DETERMINATION OF DRAINAGE PARAMETERS IN THE LOW-LYING ACID SULPHATE COASTAL WETLANDS OF KERALA, INDIA[1]

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ABSTRACT

Kuttanad, the low-lying tract in Kerala State (South-west India), is a region where excess water has caused the agricultural production to remain low. This is even more severe in the potential acid sulphate soils of Kuttanad. Besides the problems inherent to these soils, the region also experiences floods, lack of fresh water and intrusion of saline water from the Arabian Sea. A subsurface drainage system consisting of 10 cm diameter clay tiles, each of 60 cm length, was installed in a pilot area to study the effect of drainage in alleviating the problems faced by these soils. The drains were installed at a depth of about 1 m with spacings of 15 m (replicated 5 times with a drain length of 75 m) and 30 m (replicated twice with a drain length of 100 m) in order determine the drainage parameters from the field data.
The paper discusses on the evaluation of drainage parameters from field data obtained from a pilot area where subsurface drainage system was installed and the use these parameters for designing larger drainage systems. This particular study pertains to the polders of Kuttanad where the fields are always surrounded by water bodies.

With the collected drain outflow and water table subsidence data, the drainage parameters namely the hydraulic conductivity and the drainable porosity were determined. A study conducted in subsurface drained field has shown that the hydraulic conductivity values were comparatively higher for the topsoil in the experimental area. It varied directly with the mid-spacing water table height for drains close to the outside water body and exponentially for drains away from the outside water body. The transition in the mode of variation took place at a distance of 60 m from the water body. The values also showed a decreasing trend with the distance of the field from the water body for the same mid-spacing water table heights. The average equivalent hydraulic conductivity computed was 0.167 m/d for regions up to 60 m from the water body and 0.055 m/d for regions beyond that. For areas near to outside water bodies, the drainable porosity increased as the mid-spacing water table height decreased. For areas that are away from the water bodies, the drainable porosity decreased with the mid-spacing water table height and became almost constant at lower mid-spacing water table heights. The average equivalent drainable porosity for the flow domain that are away from the water bodies is 0.04.

Keywords: Subsurface drainage, Hydraulic conductivity, Drainable porosity

1 INTRODUCTION

In the context that rice holds the key to food security in India, there is an urgent need to realize the under and unexploited potential of less productive coastal wetlands through appropriate research and development interventions. In chronically low productive and problem areas where the area has begun to register negative growth rate, there is a dire need to enhance the income level of farmers to arrest this trend. This is possible only by imbibing new technologies and upgrading prevalent ones. Bridging the gap between the potential and realized yields in such areas calls for more productive research. This necessitates land and water use planning that guarantee optimum use of biophysical resources and economic security to the farmers by generation of more income and opportunities.

With a meagre geographical spread of less than 1.18% of the whole country, the state of Kerala supports over 3.43% of the its population. Farming in the State is characterized by pre dominance of tiny holdings that are incapable of sustaining farming communities with the increased population pressure. With the undulating topography arising from geological formations, rice in Kerala is cultivated in distinct macro environments ranging from 2-3 metres below mean sea level as in coastal lowlands of Kuttanad to near temperate situations at 2,500 m height in the high ranges. The coastal low lands provide favourable conditions for rice. Owing to its innate adaptation to waterlogged environment, rice can be the only food crop grown in the coastal tracts. The high rainfall coupled with undulating topography subject the low land rice fields to environmental vagaries of flash floods in the monsoon and tidal saline incursions during the summer. Impeded by poor drainage, excess water and poor water management, the potential of high yielding rice varieties is hardly realized in this region. The situation is further aggravated in acid saline problem soils owing to high acidity, salinity and accumulation of toxic salts etc inherent to these soils. This, coupled with the socio-economic constraints has tempted some of the farmers to switch over to other enterprises. In many areas, lowland rice fields have been systematically converted into coconut plantations, further altering the very ecology of these wetlands.

1.1 Relevance of Drainage

Poor drainage has been identified to be the single largest factor limiting the potentials of high yielding rice in these tracts. This is particularly true of the region where the elevation of the fields are lower than the mean sea level and natural leaching of the inherent toxic salts from the soil profile under gravity is not feasible. As a result, the cropping intensity in coastal low lands is the lowest (100% as against 161% of the state). The present trend of conversion of low productive rice lands for alternate enterprises will have serious environmental consequences and will disturb the unique ecological functions of these wetlands. In this context, subsurface drainage assumes great importance as no other method would be successful in leaching the root zone.

