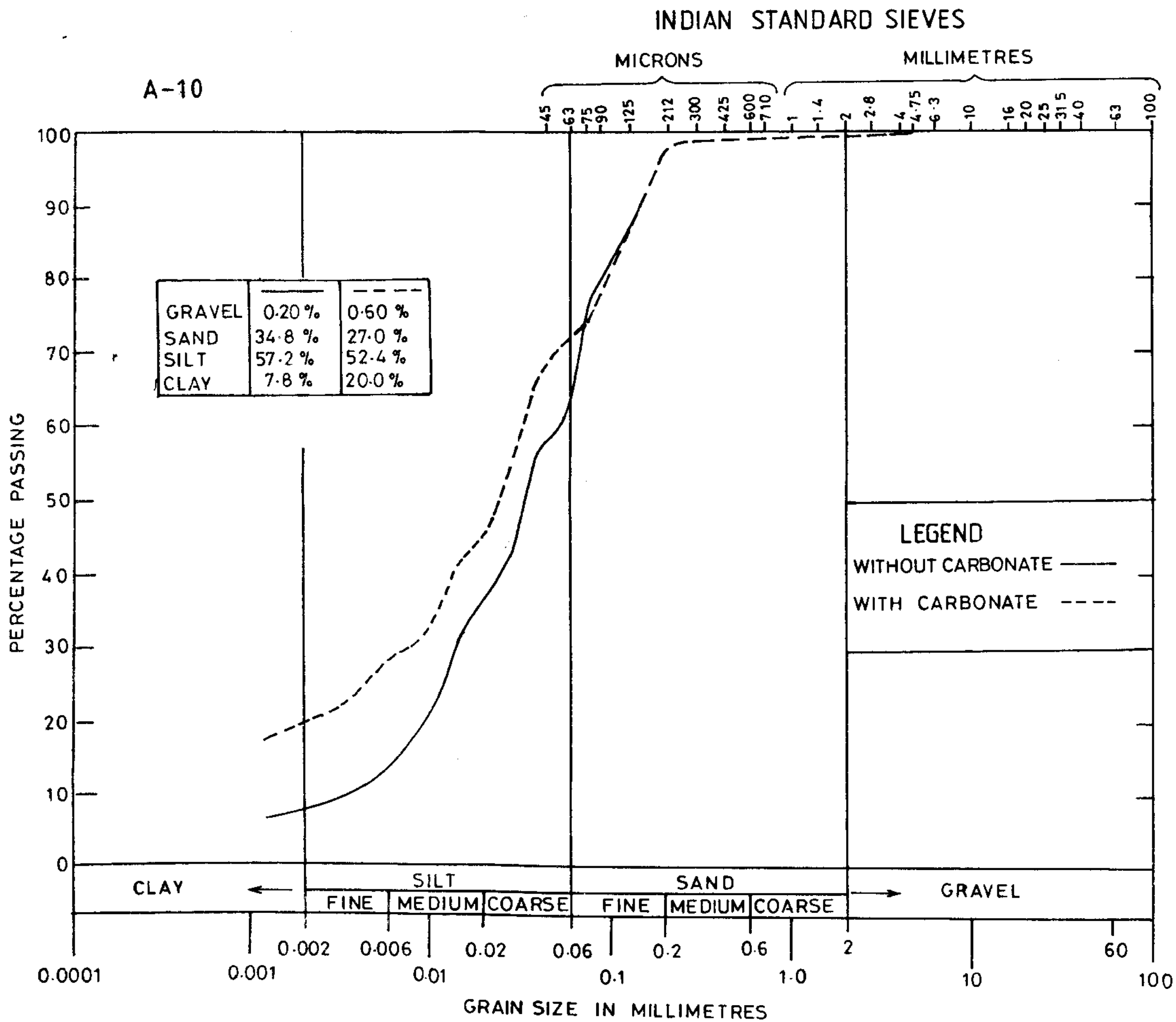
INDIAN STANDARD SIEVES
MICRONS
MILLIMETRES
45 63 75 90 125 212 300 425 600 710
1 1·4 2 2·8 4 4·75 6·3 10 16 20 25 31·5 40 63 100
A-7
WITH CARBONATE
GRAVEL = NIL
SAND = 37.5
SILT = 40.5
CLAY = 22.0
WITHOUT CARBONATE
GRAVEL = NIL
SAND = 40.0
SILT = 50.5
CLAY = 9.5
100 90 80 70 60 50 40 30 20 10 0
CLAY
SILT
FINE MEDIUM COARSE
SAND
FINE MEDIUM COARSE
GRAVEL
0·0001 0·001 0·002 0·006 0·01 0·02 0·06 0·1 0·2 0·6 1·0 2 10 60 100
GRAIN SIZE IN MILLIMETRES



INDIAN STANDARD SIEVES
MICRONS
MILLIMETRES
A-8
WITH CARBONATE
GRAVEL = NIL
SAND = 47.5
SILT =H37.7
CLAY = 14.8
WITHOUT CARBONATE
GRAVEL = 0.0
SAND = 50.0
SILT =042.0
CLAY = 8.0
CLAY
SILT
FINE
MEDIUM
COARSE
SAND
FINE
MEDIUM
COARSE
GRAVEL
GRAIN SIZE IN MILLIMETRES

