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WATER CONSERVATION AND IRRIGATION COMMISSION

A STATISTICAL SURVEY OF HYDRAULIC CONDUCTIVITY AND ITS RELATION TO SOIL TYPE IN THE M.I.A.

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May, 1974.

A STATISTICAL SURVEY OF HYDRAULIC CONDUCTIVITY VALUES OBTAINED BY THE AUGER HOLE METHOD IN THE M.I.A.

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1. Introduction

In the Murrumbidgee Irrigation Areas of New South Wales the installation of tile drains to protect plantings against waterlogging has become common practice. In situ measurements of hydraulic conductivity are carried out and the drain spacing is calculated with the steady state drainage formula of Hooghoudt (1940). This procedure contrasts with Victorian Districts where the drain spacing is usually determined on basis of soil types, particularly in the mallee landscape of the Lower Murray Areas.

Maasland (1956) investigated various formulae derived overseas and adopted them for local conditions. Maasland and Haskew (1958) discuss the factors related to the measurement of the hydraulic conductivity by the auger hole method and how the results can be processed, Talsma and Haskew (1959) investigated the watertable response to tile drains in comparison with theory.

Where information on soils is available the determination of drain spacing on basis of soil type would be easier and cheaper than the method using hydraulic conductivity measurements, the latter method involving the boring of holes, taking of field measurements and subsequent office calculations. Since the standard procedure requires one determination per acre the cost per acre may exceed $10.00. It is desirable therefore to investigate a possible relationship between soil type and hydraulic conductivity. The soil map of Taylor and Hooper (1938) is used, together with a sample from some 15,000 hydraulic conductivity determinations which have been obtained during the past 20 years for tile drainage purposes.

2. Aims of Analysis

The results that may be expected from an analysis of the available hydraulic conductivity values may be summarised as follows:-

(1) The relation between hydraulic conductivity and soil type. A ranking of soil types according to mean hydraulic conductivity values should be possible. Apart from a ranking of soil types a grouping may be possible but this would depend also on factors such as the variation of hydraulic conductivity with the depth from the soil surface.

(2) The variability of hydraulic conductivity within a soil type and the significance of the difference between farms within the same soil type. This could provide an answer as to whether a predetermined drain spacing could be used for each soil type.

(3) The variability of hydraulic conductivity within a soil type on a particular farm compared to the variability within an area for which a particular drain spacing was calculated and recommended. These results may be used to evaluate the present procedure with the aim to reduce the cost of investigations without a loss in accuracy.

(4) The variability of hydraulic conductivity within soil types on a farm or within the recommended areas may give information about the safety margin which should be applied to drainage design criteria.

(5) The variation in hydraulic conductivity with depth may provide further information about the optimal drain depth.

The above five aims will be discussed separately.

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3. Sampling

Soil maps generally are not very accurate to the extent of reflecting deep subsoil conditions. The typical profiles described may give information on the soil layering to a depth of 1.80 metres, as is the case with C.S.I.R. bulletin 118 of Taylor and Hooper (1938). However during the actual demarkation of soil types surface features are generally used more intensively than information from deeper layers, obtained by boring of holes. Therefore most soil maps would reflect the character of the upper horizons more than the deeper layers of the soil profile.

In the lower Murray Irrigation Districts of Victoria, New South Wales and South Australia and in the Goulbourn Valley near Shepparton subsoil drainage is installed at relatively shallow depth, between 0.75 and 1.50 metres depth. Under such conditions there may be a reasonable chance that the hydraulic conductivity of the water conveying layers is related to the soil types. In the Murrumbidgee Irrigation Areas, however, drainage is usually installed at about 1.80 metres depth. In these areas experience indicates that the relation between hydraulic conductivity and soil type is generally poor. Drain spacings therefore are based on measurements of hydraulic conductivity in situ.

Hydraulic conductivity values, determined for every acre of a farm are plotted on a photograph and areas of similar hydraulic conductivity values delineated. These boundaries do not generally correspond with the soil type boundaries.

For this analysis the available hydraulic conductivity values for every soil type are used to obtain a sample. The sampling procedure is not ideal because firstly not all farms are investigated and therefore the soils on these farms cannot be included in the sample, and secondly, for the farms where investigations were carried out other problems with sampling exist as discussed below.

As mentioned previously, holes are bored at a density of one per acre. At the time of measurement the watertable found may be either high (within 0.75 metres from the soil surface), normal (between 0.75 and 1.05 metres), deep (deeper than 1.05 metres) or absent (below the depth of the hole which is 1.80 - 2.10 metres). The hydraulic conductivity measured applies for the soil layers between the watertable and the bottom of the hole. In a sample all values should be comparable and this is not the case where some holes had deep watertable, some with normal watertables and some with high watertables. Since measurements with the watertable desired for the sample are not available for all holes a proper random sample cannot be obtained even for the farms which have been investigated.

It is to be realised that the results only apply for the areas for which a measurement with the watertable at the desired depth are available. Nevertheless a comparison of areas with high watertables with areas with normal or deep water tables is attempted. Since the distributions of holes with high, normal or deep watertables is rather erratic and without a particular pattern it is considered that such a comparison is a reasonable course of action.