1.2 Importance of drainage parameters

Drainage planning is generally done after gathering information by surveying the area and collecting data from auger holes, piezometers, soil samples etc. The parameters obtained from the data thus collected are fed into groundwater flow or drainage equations to arrive at the drain spacings and drain depths. Such conclusions sometimes have the following drawbacks.

- The drainage equations are often over simplified models of a very complex reality.
- The aquifer through which the groundwater-flow takes place is not at all homogeneous.
- Soils, particularly in alluvial plains, are layered and the permeability varies considerably in both horizontal and vertical directions
- It is not unusual for the permeability measured in auger holes which are located in adjacent plots to differ by several hundred percent
- The infiltration rate and drainable pore space differ with changes in soil texture and structure, even within one field, and so will soil water storage and recharge to the groundwater reservoir from irrigation losses and rain
- The inadequacy of information obtained on field conditions, both in terms of quantity and quality.

Since hydraulic conductivity is one of the most important factors influencing spacing between lateral drains for subsurface drainage systems, lateral drain spacings should be determined based on the mean value of hydraulic conductivity measurements within the area to be drained. Point measurements, however, does not take into account spatial variability of the hydraulic conductivity, and may result in large areas where the water table is shallower or deeper than the design water-table depth. Areas of shallow water table will reduce crop yield, while deeper than required water tables will result in unnecessarily expensive drainage systems.

Drainable porosity is another basic input parameter in conventional method for predicting water table drawdown. Drainable porosity is usually defined as the volume of water per unit area released when the water table falls by a unit distance. In drainage design it is conventionally assumed to be constant and treated as a soil property. Point measurements of drainable porosity can affect the drainage designs in a big way. The effective drainage porosity determined from outflow measurements can offset all field heterogeneities and is a reliable parameter in proper design.

Considering the aforesaid reasons, drainage designs are to be tested in field conditions to collect data on soil hydrological qualities such as hydraulic conductivity, drainable porosity etc. This, and related information thus arrived will represent the average values over the drained area.

2 METHODOLOGY

2.1 Study area

The area selected for the study is in the farmers' field of the Karumady village of Alappuzha District, Kerala, India The map of the experimental field with all the necessary details is shown in Figure 1. The area is a typical and representative tract of acid sulphate soil with a definite boundary and found to be very severely affected by the drainage problems. The total cropping area is 75 ha. The area is bounded by a road in the north, and water courses (water body) in the east, south and west. These canals are connected to the extensive backwater system in Kuttanad and ultimately drain into the sea.

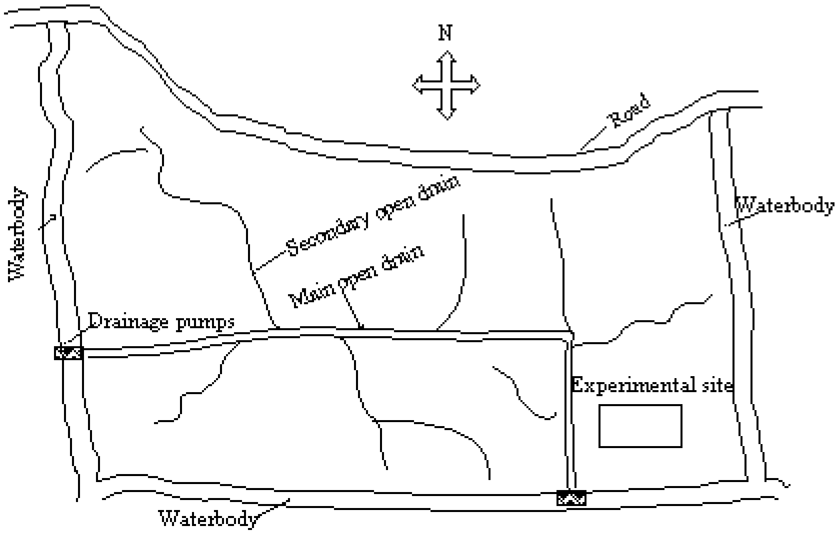

Figure 1 Experimental field

The area is 1-1.5 m below Mean Sea Level (MSL). It has strong earthen bunds along the boundary to protect floods during cultivation. Axial flow pumps are used to drain the impounded water collected during off-season. There are two pumping outlets, one with a 30 hp axial flow pump at the western boundary and another with a 20 hp axial flow pump at the southern boundary. Two main open drains, which are interconnected, lead water to the pumping bays. A number of secondary open drains join the main open drains from different parts of the field.

2.2 Subsurface drainage design layout

The layout of the drainage system is given in Figure 2. Considering the shape of the field and availability of farmers' field for *in situ* experimentation, nine lines of parallel lateral drains were installed.