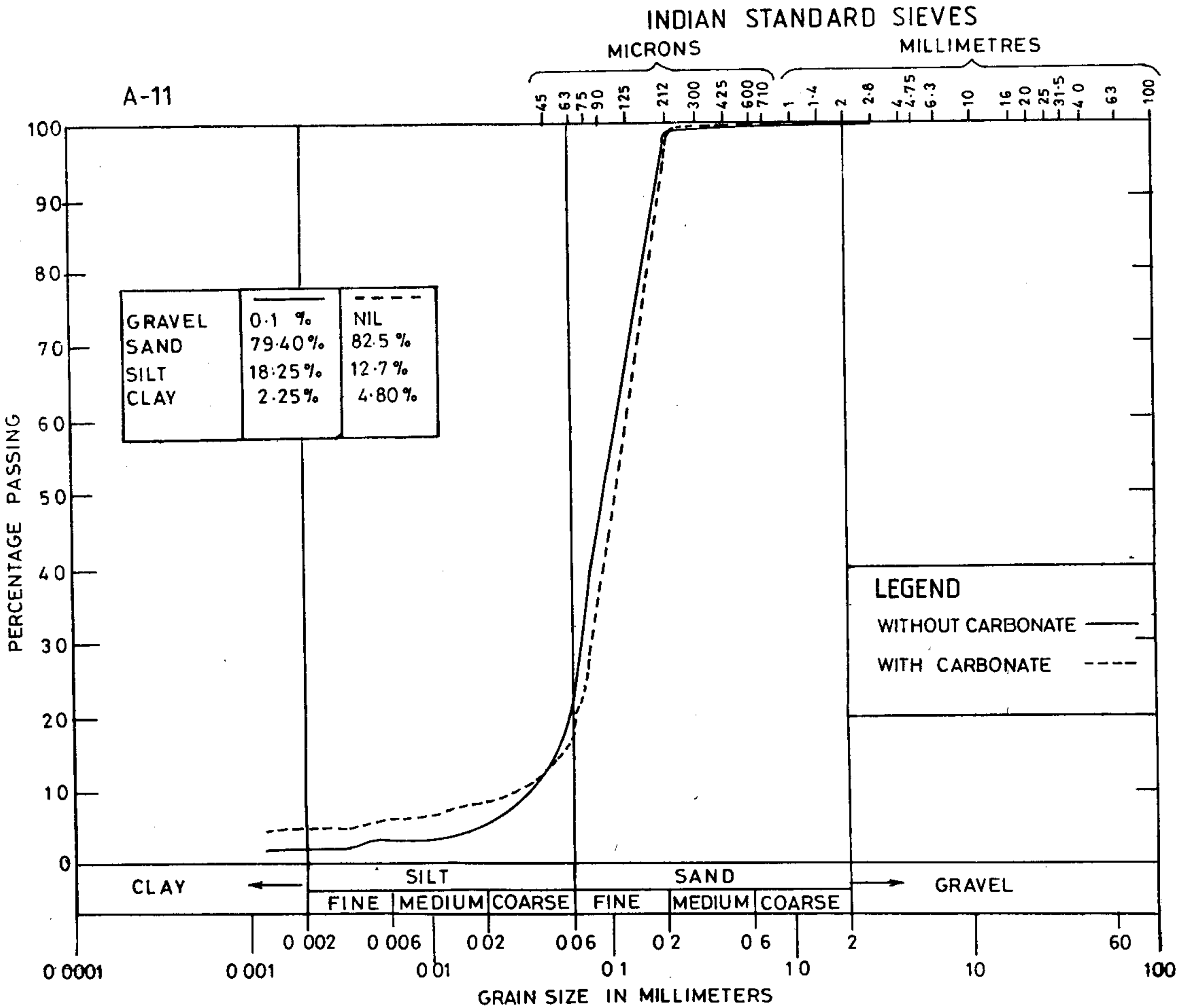
A - 9


INDIAN STANDARD SIEVES
MICRONS
MILLIMETRES
45 63 75 90 125 212 300 425 600 710
1 1·4 2 2·8 4 4·75 6·3 10 16 20 25 31·5 40 63 100
GRAVEL 0·20 % 0·20 %
SAND 61·80% 57·30%
SILT 32·2% 25·0 %
CLAY 5·8 % 17·5 %
LEGEND
WITHOUT CARBONATE
WITH CARBONATE
0 10 20 30 40 50 60 70 80 90 100
CLAY
SILT
FINE MEDIUM COARSE
SAND
FINE MEDIUM COARSE
GRAVEL
0·0001 0·001 0·002 0·006 0·01 0·02 0·06 0·1 0·2 0·6 1·0 2 10 60 100
GRAIN SIZE IN MILLIMETRES



INDIAN STANDARD SIEVES
MICRONS
MILLIMETRES
A-10
45 63 75 90 125 212 300 425 600 710
1 1.4 2 2.8 4 4.75 6.3 10 16 20 25 31.5 40 63 100
GRAVEL 0.20 % 0.60 %
SAND 34.8 % 27.0 %
SILT 57.2 % 52.4 %
CLAY 7.8 % 20.0 %
LEGEND
WITHOUT CARBONATE
WITH CARBONATE
PERCENTAGE PASSING
0 10 20 30 40 50 60 70 80 90 100
CLAY
SILT
FINE MEDIUM COARSE
SAND
FINE MEDIUM COARSE
GRAVEL
0.0001 0.001 0.002 0.006 0.01 0.02 0.06 0.1 0.2 0.6 1.0 2 10 60 100
GRAIN SIZE IN MILLIMETRES

A-11


INDIAN STANDARD SIEVES
MICRONS
MILLIMETRES
45 63 75 90 125 212 300 425 600 710
1 1·4 2 2·8 4 4·75 6·3 10 16 20 25 31·5 40 63 100
PERCENTAGE PASSING
100 90 80 70 60 50 40 30 20 10 0
GRAVEL 0·1 % NIL
SAND 79·40% 82·5 %
SILT 18·25% 12·7 %
CLAY 2·25% 4·80 %
LEGEND
WITHOUT CARBONATE
WITH CARBONATE
CLAY
SILT
FINE MEDIUM COARSE
SAND
FINE MEDIUM COARSE
GRAVEL
0 002 0 006 0 02 0 06 0 2 0 6 2 60
0 0001 0 001 0 01 0 1 1 0 10 100
GRAIN SIZE IN MILLIMETERS

analysis.

A. Sieve Analysis

1. Oven dried soil sample retained on no.200 sieve was taken for the sieve analysis.
2. The sample was sieved through a set of sieves i.e. 4, 10, 14, 20, 40, 60, 70, 200 no. sieves. The sieving was performed with mechanical sieve shaker for 5 to 10 minutes.
3. The stack of sieves were removed from sieve shaker and weight of material retained on each sieve was computed. The percentage of total soil sample retained on each sieve was also calculated.
4. The percentage of weight passing through each sieve was calculated. The calculation was started with 100 percent and substracting the percentage retained on each sieve as a cummulative procedure as given by
   Percentage passing = Percentage arriving - percentage retained
5. A plot on semilogrithmic paper of grain size versus percent passing was plotted (fig 11).

B. Hydrometer Analysis

1. The soil group passing through the sieve no.200 was oven dried and 50 gm of the sample was taken for hydrometer analysis.
2. The soil sample (50 gm) was soaked with 100 ml of sodium hexametaphosphate solution for 24 hours.
3. All the contents were transferred into the mixer cup and suitable quantity of water was added. The mixing was carried out for 2 to 3 minutes. The mixture was then carefully transferred to the sedimentation cylinder.
4. The cylinder of soil suspension was covered with rubber stopper and the suspension was carefully agigated for one minute. The jar was placed on table and the cap was removed. The hydrometer and thermameter were then inserted in the controlled jar and readings of hydrometer were taken out 0.5, 1,2,4,8,15,30,60,120, 240 and 1440 minutes.
5. The temperature of suspension was also recorded to the accuracy of 1^{o}C for each hydrometer reading.
6. Between the hydrometer readings, hydrometer was placed in another jar containing 100 ml of dispersive agent and 900ml of water and placed at the same temperature as other jar. The reading of hydrometer was calculated to find out the hydrometer corrections.
7. The diameter and the percentage finer with respect to each elapsed time interval was calculated. The grain size was plotted against percentage finer on semilog paper (fig 12).

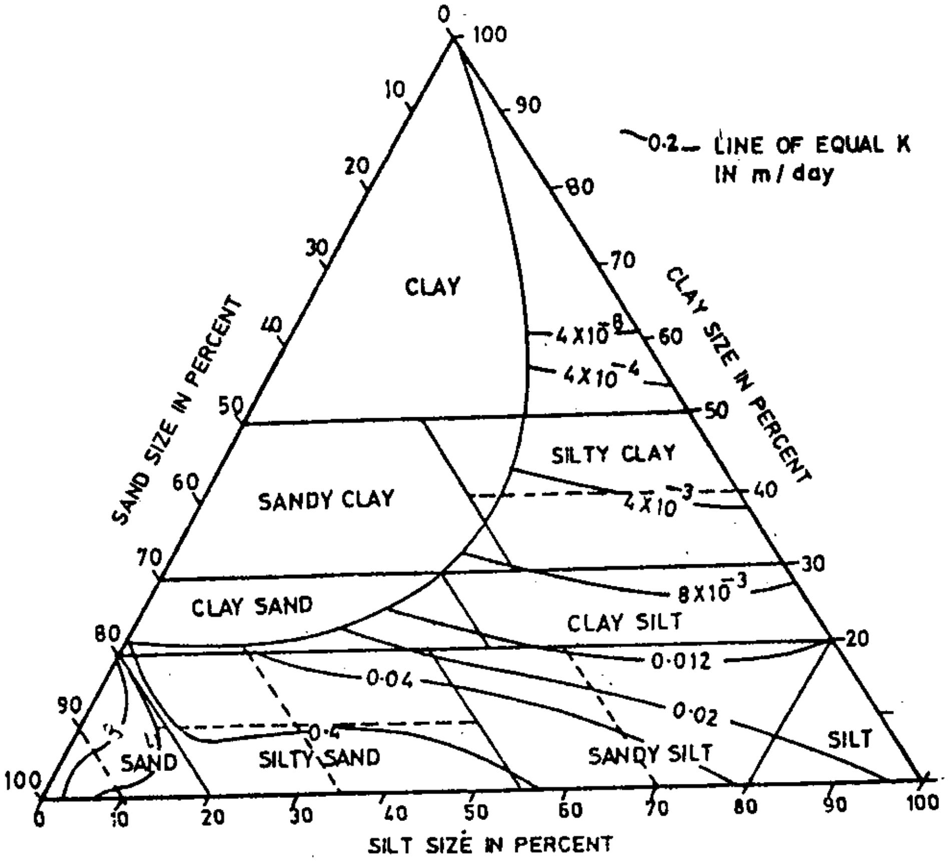


Fig No. 12: Johnson graph for saturated hydraulic conductivity

Similar procedure of analysis was applied for the soil samples after the carbonate was removed from the sample.