In this analysis only the soils of the Mirrool Irrigation Area are considered. The soil map shows a considerable range of size of unit areas for the various soil types. The complex pattern of soil type boundaries is independent of the farm portion boundaries.* A particular unit area of soil type is usually distributed over several farm portions. For the sake of simplicity all farm portions having more than 15 acres of a particular soil type within its boundaries

* The farm location plan shows that many farms consist of two or more portions, dependent on the time these farms were set apart and whether amalgamation has taken place. In this report these portions are used as unit areas and they are referred to as "farm portions"

were listed. The final sample was drawn from that listing. The sample therefore does not represent all available measurements but only the measurements within the described conditions. This procedure resulted in many measurements from minor unit areas of soil types being omitted from the analysis.

After listing of all farm portions having more than 15 acres of a particular soil type, a random sample of 10 farm portions was obtained for each soil type. Of this sample some farms were not investigated or the records were incomplete. The measurements which were available within the total remaining area of the sample were used were used for further analysis. Table 1 gives some of the details.

The proportion of farms in the sample which are not investigated does not necessarily give an indication of the proportion of farms which did not develop high watertables, although as at 1973 it may be said that most farms requiring drainage are now investigated. Within the remaining sample there is a proportion of holes which were dry at the time of measurement. For these holes the same applies.

In the last three columns of table 1 the number of measurements used for each watertable condition are given. It may be noted that it was not possible to obtain the same number of measurements from each farm portion. From one portion relatively more measurements with normal watertables may have been obtained. This bias in the analysis is to be incorporated in the assessment of the reliability of the results of following sections.

For a small number of soil types additional information was collected from other farms because the number of observations in the final analysis proved to be too small.

4. The Hydraulic Conductivity in Relation to Soil Type.

With the available information provided by the sample for each soil type calculations were made of the mean hydraulic conductivity, the standard deviation, the standard deviation of the mean and the coefficient of variation. These calculations were carried out on the data for all watertable conditions, viz high, normal and deep.

With the means, the standard deviation of the means and the number of degrees of freedom known, the various soil types could be compared to see whether the difference between the means was significant. The statistical theory as given in Snedecor and Cochran (1967) was used for these calculations.

Table 2a gives a ranking of soil types and the results of the test on the level of significance of the difference between means for normal watertable conditions. Table 2b and 2c give the same information, but for high and deep watertable conditions respectively.

From tables 2a, 2b and 2c it is evident that the hill slope soils, Tharbogang loam, Ballingall loam and Wyangan loam are amongst the most permeable soils within the M.I.A. Hanwood loam and sandy loam, and Yenda loam are the most permeable of the soils of the plain. The least permeable soils of the latter category are Camarooka sandy loam, Griffith clay loam and Beelbangera clay loam, in accordance with expectations from profile characteristics.

The ranking varies according to whether normal, high or deep watertables are considered. Although this point is discussed in more detail later it may here be noted that most soils record a lower hydraulic conductivity with deeper water tables with Banna sand being one of the most obvious examples.

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The significance levels between the means given in tables 2a, 2b and 2c indicate that there is no significant difference between the mean and hydraulic conductivity of many soils. For instance the mean of Ballingall loam is not significantly different from the mean of Wyangan loam or Tharbogang loam and the mean of Griffith loam is not significantly different from the mean of Banna sand, Hyandra sandy loam, Type 9, Bilbul clay loam or Mirrool loam, when normal watertable conditions are considered. The lack of significance of the difference between the means is caused by the rather large variability and the closeness of many of the means in the range from 0.40 to 1.20 ft/day.

The ranking appears to conform to some extent to the agricultural assessment of soils. In other words the best soils are the most permeable and the most easily drainable. The differences in the hydraulic conductivity between the various soils may be largely explained by differences in texture (Talsma and Flint, 1960).

Agricultural suitability depends not only on textural or chemical characteristics but also on factors such as moisture holding capacity, which varies (Taylor and Hooper, 1938) and drainability or susceptability for waterlogging. Tile drainage has brought about a greater similarity of the soils in their agricultural suitability, as far as the latter factor is concerned. The criteria for design of tile drainage in the M.I.A. is similar for all soil types, irrespective of texture or effective porosity. The aim is to lower the watertables between drains from 45 cm to 75 cm below soil surface within 3 days.

5. Variation of Hydraulic Conductivity Between Farm Portions of the Same Soil Type.

If there is a strong relationship between soil types as mapped and permeability, a small or insignificant difference between the means for farm portions of the same soil type may be expected. Under such conditions a drain spacing may be determined for each soil type with measurements of hydraulic conductivity being no longer required.

To investigate the above proposition the variability within the total area of the soil type, the variability within the area of the same soil on farm portions and the differences between mean hydraulic conductivity values found on farm portions need to be considered. Table 3, column 1, gives the coefficients of variation within the total area of the soil types. The means may be derived from table 2a. The coefficient of variation is the standard deviation over the mean.

No relation was found between the mean hydraulic conductivity of soil types and the coefficient of variation. The coefficient of variation ranged between 66% for Ballingall loam to 175% for Banna sand. The median value found was 92%. The frequency distribution for some soil types is obviously skew, otherwise values of over 100% would not be expected.

Table 1 shows that 184 farm portions were included in the overall sample of 19 soil types and that 139 farm portions provided the information used in this analysis. Six or more suitable measurements with normal watertables were obtained from 78 farm portions. Some variation between farm portions of the same soil type may be expected. To this end the means and coefficients of variation were calculated.