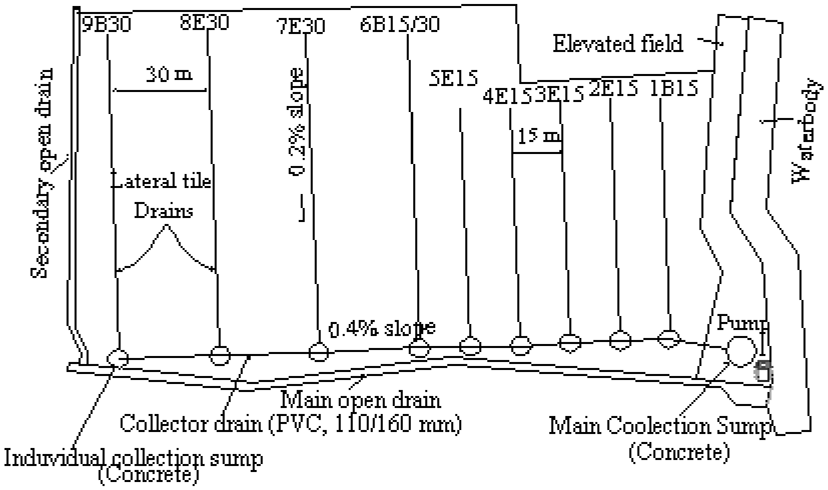

Figure 2 Layout of the drainage system

The first six lines close to the main collection sump were at 15 m spacing and the remaining at 30 m spacing. The length of first five lines was 75 m and the remaining was of 100 m. In order to offset the hydrologic interference between adjacent plots as much as possible, buffer lines were introduced between test spacings and at boundaries. Thus the first line, designated as $1B_{15}$, is a buffer line and so are the 6th and the 9th designated as $6B_{15/30}$ and $9B_{30}$ respectively. The lines $2E_{15}$, $3E_{15}$, $4E_{15}$, and $5E_{15}$ are experimental lines of 15 m spacing and the lines $7E_{30}$, and $8E_{30}$ are experimental lines of 30 m spacing. Further replication for 30 m spacing or some other spacing was not possible because of the geometry of the field.

Baked clay pipes were used as drains pipes. These pipes were of 60 cm length with an outside diameter of 125 mm and inside diameter of 100 mm, having bell mouth at one end. They were provided with fifteen 6 mm holes on 1/3rd of its peripheral area. These holes were arranged in three bands of 5 holes each. The drains were laid in a trench in which river sand was spread to a thickness of 10 cm at an average depth of 1 m. The tail end of each pipe was connected to the bell mouth of the succeeding. The pipes were placed with the peripheral holes facing the trench bottom. The main water entry is through the annular space at the joints between the bell mouth and tail end of the pipes. The average total annular space is found to be 53 cm per metre length of the drain line. After laying the drains, river sand filter was spread again over the drains to a thickness of 8 cm. The trench was then backfilled. Rigid PVC pipes were used as collector drains to carry the drainage water into the main sump. The collector pipes were laid at 0.4% slope. Based on the design calculations, 110 mm pipes were used to connect the 30 m spaced drains and 160 mm pipes were used for the 15 m spaced drains.

2.2.1 Collection sumps for drain discharge measurements

Pre-fabricated concrete rings with 60 cm outer diameter, 50 cm inner diameter and 50 cm height were used for the construction of discharge measurement sumps. These sumps were placed at the discharge end of each drain line. They were provided with holes for the entry of drainpipe and collector pipes. Adequate spacing between the drain entry and collector entry was provided for facilitating the measurement of discharges at each collection sump. All the tile drains entered into their respective collection sumps at the same elevation. A 110 mm PVC pipe of 60 cm length was used as the connecting piece between the drain line and discharge measurement sump. This provided a clean free fall of drainage water into the sump making the discharge measurements easy and accurate. Pre-fabricated concrete rings with 110cm outer diameter, 100 cm inner diameter, and 50 cm height were used to construct the main sump.

2.2.2 Observation wells for measuring water table subsidence

A series of observation wells were installed in the subsurface-drained area to record the fluctuations in the water table elevations during drainage. They were made with 40 mm PVC pipes, each having a length of 1.5 m. Five millimeter holes with a spacing of 10 cm have been drilled in six bands at the bottom 50 cm length and coil was wound around it. The bottom end of the tube is covered with polythene to prevent soil entry. The placement of observation wells in the tile-drained experimental area is shown in Figure 3.