3.3 Proceedure form measurement of field saturated hydraulic conductivity

1. A well hole was prepared at the site with the help of soil auger and sizing auger. The hole was dug with the help of soil auger to a depth 15 cm less than the desired for final well depth. The 15 cm was dug with the help of sizing auger to produce a debris free well hole of uniform geometry of dia 6 cm and bottom flat.
2. Tripod was centred over the well hole and permeameter was lowered so that the support tube entered into the well hole.
3. After the permeameter is placed, it is filled with water. Varification was then made for ensuring that both the reservoirs were connected.
4. The air inlet tip was slowly raised to establish the 5 cm well head height (H1).
5. The rate of fall of the water in the reservoir was measured at a regular time interval. The difference in readings at consecutive time interval divided by the time interval gave the rate of fall of water level, R1 in the reservoir.
6. The rate of fall of water in the reservoir was continuously monitored until it was almost same for three consecutive intervals. This rate of fall of water is called R1 and is defined as steady state rate of fall.
7. A 10 cm well head height (H2) was established and the rate of fall of water, R2, in the reservoir was obtained for stable value of R2.
8. The field saturated hydraulic conductivity (Kfs) was then calculated using following equation equation no.**5**.

4.0 Result And Discussion

The particle size analysis of the soil samples was carried out in the soil water laboratory of the Institute. The grain size distribution of the soil particles is given in tab 4. The grain size distribution for the soil after removing the carbonate from the soil sample is given in tab 5. It was observed from these tables that significant difference in the texture is there between the soil samples having carbonate and soil samples from which the carbonate is removed. This is indicated in the graphs plotted between the grain size in millimeter and the percentage passing for all the soil samples illustrated in Fig 11. From the table 4 and 5, it was found that except for soil sample A5 and A11, all the samples from which carbonate was removed have higher sand percentage as compaired to the samples containing carbonate.

Similarly the carbonate minus soil samples have higher silt percentage as compaired to the carbonate plus soil samples except for soil sample A6. As regards clay soil samples minus carbonate have quite less percentage of clay as compaired to soil samplesplus carbonate.

Tab.4: Particle size analysis for soil sample containing carbonate

S.No.	Sample No.	Gravel %	Sand %	Silt %	Clay %
1.	A1	0.80	46.20	33.50	19.50
2.	A2	1.00	52.80	27.70	19.50
3.	A3	0.70	55.70	26.10	17.50
4.	A4	0.00	27.00	58.00	15.00
5.	A5	5.10	9.90	72.50	12.50
6.	A6	0.1	11.30	58.10	30.50
7.	A7	0.0	37.50	40.50	22.00
8.	A8	0.00	47.50	37.70	14.80
9.	A9	0.20	57.30	25.00	17.50
10.	A10	0.60	27.00	52.40	20.00
11.	A11	0.00	82.50	12.70	4.80

Tab. 5: Particle size analysis for soil sample after carbonate is removed.

S.No.	Sample No.	Gravel %	Sand %	Silt %	Clay %
1.	A1	0.00	53.75	40.75	5.50
2.	A2	0.00	53.50	41.00	5.50
3.	A3	0.00	61.75	33.50	5.00
4.	A4	0.00	35.00	59.25	5.75

5.	A5	0.40	7.85	83.00	8.75
6.	A6	0.10	37.40	56.20	6.30
7.	A7	0.00	40.00	50.50	9.50
8.	A8	0.00	50.00	42.00	8.00
9.	A9	0.20	61.80	32.20	5.80
10.	A10	0.20	34.80	57.20	7.80
11.	A11	0.10	79.40	18.25	2.25

Tab.6: Variation of saturated hydraulic conductivity with % of carbonate

S.No.	Sample No.	Saturated hydraulic conductivity Ks in m/day			% of carbonate
		By Guelph Permeameter	By Johnson's Graph Carbonate present	Carbonate removed	
1.	A1	0.069	0.02	0.4	1.68
2.	A2	very small	0.023	0.4	1.42
3.	A3	0.44	0.04	0.4	0.9
4.	A4	0.003	0.016	0.2	2.09
5.	A5	-	0.014	0.019	3.75
6.	A6	-	0.006	0.22	1.50
7.	A7	0.05	0.009	0.04	1.50
8.	A8	-	0.04	0.31	1.54
9.	A9	0.9	0.04	1	1.84
10.	A10	0.1	0.0116	0.19	0.95
11.	A11	6 (very high)	4	2	1.27

The saturated hydraulic conductivity of the soil samples measured by Guelph permeameter is given in tab 6. The relationship between in situ saturated hydraulic conductivity and texture has also been given by Johnson (1963) (Fig 12). The saturated hydraulic conductivity values obtained from the Johnson graph for the soil samples with and without carbonate are given in tab 6. It has been observed that most of the saturated hydraulic conductivity values for soil samples having carbonate corresponds well with the saturated hydraulic conductivity values obtained by Guelph permeameter. The saturated hydraulic conductivity values given by Johnson's graph for most of the soil samples without carbonate are much higher as compared to the in situ values obtained by Guelph permeameter.This is due to the fact that the carbonate present in the soil is acting as a cementing material by way of filling the pores of the soil and blocking the flow of water through these pores. Thus, reducing the saturated hydraulic conductivity of the soil. The percentage of carbonate present in each sample was found out and is presented in tab 6.

The depth to watertable contours plotted for pre monsoon and post monsoon for year 1991 are given in Fig 13. From the figures it is quite clear that the water table in the district is fairly deep and there is no problem of waterlogging due to ground water table rise. The waterlogging problem that is existing in the study area is mainly due to the inadequate surface drainage system. When rainfall comes, because the hydraulic conductivity of the soil of the area is poor (due to the presence of carbonate) and the existing drains in the area are perheps not adequately designed to handle this increased runoff the water gets stagnated in the fields and creates waterlogging and consequently crop failure. Therefore, the actual runoff taking place from the fields should be found out and the existing surface drainage system should be redesigned accordingly.

5.0 Conclusions

The soil of the area is containing carbonate which in turn is resulting in poor saturated hydraulic conductivity. The area is suffering from the problem of surface waterlogging or water stagnation. There is an urgent need to redesign the surface drainage system based on the the actual surface runoff taking place from the fields.

6.0 Suggestions for further research

1. The actual area suffering with the problem of carbonate should be found using settelite data.
2. Based upon the rainfall records and the land use of the area. The total volume of runoff should be found out using SCS method.
2. Taking suitable factor of safety for preventing crop damage an efficient drainage system should be designed for the area.