For any soil type it was found that the mean hydraulic conductivities on farm portions were significantly different from each other in many instances. This indicates that it would be wrong to assume a standard drain spacing for every soil type. The situation needs to be determined for every farm separately by means of measurements of hydraulic conductivity.

The coefficients of variation applying for the total area of the soil types and those applying for the area of the same soils on farm portions are shown in table 3. For three soil types, Tharbogang loam, Wyangan loam and Yoogali loam, the sample did not provide any farms having more than 6 suitable measurements. A variable number of farms meeting that requirement was included in the sample for the other 16 soil types. Table 3 demonstrates that the coefficients of variation of the hydraulic conductivity of the soil of farm portions is generally less than the coefficient of variation within the total area of the soil type. This is most obvious for Banna sand where the values on farm portions range between 43 and 95% whilst the overall coefficient of variation is 175%. The higher value applying for the total area of the soil types is attributed to the frequently large difference between farm portions.

Whilst the median value of the coefficient of variation for the total area of soil types was found to be 92%, the median coefficient of variation for the area of soils within farm portions is 69%, a substantially lower figure. The variability of hydraulic conductivity in deep subsoil horizons is discussed in section 7.

6. Variability Within Soil Types and Within Recommended Areas on Farms

Although no particular drain spacing can be determined for every soil type it may be possible to reduce the cost of investigations on a farm by using the soil boundaries and carrying out the required number of measurements within each soil type on the farm. Such a procedure would depend on the variability and the hydraulic conductivity within the soil type and within recommended areas. These latter areas are based on measurements of hydraulic conductivity at a density of one hole per acre together with a subjective demarkation of areas in which similar hydraulic conductivity values are found.

The change to recommendations according to soil type on each farm would only be worthwhile if drainage efficiency is not reduced and if the cost of investigations is less than under the present procedure.

The sample used for the analysis of this report includes 78 farms which have more than 15 acres of one soil type and a sufficiently large number of measurements of hydraulic conductivity with normal watertables. The means, standard deviation and coefficient of variation have been determined for these 78 farms.

A total of 42 recommended areas were randomly selected for the assessment of the variability within recommendations. Again the means, the standard deviations and the coefficient of variation were determined.

No significant relation between the means and the coefficient of variation was found for the sample using soil types on farms. For the sample using recommended areas on farm portions the relation was found to be positive and weakly significant ($r = 0.32$) at the 5% level. This result is in contrast with the result of Talsma and Flint who found that with increasing sandiness in the subsoil, which usually corresponds with a higher hydraulic conductivity, the coefficient of variation becomes less. The variability of the hydraulic conductivity in the deep subsoil is to be discussed in section 7.

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For both the sample with soil types on farms and the sample with recommended areas on farms the relation between the means and the standard deviation was found to be highly significant ($r = 0.99$ and 0.86) at the 1% level. This result is in accordance with most other work carried out (Jonkers 1972, Willardson and Hurst, 1965). The graphs published by the latter investigators shows that the regression line tends to go through the origin of the coordinate system, in accordance with the result that the coefficient of variation does not vary significantly with an increase in mean hydraulic conductivity.

No significant relation was found between the number of degrees of freedom of a subsample and the coefficient of variation, both for the sample with soil types on farms and the sample with recommended areas on farms. Therefore the variability of the hydraulic conductivity does not appear to increase with the increase in number of measurements or rather the increase in the area from which measurements are to be obtained. Nevertheless the reliability of the mean hydraulic conductivity will improve with the number of observations taken, becaure the standard deviation of the mean is the sample standard deviation divided by the square root of the number of observations.

For the sample with soil types on farms portions the median coefficient of variation was found to be 69%. For the sample with areas on farms as recommended for tile drainage the median coefficient of variation was found to be 57%. The difference between the means was found to be significant at the 5% level. Hence the variability within recommended areas appears slightly less than the variability within soil types on farm portions and the use of soil type boundaries would not give a better accuracy of the drain spacing where this is determined.

7. The Variability of the Hydraulic Conductivity in the Deep Subsoil.

The variability of the hydraulic conductivity in the deep subsoil presumably is related to its characteristics. Some of the aspects are discussed below. Table 4 gives a ranking of the coefficients of variation for soil types as determined from the sample. There is no relation between the coefficient of variation and the mean. This contrasts with previous results of Talsma and Flint (1960) who report lower values for sandy loam horizons than for clayey horizons.

The subsoil characteristics as described by Taylor and Hooper (1938) are also given in table 4. It appears that subsoils of consistently heavy texture, such as occur with Camarooka sandy loam, Beelbangera clay loam or Griffith clay loam have hydraulic conductivities with a lower coefficient of variation than the soils with a more sandy subsoil of mixed origin, such as Hyandra sandy loam or Type 9.

Where a layering is more obvious, such as with Banna sand which has a variable thicknesses of topsoil, or Mirrool loam and Yoogali loam with an apparent lightening of texture in the subsoil, the coefficient of variation was found to be high. The relative thickness of soil horizons, due to the mode of deposition, undoubtedly is of relevance in these cases.

Ballingall loam has a relatively low coefficient of variation, despite the hard pan which is supposedly occurring at 75 cm depth. Apparently this soil is rather uniform beyond that depth. The sample for Tharbogang loam was small, and the subsoil frequently is cemented which may explain its high coefficient of variation.