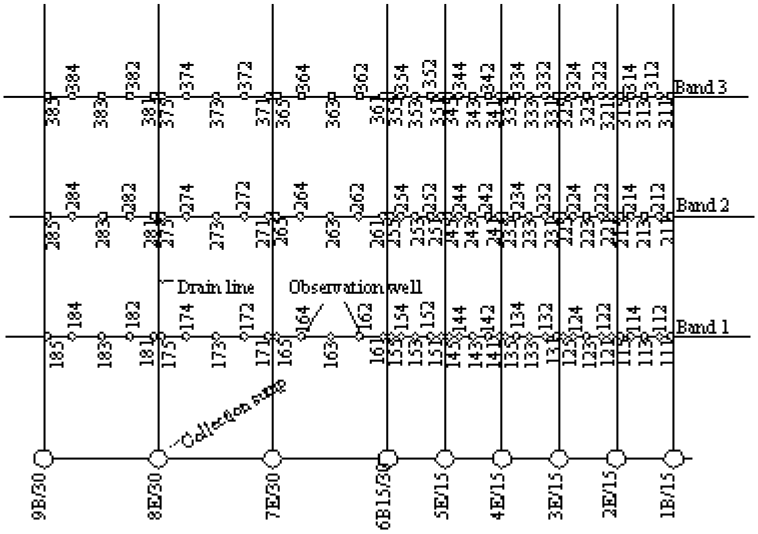

Figure 3 Layout of the observation wells

They were installed in three bands, each band perpendicular to the drain lines at L/4, L/2, and 3/4 L distances from the discharge end where L is the length of the drain in meter. For a 75 m long drain these bands of observation wells were at 18.75 m, 37.5 m, and 56.25 m from the collection sump and for a 100 m long drain they were at 25 m, 50 m, and 75 m. The observation wells were placed on these bands at 0.40 m, at $S/8$ and $S/2$ from the drains where 'S' is the spacing in meter. The nomenclature of observation wells is based on the location of each drain. The first digit represents the band number, the second digit, the drain number and the third, the serial number of the observation wells towards the western side of the drain line. Thus, all observation wells ending with the digit 3 represents the mid-spacing observation wells. There were altogether 120 observation wells installed in the experimental area.

2.2.3 Data Collection

The field was initially flooded with water to bring the water table nearer to the surface. Once the water table was stabilized, initial reading from all the observation wells was taken. This was followed by continuous drainage pumping for 120 hours. Drawdown in observation wells and drain discharge into collection sumps were taken at varying time intervals during drainage. Initially, readings were taken at short intervals. The drain discharges were taken using a bucket and stop watch at varying time intervals from all the drains. Water table subsidence was measured using electric depth gauges.

2.2.4 Hydraulic conductivity

The field data collected from experimental area were used to determine the drainage parameters. It was assumed that the hydrologic, soil, and topographic conditions in the experimental area were representative of those prevailing in the entire area under investigation.

The van Schilfgaarde equation (1963) given below (1) was used for finding hydraulic conductivity values from the field data.

$$L = 3A\left[\frac{K\,t\,(d_e + h)(d_e + h_0)}{2f\,(h_0 - h)}\right]^{1/2} \tag{1}$$

where
L = drain spacing, m;
A = a constant;
K = effective hydraulic conductivity, m/d;
t = time, d;
d_e = equivalent depth as defined by Hooghoudt, m;
h = mid-spacing water table height, m at time t;
h_0 =initial mid-spacing water table height, m;
f = porosity.

The term A is defined as

$$A = \left[\ 1 - \left(\frac{d_e}{d_e + h_0}\right)^2\ \right]^{1/2} \tag{2}$$

It was assumed that the water table is essentially flat and, therefore,

$$f = \frac{q\ t}{h_0 - h} \tag{3}$$

where
q = average drain outflow during time t, m/d;

The equivalent depth, d_e, is calculated from the expression after Hooghoudt (1940)

$$d_e = \frac{D}{\frac{8D}{\pi L}\ln\left(\frac{D}{u}\right) + 1} \tag{4}$$

where
u = ¶r, r being the radius of the drain, m;
D = depth to impermeable layer, m;

Investigations had shown that the impervious layer is far below the soil and always exceeded more than half the spacing and hence D was taken as $L/2$.
Substituting Equation (3) into (1) and solving for K, yields

$$K = \frac{2\ q\ L^2}{9\ A^2\,(d_e + h)(d_e + h_0)} \tag{5}$$

The effective hydraulic conductivity was computed for the entire profile using Equation (5) for varying water table height, h, of 1 cm interval starting from the initial water table height, h_0. The drain discharge, q, for corresponding head was calculated first by computing the time required for the water table to drop to that head using the time-hydraulic head relationship developed from field data and then calculating the discharge rate for that time from the time-discharge relationship, also developed from field data. The equivalent hydraulic conductivity for each drain for the soil profile was found taking the weighted average using Equation- 6.

$$K_{eq} = \frac{1}{h_0 - h}\int K(h)\ dh \tag{6}$$

where *K(h)* is the hydraulic conductivity as a function of mid-spacing water table height.