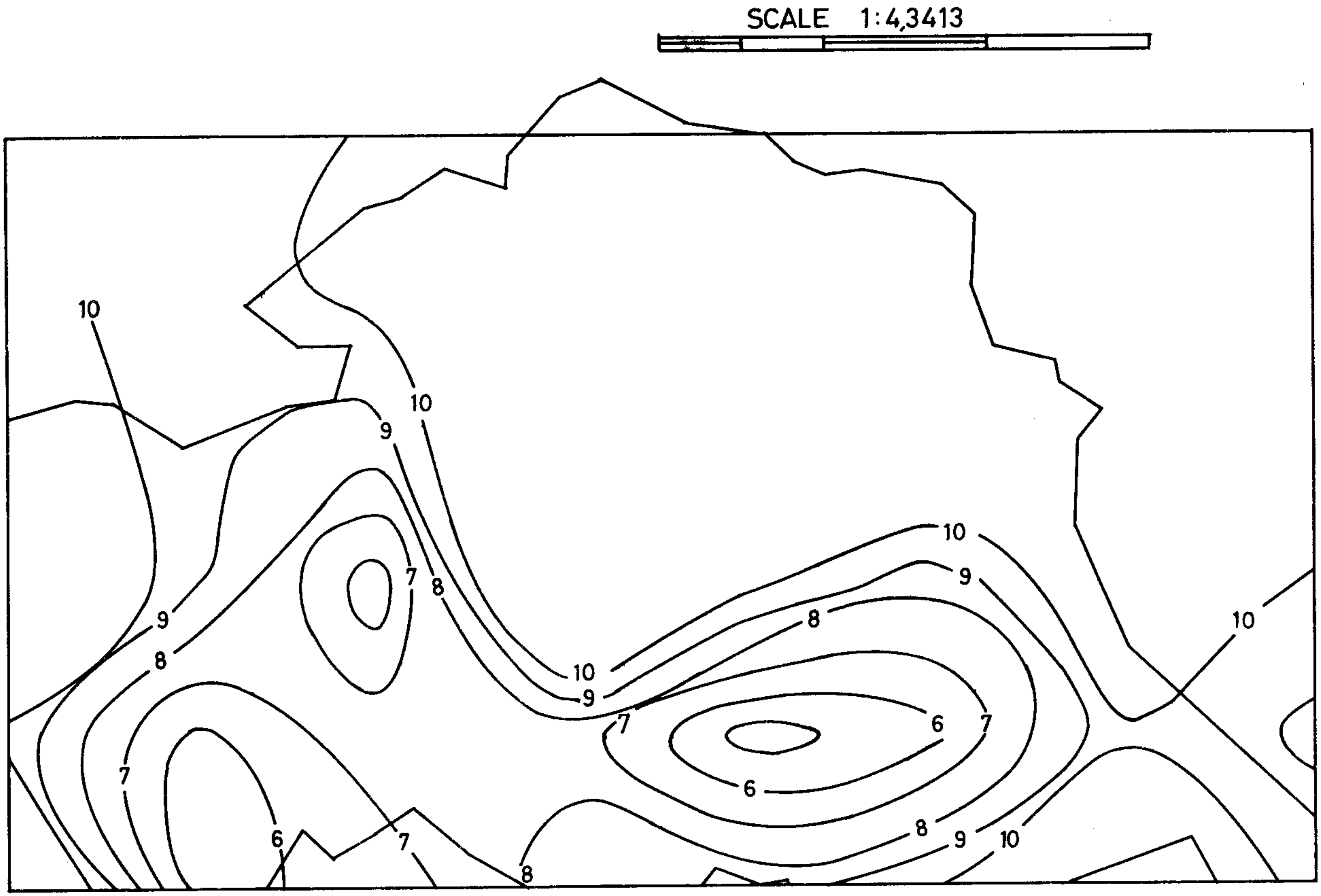


FIG. 13 a —DEPTH TO WATER TABLE MAP FOR PRE MONSOON 1991

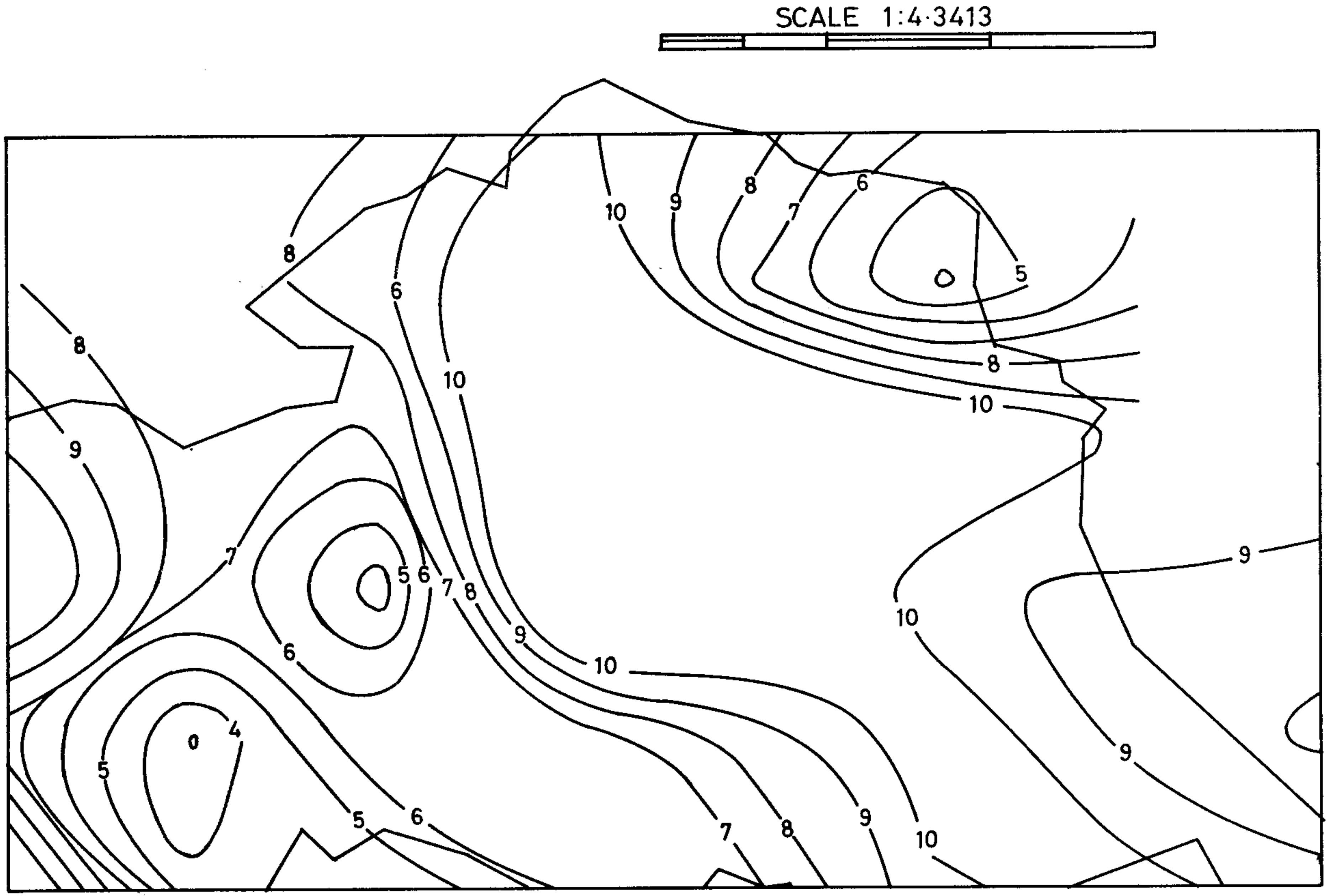


FIG.13 b – DEPTH TO WATER TABLE MAP FOR POST MONSOON 1991