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The coefficients of variation found for heavy subsoils in this analysis correspond roughly with the values so found by Talsma and Flint (1960), viz about 70-90%. The earlier paper shows values as low as about 23% for sandy loam subsoil horizons whilst for soil types which are described as having such horizons, values of more than 90% were found in the current analysis. Apparently the variation and inconsistency in texture of subsoil horizons, together with an occurrence of variable degrees of cementation is much more pronounced in subsoils of lighter texture compared to subsoils of heavy texture.

8. The Change of Hydraulic Conductivity With Depth

It has already been mentioned that there is a change in hydraulic conductivity with depth. This has repercussions on whether the optimal drain depth is in fact 1.80 metres as is at present commonly (though not always) used in the M.I.A. It may be possible to give a listing of soils which have similar change in hydraulic conductivity with depth in common.

Table 5 shows the means of measurements for each soil type for normal, high and deep watertable conditions. For the two latter categories it is also shown whether the difference with normal watertables is significant. The values of the hydraulic conductivity of the various soil layers, computed from this information are shown in the columns 4, 5 and 6 of Table 5.

The non significance of the difference between means for high, normal and deep watertables is sufficiently common to cast doubts on the results. They nevertheless show some trends which are in accordance with experience. Table 6, which is based on the figures of the last three columns of table 5, shows that there is no significant difference in hydraulic conductivity with depth for several soils. Many other soils have a decreasing hydraulic conductivity with depth for several soils. Many other soils have a decreasing hydraulic conductivity with depth and some soils appear to have their highest conductivity between 0.90 and 1.40 metres below soil surface. Although the results in this table are of low reliability and some soils probably are not grouped in the correct category, it does indicate that there are many soils which possibly would drain as well if drains were installed at 1.50 metres depth and that little is gained by the extra 30 cm, which is current practice. This is in accordance with some of the conclusions of Talsma and Flint (1960).

9. The Safety Margin For Design of Drainage Installations

A safety margin for design of drainage installations may be introduced in various ways. The depth to the impermeable layer may be chosen conservatively, the drainage discharge criterion may be chosen larger than expected from long term rainfall frequency data, or the mean hydraulic conductivity or the calculated spacing may be decreased by a proportion. Some of these procedures are used at present. The steady state design criterion is based on 5 mm/day, although whilst rainfall frequency analysis of winter rainfall data shows that about 4 mm/day is not exceeded more than very infrequently. The geometric mean of the hydraulic conductivity is calculated rather than the arithmetic mean, accounting for some of the variance occurring between the observations of a sub-area.

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For an area for which measurements of the hydraulic conductivity were available at one per acre, the arithmetic mean hydraulic conductivity (k) and the drain spacing (S) can be calculated using the drainage criterion (q) and the other factors required. About half the area will then be overdrained because k is above average and about half the area will be underdrained. The latter area will discharge at a rate less than q. It depends on the variability of k how large a proportion of land will discharge substantially less than q, the design discharge criterion, to the extent that the plantings may suffer from waterlogging. Since for a particular drain spacing, k is directly related to q, these two factors may be compared.

The standard deviation of the observations for a recommended area averages about 57% as mentioned in a preceding section. From this it follows that with for instance 12 observations the standard deviation of the mean would be 16.5% of the mean.

The arithmetic mean is an estimate of the actual mean which is unknown. The probability that the actual mean is within a certain proportion of the arithmetic mean may be assessed. Table 7 column 2 gives the probabilities in which the ratios of arithmetic mean/actual mean may be exceeded. It can be seen that the ratio varies between 0.8 and 1.3 in 84% of the cases.

The geometric mean has been used in preference to the arithmetic mean to account for some of the variability. The geometric mean is frequently found to be more than 15% less than the arithmetic mean. It is claimed that its use would introduce sufficient safety margin.

For various ratios of the arithmetic mean over the actual mean and for drains designed according to the arithmetic mean or the geometric mean the percentages of area that would drain at a rate less than the design discharge q or half this rate 0.5 q have been calculated. It was assumed that the normal frequency distribution for hydraulic conductivity values applies within the area of a recommendation. Table 7 gives the results.

It may be found that, using the arithmetic mean, the area draining at a rate less than 0.5 q is 15 to 26%. The use of the geometric mean reduces this percentage somewhat but not as much as may have been expected.

The above discussion cannot be conclusive since the scope of this report does not allow introduction of other factors, such as rainfall frequencies, coefficient of runoff, evaporation, storage capacity in the soil and plant reaction to high water tables. However, the results do provide information on the safety margin which was not previously available.

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10. Summary

A survey was conducted of the available hydraulic conductivity values obtained for the design of subsoil drainage installations. The purpose was to statistically analyse any relationships between soil types and permeability, to collect information about the variability of hydraulic conductivity and to explore possible means to reduce the cost of investigations which are carried out for tile drainage design.

It proved very difficult to obtain a reliable sample from the available information because not all soils in horticultural land had developed high watertables or were fully investigated. The results obtained from a sample based on the available information showed extreme variability of hydraulic conductivity within soil types, with the coefficient of variation having a median value of 92%.

The differences between means of hydraulic conductivity of soil types were tested on their significance. This calculation was carried out for high, normal and deep watertable conditions. The resulting ranking of soil types showed that the hill slope colluvial soils are more permeable than the plain soils and that in the latter category the difference between soil types frequently is significant.