2.2.5 Drainable porosity

Drainable porosity, *f*, defined as the ratio of the drained voids volume to the total volume of the voids plus the volume of the soil particles, is a necessary parameter in all equations that predict drawdown. During drainage it is not normally a constant, but is related, among other things, to the water table depth. Both the time of drawdown and the shape of the water table depend on the particular way in which drainable porosity is related to water table depth. The drainable porosity is not used as such in the drawdown equations. The average porosity value for a drawdown depth is used for calculations. This average value is called the equivalent drainable porosity, f_{eq}. Drainable porosity at any point in the soil is not solely a function of water table depth but is also determined by the time during which the drainage is permitted before the water table falls to a new position. The time required for a prescribed drawdown is affected by the size, depth, and spacing of the drains. The importance of drainable porosity lies in the fact that all drawdown equations use this term to be multiplied with the drawdown to find the total volume of drainable water. The equivalent drainable porosity of the soil profile was determined using Equation-7 proposed by Taylor (1960).

$$f_n(h) = \frac{V_n - V_{n-1}}{A(h_n - h_{n-1})} \qquad (7)$$

where

f = equivalent drainable porosity;

h = water table depth, m;

V = cumulative outflow volumes, m^3;

A = area through water falls, m^2; and

n =subscript showing the position of water table depth.

The entire drained soil profile was divided into slabs of 1 cm thick. The time required to lower the water table from initial depth, h_0, to 1 cm below was obtained from the time-hydraulic head relationship. The total volume of water drained during that period is the area below the drain discharge hydrograph for the same period, which was obtained by integrating the equation developed for time-drain discharge relationship for the same time period. The drainable porosity of the slab in the profile was obtained by dividing the total volume drained by the slab thickness. The drainable porosities for successive slabs of 1 cm thickness were found out for the entire range of water table drawdown for all the drains. Relationships were then developed for drainable porosity with respect to the mid-spacing water table. The average equivalent drainable porosity for each drain for the soil profile tested was found out by taking the weighted average using equation-8.

$$f_{eq} = \frac{1}{h_0 - h_t} \int f(h)\,dh \qquad (8)$$

where *f(h)* is the drainable porosity as a function of water table height.

3 RESULTS

The field data on water table drawdown due to drainage were converted to their respective hydraulic heads. The average hydraulic head (average of 6 mid-spacing observation wells adjacent to each drain) was used for the analysis. The drain line and its respective adjacent observation well influenced by the drain are given in Table 1.

Table 1 Observation wells influenced by the drains

Drain line	Adjacent observation wells					
$2E_{15}$	113	213	313	123	223	323
$3E_{15}$	123	223	323	133	233	333
$4E_{15}$	133	233	333	143	243	343
$5E_{15}$	143	243	343	153	253	353
$7E_{30}$	163	263	363	173	273	373
$8E_{30}$	173	273	373	183	283	383

The best-fit curves were drawn by plotting average hydraulic heads at mid-spacing versus time and drain discharge versus time. Figures 4 and 5 show the comparative discharges and drawdowns for all the drains. Looking at the figures it is observed that a progressive decline occurs in the discharge rates and hydraulic heads at identical times for different drains. This decline depends on the distance of these drains from the adjacent water body (see Figure 2 for location of drains from water body).

This is caused by the specific feature of the polders in the area that are surrounded by water bodies, the water level of which are always higher than that of the field and thereby contributes a substantial lateral seepage. The influence of the water bodies was visible up to a distance of 60 m though it decreased with distance. As the drainage continued, the drop in discharge rate and hydraulic head stabilized and almost became steady later on. The regression equations to predict the hydraulic head and drain discharges at various times are given in Table 2.

3.1 Hydraulic conductivity

The effective hydraulic conductivity was calculated using the drain outflow observations. Using the time-hydraulic head and time-discharge relationships developed (Table-2), the volume of water drained for a particular soil profile depth starting from initial water table depth, was estimated. Equivalent hydraulic conductivity was then calculated using equation-5 for a particular mid-spacing water table height.