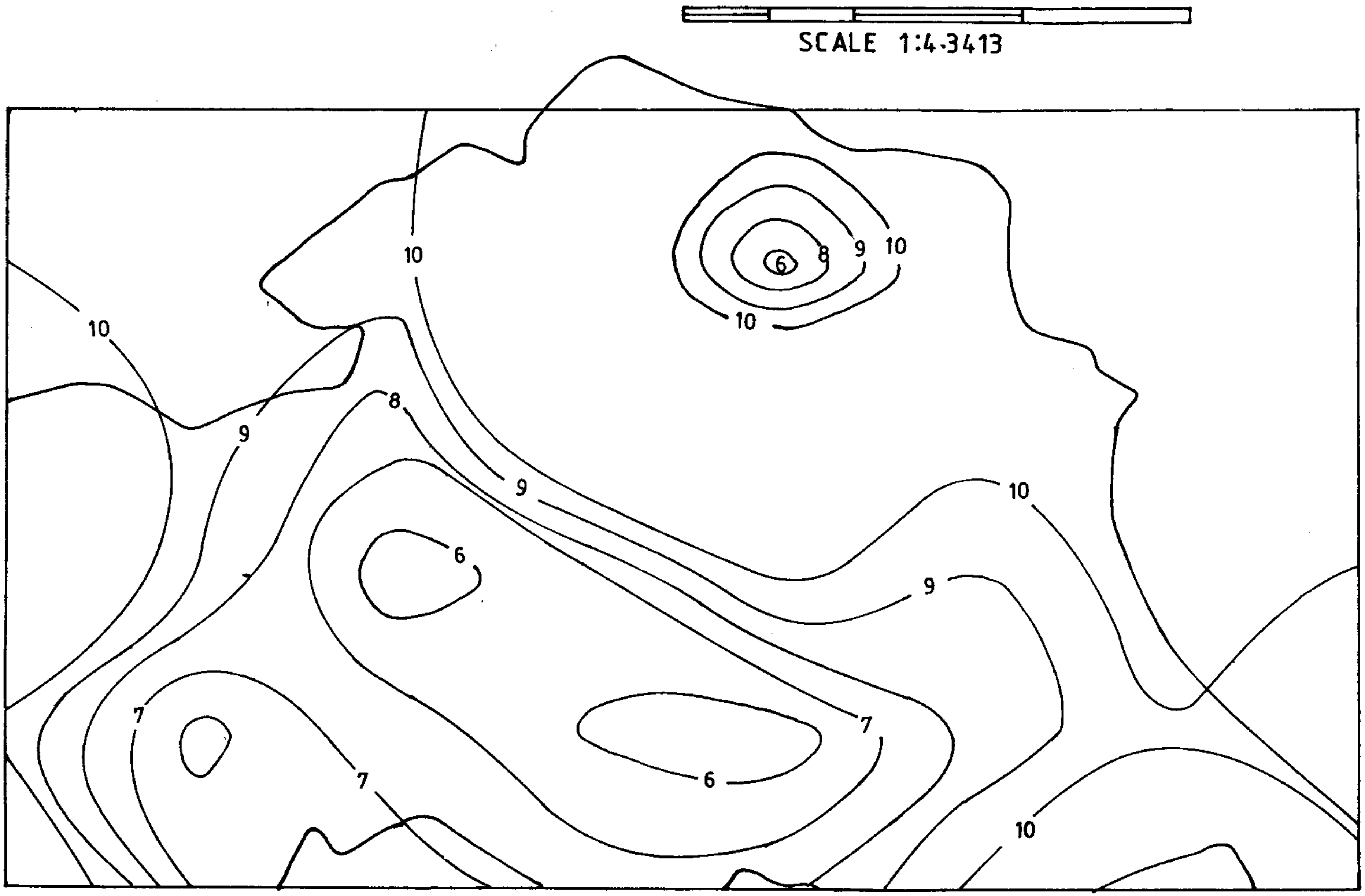


FIG.13c-DEPTH TO WATERTABLE MAP FOR PREMONSOON 1990

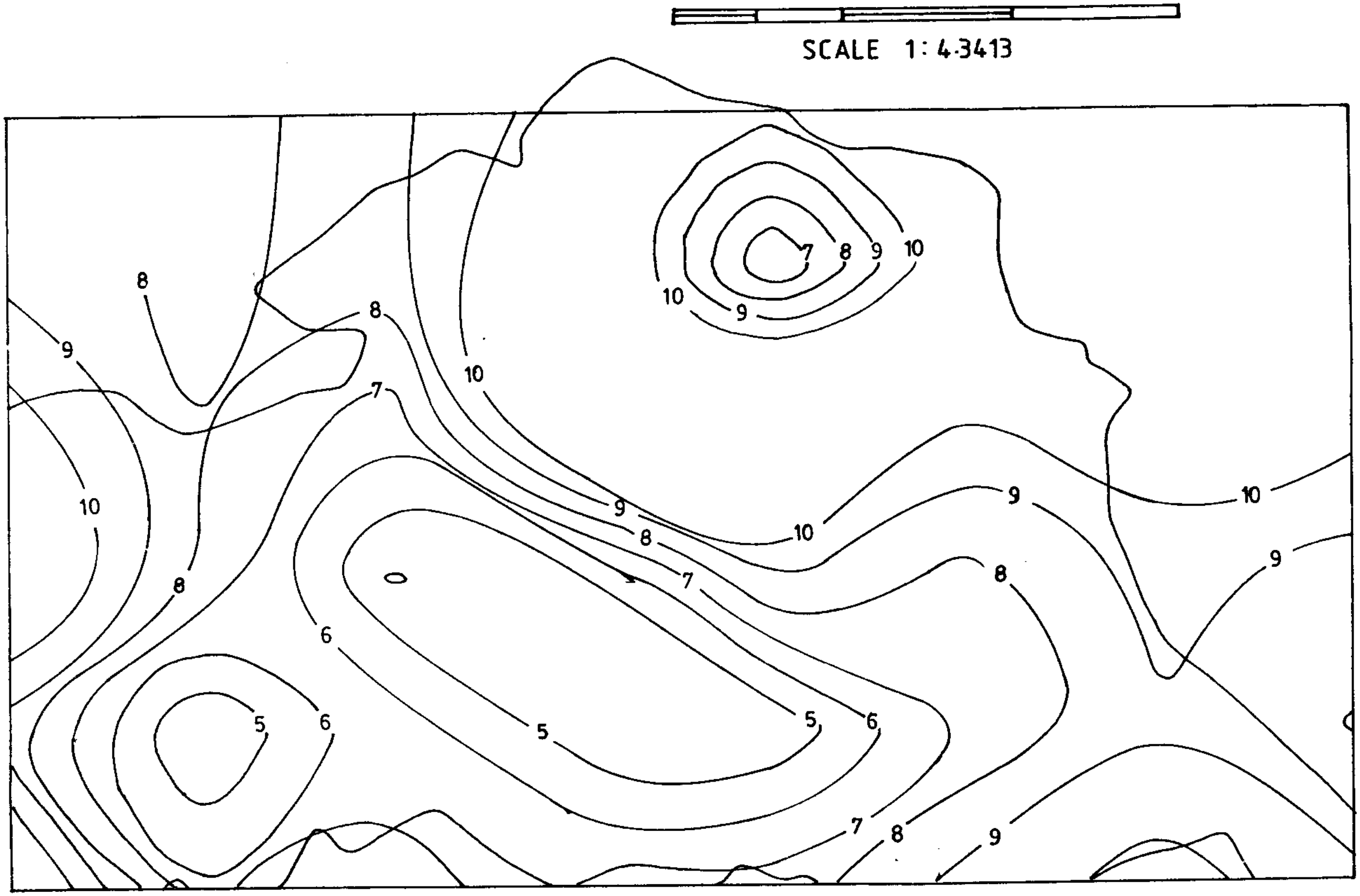


FIG.13d-DEPTH TO WATERTABLE MAP FOR POSTMONSOON 1990

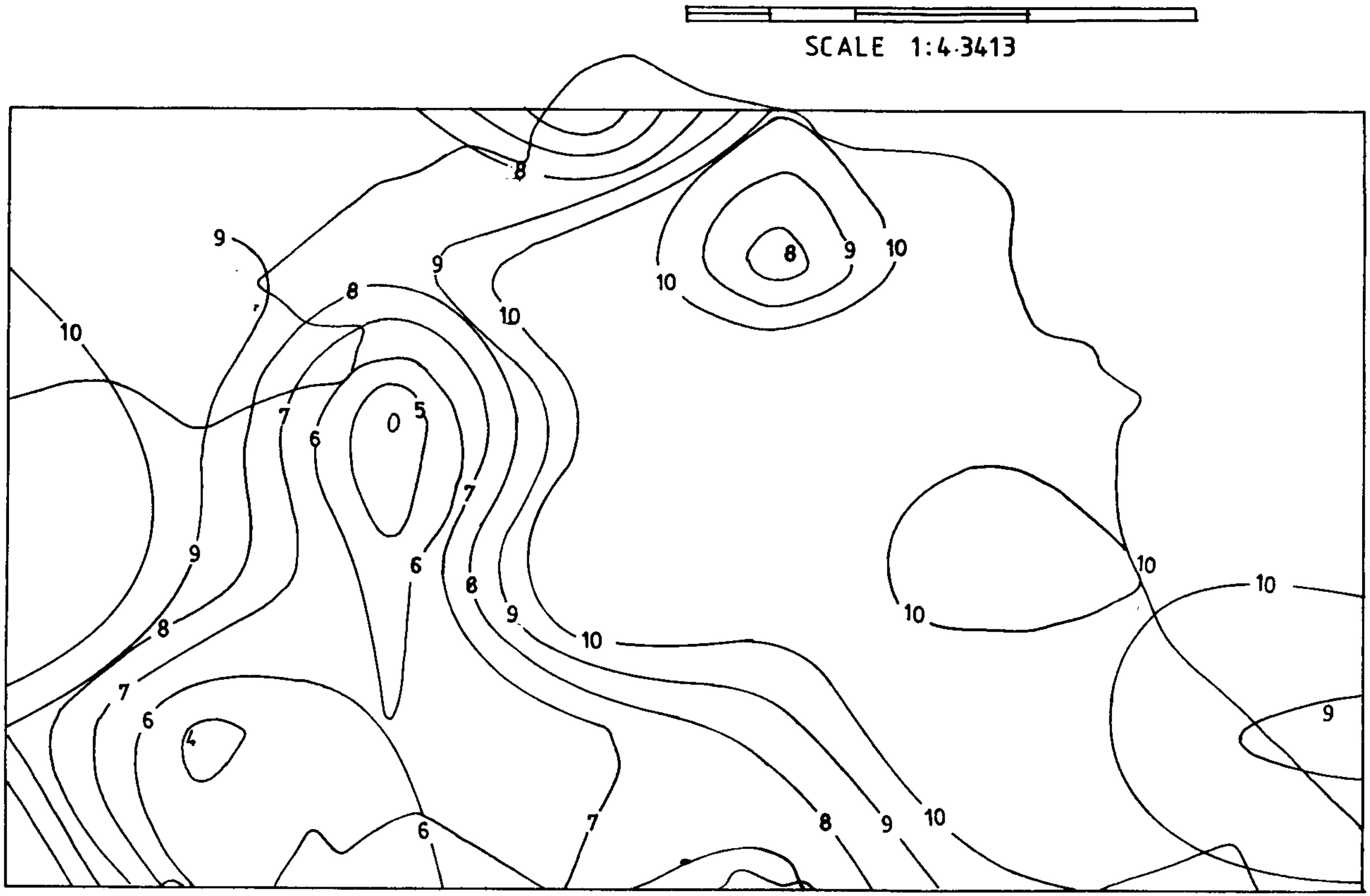