Within a soil type it was found that there is a difference between farm portions so that a uniform spacing may not be adopted for any soil type. For farm portions it was found that there appears a greater variability within soil types than within recommended areas for tile drainage as determined by the current procedure. Therefore, in the M.I.A., it will not be advantageous to design tile drainage investigations on basis of soil boundaries for horticultural farms.

The hydraulic conductivity varies with depth. This is of relevance for the optimal drain depth and for the depth of holes on which hydraulic conductivity should be measured. For many soils the drain depth should possibly be 1.50 metres instead of 1.80 metres because the additional 30 cm does not appear to contribute greatly towards an increased flow to the drain.

The variance of the hydraulic conductivity around the mean gives further information of the safety margin which should be applied to the drainage criteria. With the current practice there may be more than 20% of the tile drained area that discharges at a rate less than half the design discharge.

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TABLE 1. Basic Information on Sampling Procedure

l Type (*1)	(1) Acreage Within Mirrool	(2) No. of Portions With More Than 15 Acres	(3) No. of Farms in Sample	(4) Farms not Investigated (% of (3))	(4a) Farms with Incomplete Record (% of (3))	(5) Total Area Remaining in Sample (Acres)	(6) Area Without Watertables (*2) (% of (5))	(7) No. of measurements available (*3)	(8)	(9)
								Normal WT	High WT	Low WT
lingall Loam	895	10	10	20	-	145	12	57	17	47
na Sand	620	13	10	-	-	222	18	87	42	55
lbangera Clay Loam (*4)	1083	24	10	10	-	174	20	80	19	80
bul Loam	1199	22	10	20	-	147	16	73	23	50
bul Clay Loam	550	7	7	-	-	121	16	71	7	40
rooka Sandy Loam	682	12	10	10	20	140	13	63	84	30
ffith Loam	2132	50	10	10	-	167	10	92	45	45
ffith Clay Loam	1083	17	10	50	10	70	14	38	16	42
wood Loam	3057	68	14	29	-	293	30	54	23	129
wood Sandy Loam	1891	32	10	20	-	207	25	58	30	61
ndra Sandy Loam	388	6	6	-	-	113	11	52	56	38
daryan Loam	1457	29	10	-	-	217	13	101	15	105
rool Loam	1232	24	10	30	-	184	25	65	41	44
rbogang Loam (*4)	1009	24	10	70	10	38	26	18	2	45
e 9	494	13	10	-	20	144	23	66	17	44
ngan Loam	404	13	10	70	-	69	46	19	6	11
bil Sandy Loam	695	15	10	10	-	226	5	83	41	45
da Loam	800	7	7	-	10	104	1	57	27	26
gali Loam	548	16	10	10	20	149	23	48	17	48
al or Average	20219	402	184	19.5%	5%	2930	18.9 (*5)	1182	·528	986

(*1) Only those soil types with more than 400 acres in Mirrool are listed.

(*2) This figure applies for the dates of investigations only.

(*3) Where this figure exceeds 80 only 80 randomly chosen figures were used for calculations.

(*4) The information referred to in columns 7, 8 and 9 has been augmented with information from other farms for these soil types because insufficient information was obtained from the sample.

(*5) As percentage of column (1).

TABLE 1A. NORMAL WATERTABLES (1) LEVELS OF SIGNIFICANCE OF DIFFERENCES BETWEEN GEOMETRIC MEANS OF HYDRAULIC CONDUCTIVITY.

SOIL TYPE	GEOMETRIC MEAN K (ft/day)	OTHER SOIL TYPE IN COMPARISON																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Ballingall loam	2.47	0																		
Tharbogang loam	2.09	-	0																	
Wyangan loam	1.56	-	-	0																
Hanwood loam	1.44	**	-	-	0															
Hanwood Sandy loam	1.13	**	-	-	-	0														
Yenda loam	0.99	**	*	-	*	-	0													
Bilbul loam	0.82	**	**	*	**	-	-	0												
Griffith loam	0.60	**	**	**	**	**	**	*	0											
Banna Sand	0.55	**	**	**	**	**	**	*	-	0										
Hyandra Sandy loam	0.51	**	**	**	**	**	**	**	-	-	0									
Bilbul Clay loam	0.49	**	**	**	**	**	**	**	-	-	-	0								
Type 9	0.47	**	**	**	**	**	**	**	-	-	-	-	0							
Yambil Sandy loam	0.39	**	**	**	**	**	**	**	**	*	-	-	-	0						
Jondaryan loam	0.36	**	**	**	**	**	**	**	**	**	*	*	-	-	0					
Yoogali loam	0.34	**	**	**	**	**	**	**	**	*	*	-	-	-	-	0				
Mirrool loam	0.34	**	**	**	**	**	**	**	**	**	*	*	-	-	-	-	0			
Camarooka Sandy loam	0.31	**	**	**	**	**	**	**	**	**	**	**	*	-	-	-	-	0		
Beelbangera Clay loam	0.30	**	**	**	**	**	**	**	**	**	**	**	**	-	-	-	-	-	0	
Griffith Clay loam	0.23	**	**	**	**	**	**	**	**	**	**	**	**	**	**	*	*	-	-	0

- No significant difference between the geometric means
* Difference is significant at the 5% Level
** Difference is significant at the 1% level

(1) Holes bored to 1.80 - 2.10 metres depth, watertables during measurement between 0.75 and 1.05 metres below soil surface.