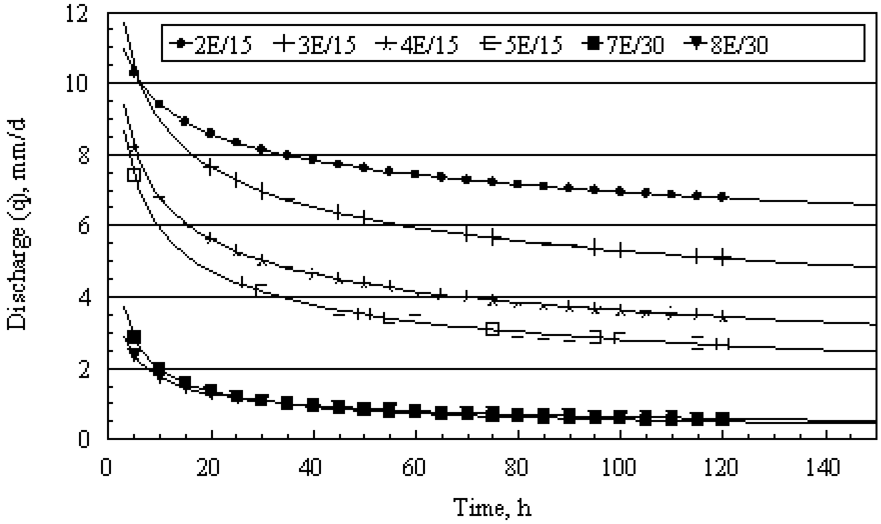

Figure 4 Drain Discharge with respect to time.

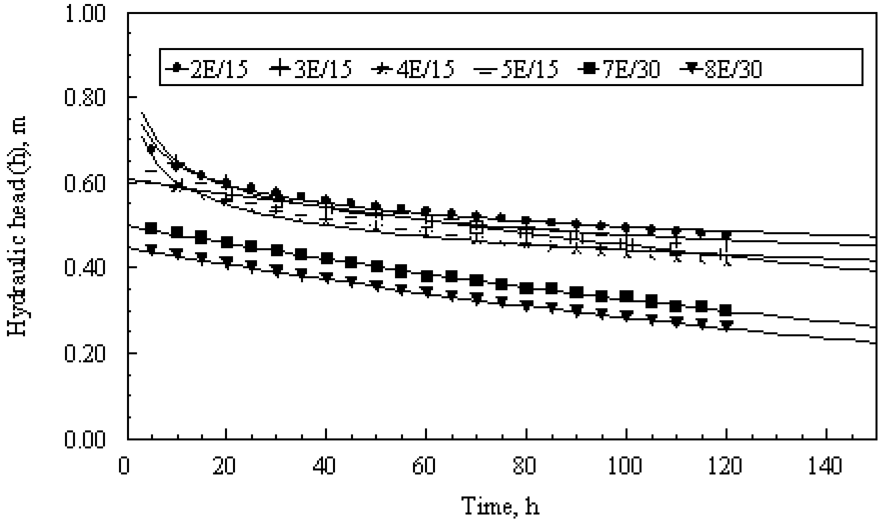

Figure 5 Hydraulic head with respect to time.

The relationship obtained for the hydraulic conductivity as a function of mid-spacing water table height is shown in figure 6. The values were higher for the topsoil. It varied directly with the mid-spacing water table height for drains close to the outside water body ($2E_{15}$, $3E_{15}$ and $4E_{15}$) and exponentially for drains away from the outside water body ($5E_{15}$, $7E_{30}$ and $8E_{30}$). The transition in the mode of variation took place at a distance of 60 m from the water body. The values also showed a decreasing trend with the distance of the field from the water body for the same mid-spacing water table heights.

The regression equations developed for hydraulic conductivity, K, for each drain as a function of mid-spacing water table height, h at time, t, along with its equivalent values, K_{eq}, for the entire flow domain is given in Table 3. The equivalent hydraulic conductivity for the flow domain was found by taking the weighted average using Equation-6.

Table 2 Regression equations to predict hydraulic head and drain discharge from field observations

Drain No	Initial Water table height, h_0, (m)	Equations developed from field data	
		h (m) vs time (h)	q (mm/d) vs time (h)
2E$_{15}$	0.69	$h = 0.835\ t^{-0.113}$	$q = 12.69\ t^{-0.131}$
3E$_{15}$	0.68	$h = 0.889\ t^{-0.135}$	$q = 15.06\ t^{-0.227}$
4E$_{15}$	0.66	$h = 0.821\ t^{-0.135}$	$q = 12.73\ t^{-0.273}$
5E$_{15}$	0.66	$h = 0.608\ e^{-0.0029\ t}$	$q = 12.47\ t^{-0.324}$
7E$_{30}$	0.51	$h = 0.499\ e^{-0.0043\ t}$	$q = 6.85\ t^{-0.546}$
8E$_{30}$	0.44	$h = 0.497\ e^{-0.0046\ t}$	$q = 4.74\ t^{-0.438}$