FIG. 13e – DEPTH TO WATERTABLE MAP FOR PREMONSOON 1989

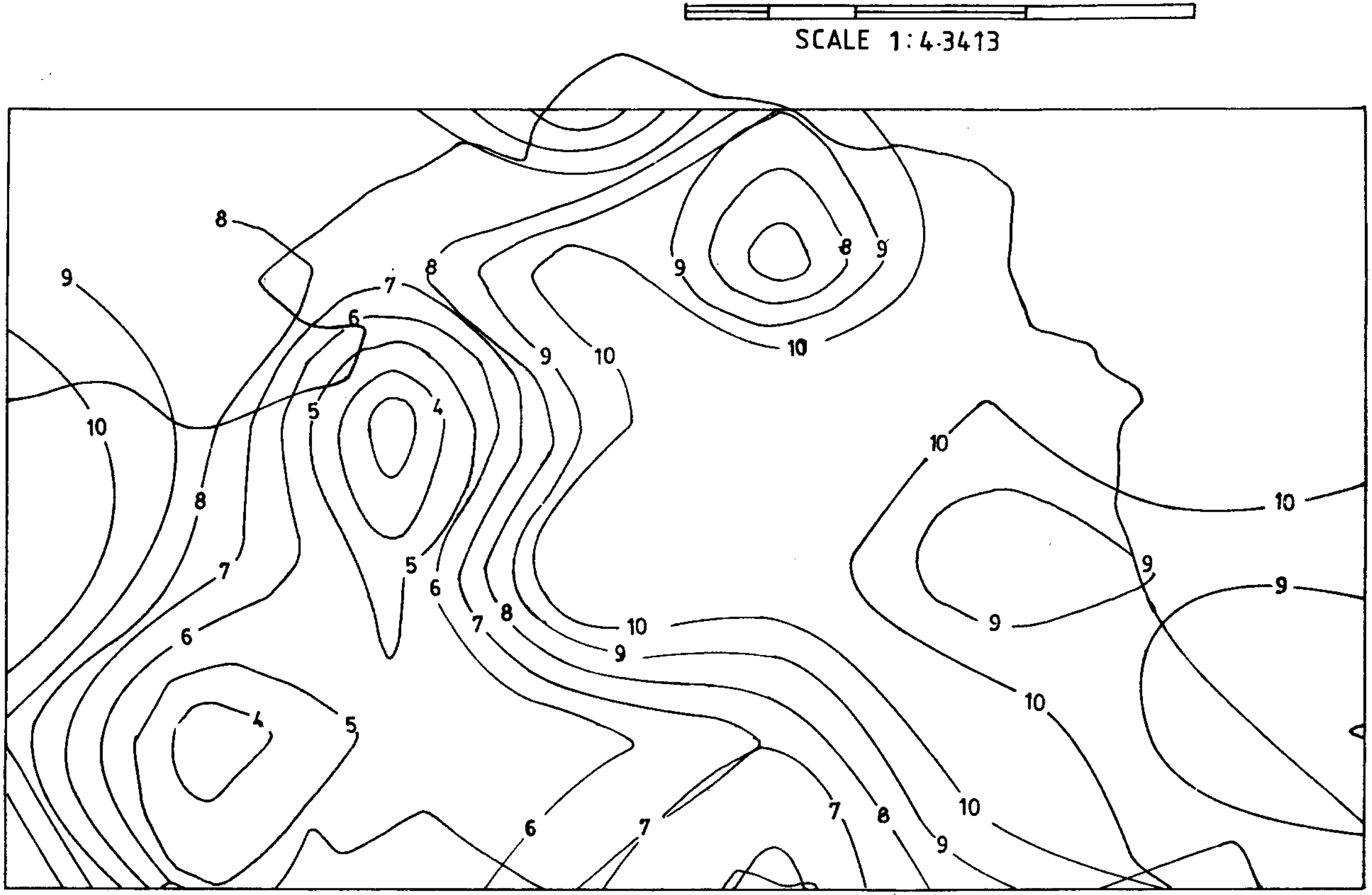


FIG. 13f-DEPTH TO WATERTABLE MAP FOR POSTMONSOON 1989

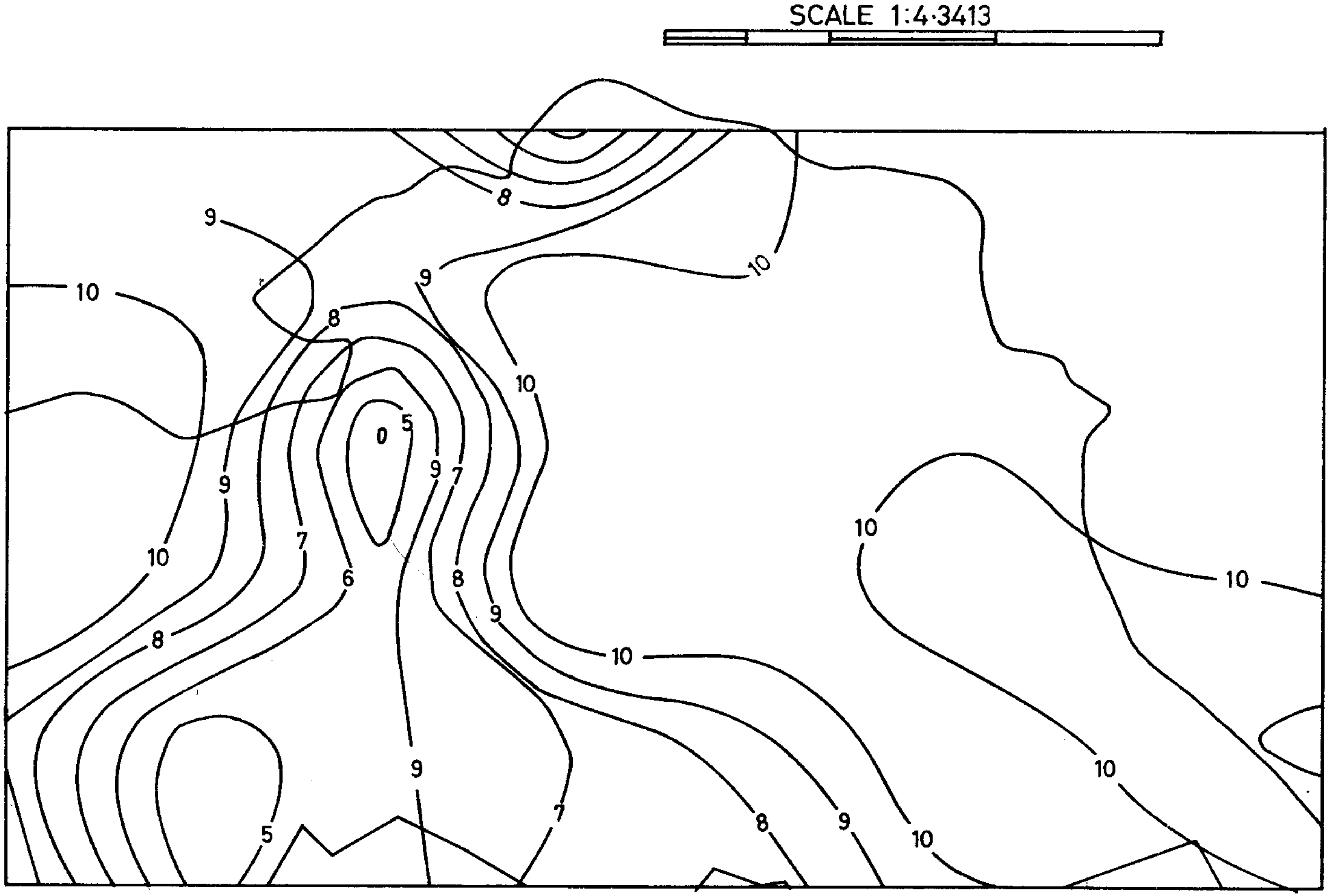