TABLE 2A. NORMAL WATERTABLES (1) LEVELS OF SIGNIFICANCE OF DIFFERENCES BETWEEN MEANS OF HYDRAULIC CONDUCTIVITIES

Rank	Soil Type	Mean							Other Soil Type in Comparison												
		k-(ft/day)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Tharbogang loam	4.35	0																		
2	Ballingall loam	3.10	-	0																	
3	Hanwood loam	2.27	-	*	0																
4	Wyangan loam	2.22	-	-	-	0															
5	Hanwood Sandy loam	1.77	-	**	-	-	0														
6	Yenda loam	1.38	-	**	**	-	-	0													
7	Bilbul loam	1.23	-	**	**	*	**	-	0												
8	Banna Sand	0.94	*	**	**	*	**	-	-	0											
9	Griffith loam	0.85	*	**	**	**	**	**	*	-	0										
10	Hyandra Sandy loam	0.74	*	**	**	**	**	**	**	-	-	0									
11	Type 9	0.71	*	**	**	**	**	**	**	-	-	-	0								
12	Bilbul clay loam	0.70	*	**	**	**	**	**	**	-	-	-	-	0							
13	Mirrool loam	0.64	*	**	**	**	**	**	**	-	-	-	-	-	0						
14	Yoogali loam	0.57	*	**	**	**	**	**	**	-	*	-	-	-	-	0					
15	Yambil Sandy loam	0.52	*	**	**	**	**	**	**	*	**	-	-	-	-	-	0				
16	Jondaryan loam	0.48	*	**	**	**	**	**	**	*	**	*	*	*	-	-	-	0			
17	Beelbangera Clay loam	0.43	*	**	**	**	**	**	**	**	**	**	**	**	-	-	-	-	0		
18	Camarooka Sandy loam	0.41	*	**	**	**	**	**	**	**	**	**	**	**	-	-	-	-	-	0	
19	Griffith Clay loam	0.30	*	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	*	*	0

- No significant difference between the means
* Difference is significant at the 5% level
** Difference is significant at the 1% level

(1) Holes bored to 1.80-2.10 metres depth, watertables during measurement between 0.75 and 1.05 metres bel soil surface.

TABLE 2B. HIGH WATERTABLE (1): LEVELS OF SIGNIFICANCE OF DIFFERENCE BETWEEN MEANS OF HYDRAULIC CONDUCTIVITY

Rank	Soil Type	Mean k (ft/day)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Ballingall loam	5.02	0																		
2	Wyangan loam	2.91	-	0																	
3	Tharbogang loam	2.48	-	-	0																
4	Yenda loam	1.96	*	-	-	0															
5	Hanwood loam	1.88	*	-	-	-	0														
6	Hanwood sandy loam	1.47	*	-	-	-	-	0													
7	Banna Sand	1.34	*	-	-	*	-	-	0												
8	Bilbul loam	1.18	*	-	-	*	-	-	-	0											
9	Bilbul clay loam	1.15	*	-	-	*	-	-	-	-	0										
10	Griffith loam	0.98	**	-	-	**	**	*	*	-	-	0									
11	Mirrool loam	0.98	**	-	-	**	**	*	-	-	-	-	0								
12	Hyandra Sandy loam	0.90	**	-	-	**	**	*	*	-	-	-	-	0							
13	Yambil Sandy loam	0.90	**	-	-	**	**	*	*	-	-	-	-	-	0						
14	Type 9	0.76	**	-	-	**	**	*	*	-	-	-	-	-	-	0					
15	Griffith Clay loam	0.73	**	-	-	**	**	*	*	-	-	-	-	-	-	-	0				
16	Yoogali loam	0.72	**	-	-	**	**	**	**	-	-	*	-	-	-	-	-	0			
17	Beelbangera Clay loam	0.61	**	*	-	**	**	**	**	*	-	**	*	-	-	-	-	-	0		
18	Camarooka Sandy loam	0.55	**	*	**	**	**	**	**	**	*	**	**	**	*	-	-	-	-	0	
19	Jondaryan loam	0.49	**	*	**	**	**	**	**	**	*	**	**	**	*	-	-	-	-	-	0

- No significant difference between means
* Difference significant at 5% level
** Difference significant at 1% level

(1) Holes 1.80-2.10 metres deep, watertable at time of measurement within 0.75 metres from soil surface.

TABLE 2C. DEEP WATERTABLES (1); LEVEL OF SIGNIFICANCE OF DIFFERENCE BETWEEN MEANS OF HYDRAULIC CONDUCTIVITY.