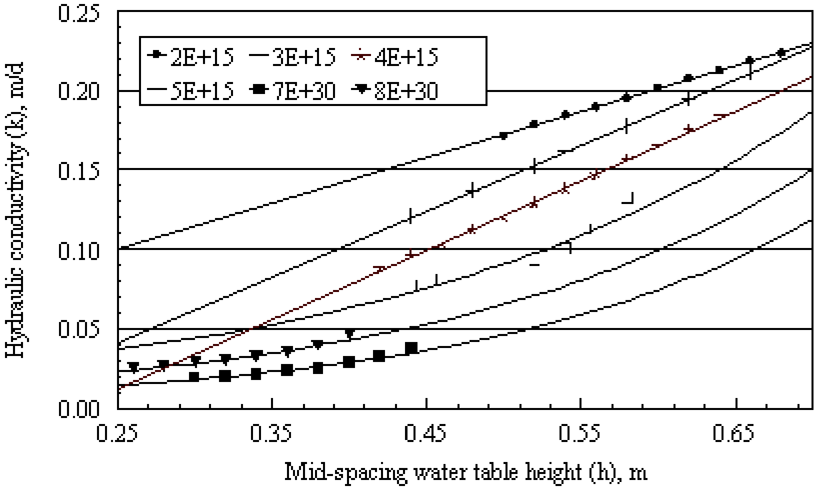

Figure 6 Variation of hydraulic conductivity within the flow domain at different water table heights

Table 3 Regression equations for the variation of hydraulic conductivity within the flow domain in relation to mid-spacing water table heights

Drain No	Equations developed for effective hydraulic conductivity near the vicinity of the drains	Equivalent hydraulic conductivity, K_{eq} (m/d)
2E$_{15}$	K=0.028 + 0.287 h	0.194
3E$_{15}$	K=-0.063 + 0.414 h	0.173
4E$_{15}$	K=-0.096 + 0.438 h	0.134
5E$_{15}$	$K = 0.0148\ e^{3.62\ h}$	0.100
7E$_{30}$	$K = 0.00434\ e^{4.74\ h}$	0.030
8E$_{30}$	$K = 0.00804\ e^{4.18\ h}$	0.036

The average K_{eq} computed was 0.167 m/d (between 2E15, 3E$_{15}$ and 4E$_{15}$) and 0.055 m/d (between 5E15, 7E$_{30}$ and 8E$_{30}$) respectively for the two distinct regions (up to 60 m from the water body and beyond that).

3.2 Drainable porosity

The drainable porosity was also calculated using the drain outflow observations. Using the time-hydraulic head and time-discharge relationships developed (Table-2), the volume of water drained for a particular soil profile depth of small thickness (I cm in this case), starting from initial water table depth, was estimated. The drainable porosity was calculated by dividing the total volume drained by the soil profile thickness from where the drainage has taken place. The drainable porosity for the entire profile was found out similarly. The relationship obtained for the drainable porosity as a function of mid-spacing water table height is shown in figure 7.

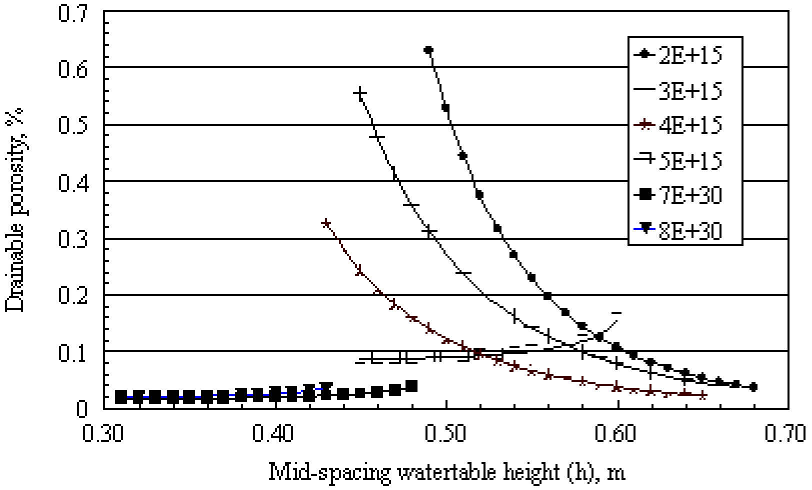

Figure 7 Variation of drainable porosity within the flow domain at different water table heights