FIG.13g–DEPTH TO WATER TABLE MAP FOR PRE MONSOON 1988

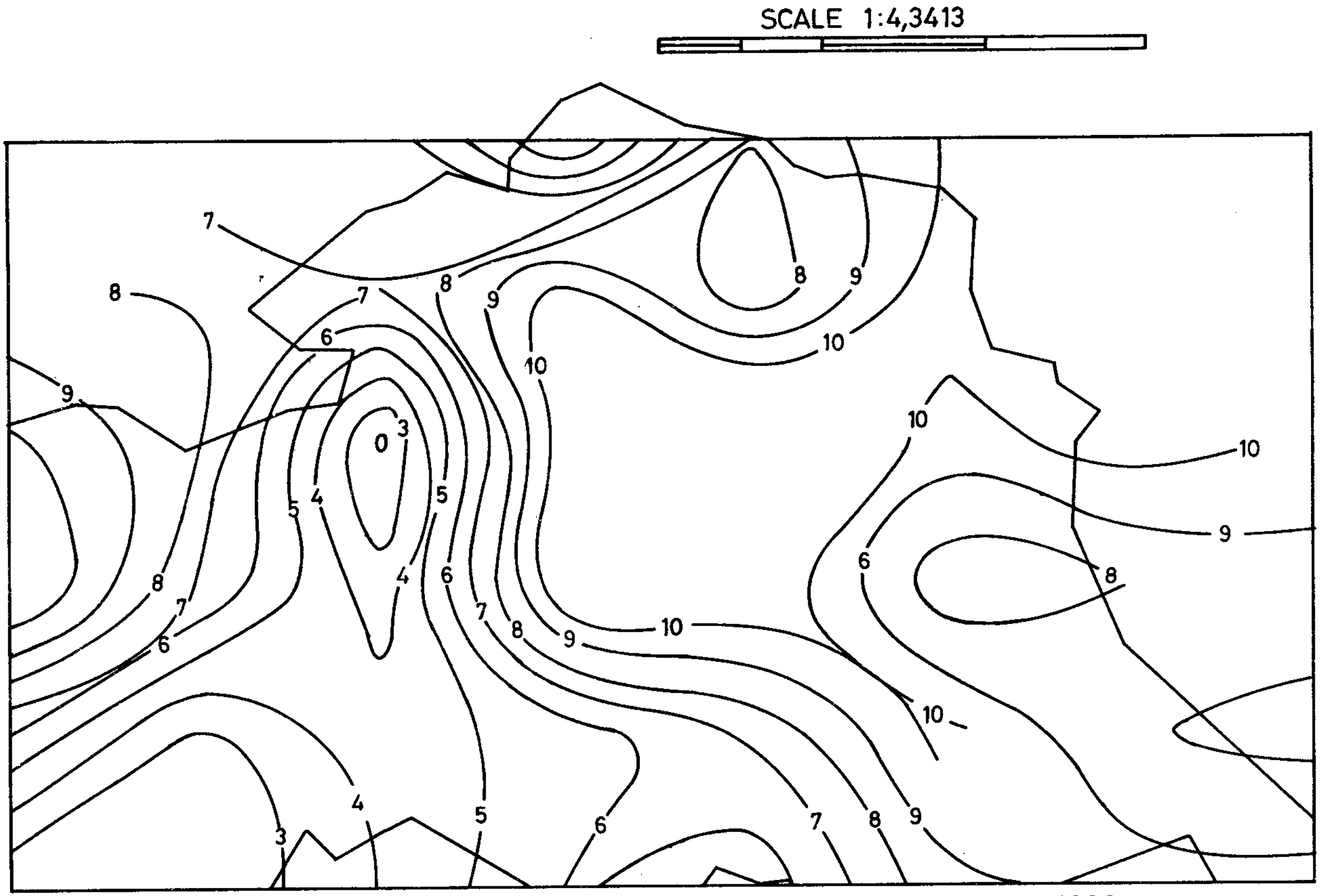


FIG.13h- DEPTH TO WATER TABLE MAP FOR POST MONSOON 1988

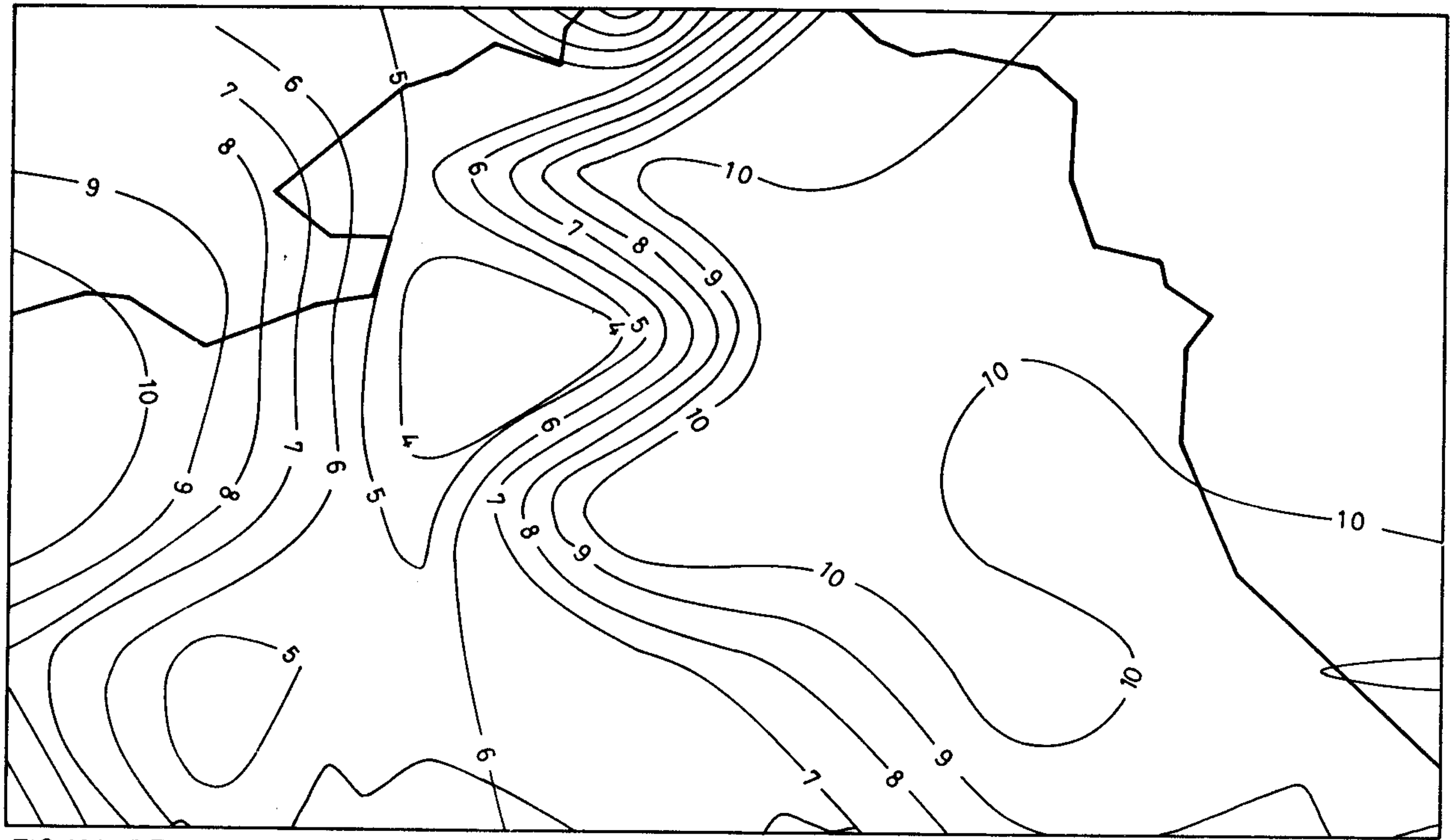


FIG.13i - DEPTH TO WATER TABLE MAP FOR PRE-MONSOON 1987