nk	Soil Type	Mean k (ft/day)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Ballingall loam	3.70	0																		
	Tharbogang loam	3.35	-	0																	
	Wyangan loam	2.37	**	-	0																
	Hanwood loam	1.36	**	*	-	0															
	Yenda loam	1.14	**	**	-	-	0														
	Hanwood Sandy loam	0.95	**	**	-	-	-	0													
	Yoogali loam	0.66	**	**	-	**	-	-	0												
	Bilbul loam	0.51	**	**	-	**	**	*	-	0											
	Griffith loam	0.51	**	**	*	**	**	*	-	-	0										
	Hyandra Sandy loam	0.41	**	**	*	**	**	**	-	-	-	0									
	Type 9	0.28	**	**	*	**	**	**	-	-	-	-	0								
	Banna Sand	0.37	**	**	*	**	**	**	-	-	-	-	-	0							
	Jondaryan loam	0.36	**	**	*	**	**	**	-	-	-	-	-	-	0						
	Mirrool loam	0.34	**	**	*	**	**	**	-	-	*	-	-	-	-	0					
	Bilbul Clay loam	0.28	**	**	*	**	**	**	*	*	**	-	-	-	-	-	0				
	Yambil Sandy loam	0.25	**	**	*	**	**	**	*	*	**	-	-	-	-	-	-	0			
	Beelbangera clay loam	0.23	**	**	*	**	**	**	*	**	**	-	*	-	*	-	-	-	0		
	Camarooka sandy loam	0.21	**	**	*	**	**	**	**	**	**	*	*	-	*	-	-	-	-	0	
	Griffith clay loam	0.19	**	**	*	**	**	**	**	**	**	*	*	-	**	*	-	-	-	-	0

- No significant difference between means
* Difference is significant as 5% level
** Difference is significant at 1% level

(1) Holes 1.80-2.10 metres deep, watertables deeper than 1.05 metres.

TABLE 3. COEFFICIENTS OF VARIATION APPLYING FOR THE TOTAL AREA OF SOIL TYPES AND COEFFICIENTS OF VARIATION OF SOIL TYPES ON FARM PORTIONS.

Rank	Soil Type	For Total Area of Soil Type%	Farm Portions With 6 or more Observations							Median Farms %
			Farm 1 %	Farm 2 %	Farm 3 %	Farm 4 %	Farm 5 %	Farm 6 %	Farm 7 %	
1	Ballingall loam	65	55	72	31	47	-	-	-	51
2	Camarooka Sandy loam	68	57	38	46	61	113	-	-	57
3	Griffith clay loam	71	79	58	81	-	-	-	-	79
4	Yambil Sandy loam	77	34	61	60	69	54	-	-	60
5	Yenda loam	77	51	55	111	79	59	55	-	57
6	Beelbangera clay loam	83	76	45	56	92	50	75	61	61
7	Wyangan loam	84	-	-	-	-	-	-	-	-
8	Jondaryan loam	88	135	68	55	71	104	-	-	71
9	Hanwood sandy loam	90	78	61	74	84	60	-	-	74
10	Griffith loam	92	88	57	47	78	98	69	64	69
11	Bilbul	94	61	85	79	52	-	-	-	70
12	Hanwood loam	95	62	89	69	59	-	-	-	66
13	Bilbul clay loam	95	71	73	30	90	-	-	-	72
14	Type 9	97	79	66	57	81	75	-	-	75
15	Hyandra sandy loam	102	69	151	67	-	-	-	-	69
16	Yoogali loam	113	-	-	-	-	-	-	-	-
17	Mirrool loam	139	160	117	86	80	81	-	-	86
18	Tharbogang loam	146	-	-	-	-	-	-	-	-
19	Banna Sand	175	43	95	52	78	66	26	-	52
Median (of medians) or Total		92	-	-	-	-	-	-	-	69%

(*) With six or more observations.

TABLE 4. RANKING ACCORDING TO COEFFICIENT OF VARIATION AND SUBSOIL CHARACTERISTICS

		Sample Coefficient of Variation %	Sample Mean k Normal W.T. ft/day	Type of Subsoil (Taylor and Hooper, 1938)
1	Ballingall loam	65	3.10	Hardpan at 75 cm
2	Camarooka Sandy loam	68	0.41	Heavy
3	Griffith Clay loam	71	0.30	Heavy
4	Yambil sandy loam	77	0.52	Heavy
5	Yenda loam	77	1.38	Increasing clay content with depth
6	Beelbangera clay loam	83	0.48	Heavy
7	Wyangan loam	84	2.22	Light clay at 60 cm
8	Jondaryan loam	88	0.48	Sandy subsoil
9	Hanwood sandy loam	90	1.77	Pronounced sandiness with depth
10	Griffith loam	92	0.85	Heavier with depth
11	Bilbul loam	94	1.23	Heavier with depth
12	Hanwood loam	95	2.27	Sandy at depth
13	Bilbul clay loam	95	0.70	Heavier with depth
14	Type 9	97	0.71	Variable Subsoil
15	Hyandra Sandy loam	102	0.74	Mixed sandy and clayey subsoil
16	Yoogali Loam	113	0.57	Light middle subsoil
17	Mirrool loam	139	0.64	Light middle subsoil
18	Tharbogang loam	146	4.35	Rubble, some frequently cemented subsoil
19	Banna sand	175	0.94	Clay loam, and light clay subsoil
Median		92%	0.74	