For areas near drains $2E_{15}$, $3E_{15}$, and $4E_{15}$, the drainable porosity increased as the mid-spacing water table height decreased. These drains are located nearer to the outside water bodies (see Figure 2 for their locations) and a significant amount of recharge enters the field due to their proximity to the outside water bodies. During drainage, the water table fell at a faster rate and almost became steady at later stages (see Figure 5) because of the recharge from the adjoining water bodies. Thus the total volume of water drained is comparatively more attributing to higher drainable porosities at lower water table heights. This recharge effect was found to be prominent up to the drain $4E_{15}$, which is located at a distance of 60 m away from the water body. The drainable porosity found out by this method for areas near drains $2E_{15}$, $3E_{15}$, and $4E_{15}$ does not represent the true values and would be considerably in error because of this recharge effect. This is true for the cases if an appreciable quantity of artesian water are entering the drained area or if deep seepage losses are great (Taylor, 1960). Hence drainable porosity values calculated near these drains ($2E_{15}$, $3E_{15}$, and $4E_{15}$) were not used for further analysis. For areas near drains $5E_{15}$, $7E_{30}$, and $8E_{30}$, the drainable porosity decreased with the mid-spacing water table height and became almost constant at lower mid-spacing water table heights. This showed that this region is away from the recharge influence and the drainable porosity values calculated represented the real values. The constant region of the graph for drains $5E_{15}$, $7E_{30}$, and $8E_{30}$, implies a fairly homogenous soil. The slight decrease in drainable porosity in case of $5E_{15}$, $7E_{30}$, and $8E_{30}$, with declining water table may be due to a compact soil layer immediately below the surface. Hence, drainage designs are to be made separately for areas up to 60 m away from water bodies and for distances beyond that. When drainage designs are made for areas nearer to water bodies, the recharge component should be incorporated for arriving at a proper design. The regression equations developed for drainable porosity, f, with respect to the mid-spacing water table height, h, at time, t, for the flow domain along with the equivalent drainable porosity values are given in Table 4. The equivalent drainable porosity for each drain catchments for the flow domain was found by taking the weighted average using Equation-8. The average equivalent drainable porosity for the flow domain for areas near drains $5E_{15}$, $7E_{30}$, and $8E_{30}$, is 0.04.

Table 4 Regression equations for the variation of drainable porosity within the flow domain in relation to mid-spacing water table heights

Drain No	Equations developed for drainable porosity near the vicinity of the drains	Equivalent drainable porosity, f_{eq}
$5E_{15}$	$f = 0.0198\ e^{3.086\ h}$	0.10
$7E_{30}$	$f = 0.00382\ e^{4.267\ h}$	0.02
$8E_{30}$	$f = 0.00502\ e^{4.204\ h}$	0.02

4 CONCLUSION

Hydraulic conductivity is one of the most important factors influencing spacing between lateral drains in subsurface drainage systems. While methods for determining hydraulic conductivity and drainable porosity have been rigorously developed and thoroughly tested, the properties often vary widely from point to point in the field and usually require numerous measurements to obtain field-effective values. Accurate measurement of these two input parameters in drain spacing equations is important in the successful technical and economical design of any drainage system.

A detailed study conducted in subsurface drained field has shown that the hydraulic conductivity values (*K*) varied directly with the mid-spacing water table height for drains close to the outside water body and exponentially for drains away from the outside water body. The transition in the mode of variation in the experimental area took place at a distance of 60 m from the outside water body. The *K* values also showed a decreasing trend with the distance of the field from the water body for the same mid-spacing water table heights. The computed average equivalent *K* was 0.167 m/d for regions up to 60m from the water body and 0.055 m/d for regions beyond that.

Drainable porosity, defined as the ratio of the drained voids volume to the total volume of the voids plus the volume of the soil particles, is a necessary parameter in all drain spacing equations that predict drawdown. During drainage it is not normally a constant, but is related, among other things, to the water table depth for areas near to outside water bodies, the drainable porosity increased as the mid-spacing water table height decreased. Being nearer to the outside water bodies, a significant amount of recharge entered the field and was intercepted by the subsurface drain. During drainage, the water table fell at a faster rate and almost became steady at later stages because of the recharge from the adjoining water bodies. Thus the total volume of water drained was comparatively more attributing to higher drainable porosities at shallow water table heights. This recharge effect was found to be prominent up to a distance of 60 m away from the water body. For the drains that were away from the water bodies, the drainable porosity decreased with the mid-spacing water table height and became almost constant at lower mid-spacing water table heights. This showed that the drained region was away from the recharge influence and the drainable porosity values calculated represented the real values. Hence, drainage designs are to be made separately for areas away from water bodies and for areas nearer to water bodies if these water bodies have definite influence (like recharge) on the adjoining areas. When drainage designs are made for areas nearer to water bodies, the recharge component should be incorporated for arriving at a proper design. The average equivalent drainable porosity arrived at from the experiments for the flow domain of the drains that are away from the water bodies was 0.04.

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