SCALE 1:4,3413

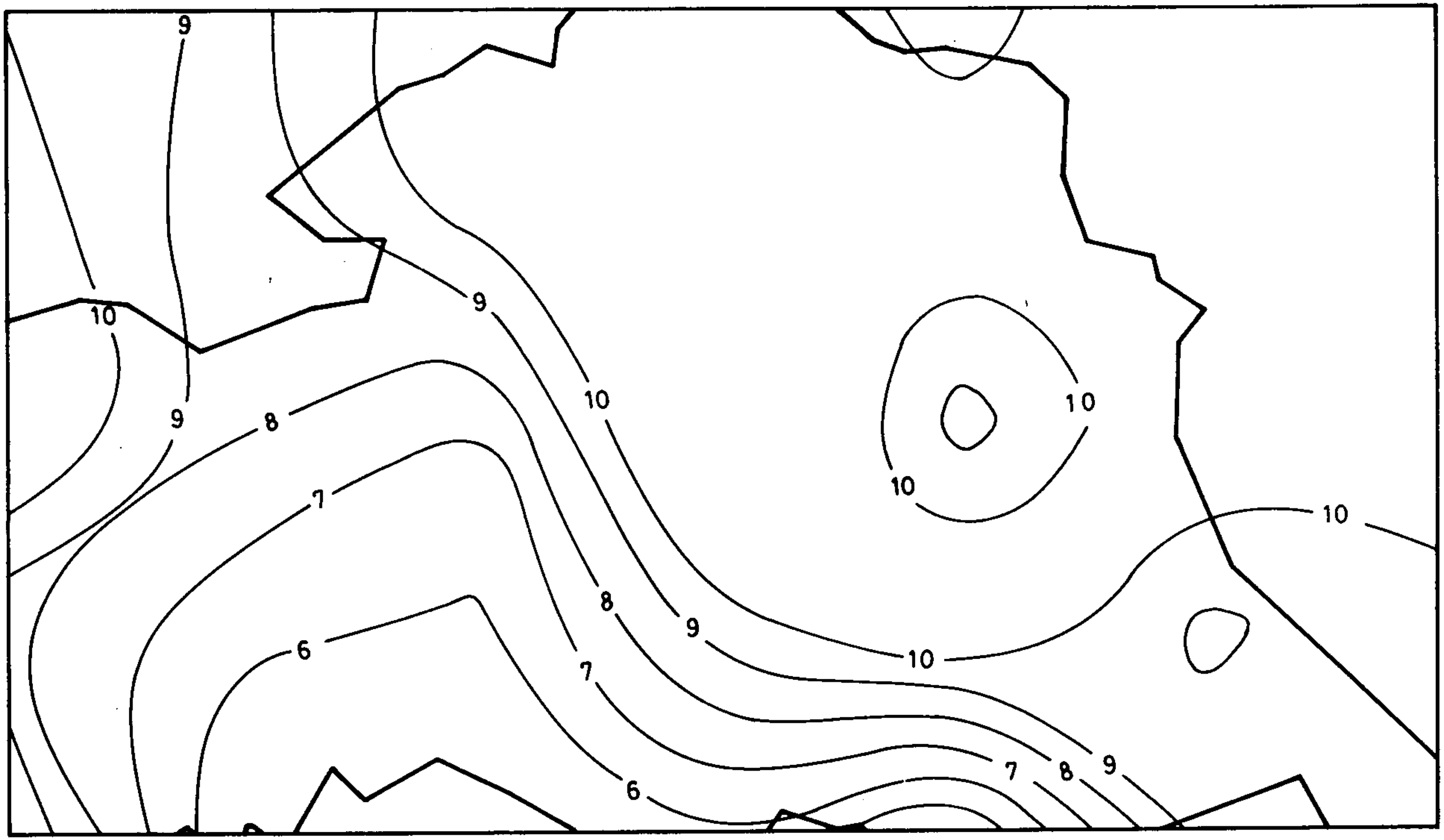


FIG.13j – DEPTH TO WATER TABLE MAP FOR POST-MONSOON 1987

SCALE:- 1:4,3413

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