TABLE 5. THE RELATION BETWEEN THE HYDRAULIC CONDUCTIVITY AND DEPTH

Soil Type	Mean k Normal W.T. (1) ft/day	Mean k High WT (2) ft/day	Mean k Deep WT (3) ft/day	Most likely average hydraulic conductivity			Signific level di ence Col (2) and (7)
				d1 = 0.50 - 0.90 (4) ft/day	d2 = 0.90 - 1.40 (5) ft/day	d3 = 1.40 - 1.90 (6) ft/day	
Tharbogang loam	4.35	2.48 (NS)	3.35 (NS)	3.60	3.60	3.60	NS
Ballingall loam	3.10	5.02 (NS)	3.70 (NS)	3.60	3.60	3.60	NS
Hanwood loam	2.27	1.88 (NS)	1.36 (**)	0.90	3.18	1.36	NS
Wyangan loam	2.22	2.91 (NS)	2.37 (NS)	2.38	2.38	2.38	NS
Hanwood Sandy loam	1.77	1.47 (NS)	0.95 (**)	0.73	1.99	0.95	NS
Yenda loam	1.38	1.96 (*)	1.14 (NS)	3.41	1.62	1.14	*
Bilbul loam	1.23	1.18 (NS)	0.51 (**)	1.05	1.95	0.51	**
Banna Sand	0.94	1.34 (NS)	0.37 (**)	2.34	1.51	0.37	**
Griffith loam	0.85	0.98 (NS)	0.51 (**)	1.30	1.19	0.51	**
yandra Sandy loam	0.74	0.90 (NS)	0.41 (*)	1.30	1.07	0.41	**
Type 9	0.71	0.76 (NS)	0.38 (**)	0.89	1.04	0.38	*
Bilbul clay loam	0.70	1.15 (NS)	0.28 (**)	2.52	1.12	0.28	**
Mirrool loam	0.64	0.98 (*)	0.34 (*)	1.84	0.94	0.34	**
Yoogali loam	0.57	0.72 (NS)	0.66 (NS)	0.63	0.63	0.63	NS
Yambil sandy loam	0.52	0.90 (*)	0.25 (**)	1.85	0.79	0.25	**
ondaryan loam	0.48	0.49 (NS)	0.36 (NS)	0.43	0.43	0.43	NS
Beelbangera Clay loam	0.43	0.61 (NS)	0.23 (**)	1.06	0.63	0.23	**
amarooka sandy loam	0.41	0.55 (*)	0.21 (**)	0.90	0.61	0.21	**
Griffith clay loam	0.30	0.73 (*)	0.19 (*)	1.80	0.41	0.19	**

Remarks:- (a) Where there is no significant difference between the means of columns (1), (2) and (3), a common mean, applying for all soil layers is calculated.

(b) Where either column (2) or (3) or both are significantly different from column (1), column (4) and (5) are calculated using the formula (KD = k1 d1 + k2 d2). Column (6) is equal to column (3) in such cases.

TABLE 6. SOIL TYPES RANKED ACCORDING TO VALUES OF HYDRAULIC CONDUCTIVITY WITH DEPTH AND INDICATION OF OPTIMAL DRAIN DEPTH

		Mean k 0.50 - 0.90m ft/day	Mean k 0.90 - 1.40m ft/day	Mean k 1.40 - 1.90m ft/day	
A.	Hydraulic Conductivity Same With Depth				
1.	Tharbogang loam	3.60	3.60	3.60	
2.	Ballingall loam	3.60	3.60	3.60	To be drained at 1.80 metres depth.
3.	Wyangan loam	2.38	2.38	2.38	
4.	Yoogali loam	0.63	0.63	0.63	
5.	Jondaryan loam	0.43	0.43	0.43	
B.	Hydraulic Conductivity Decreasing With Depth				
1.	Yenda loam	3.41	1.62	1.14	
2.	Griffith loam	1.30	1.19	0.51	To be drained at 1.80 metres depth.
3.	Hyandra Sandy loam	1.30	1.07	0.41	
4.	Banna Sand	2.34	1.51	0.37	
5.	Bilbul clay loam	2.52	1.12	0.28	
6.	Mirrool loam	1.84	0.94	0.34	
7.	Yambil sandy loam	1.85	0.79	0.25	To be drained at 1.50 metres depth.
8.	Beelbangera clay loam	1.06	0.63	0.23	
9.	Griffith clay loam	1.80	0.41	0.19	
10.	Camarooka sandy loam	0.90	0.61	0.21	
C.	Hydraulic Conductivity Peaks at 0.90 - 1.40 m Depth				
1.	Hanwood loam	0.90	3.18	1.36	To be drained at 1.80 metres depth.
2.	Hanwood sandy loam	0.73	1.99	0.95	
3.	Bilbul loam	1.05	1.95	0.51	
4.	Type 9	0.89	1.04	0.38	To be drained at 1.50 metres depth

TABLE 7. PROBABLE RANGE OF RATIO ARITHMETIC MEAN/ACTUAL MEAN AND PERCENTAGE OF AREAS DRAINING AT RATES EQUAL TO OR HALF THE DESIGN DISCHARGE.

Arithmetic Mean / Actual Mean	Probability that Ratio of (1) is Exceeded	Percentage of Area Draining at Design discharge **q** or less		Percentages of Area draining at half the design discharge q or less	
		Design with Arithmetic Mean	Design with Geometric Mean	Design with Arithmetic Mean	Design with Geometric Mean
(1)	(2)	(3)	(4)	(5)	(6)
0.7	99%	30%	24%	13%	11%
0.8	93	36	29	15	12
0.9	75	43	34	17	14
1.0	50	50	40	19	16
1.1	29	57	46	21	18
1.2	16	64	52	24	20
1.3	9	69	56	26	21
1.5	2	82	69	34	27