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# SOME PROPERTIES OF KIRKHAM'S METHOD FOR DRAIN SPACING DETERMINATION IN MARSHY - GLEY SOIL

**Nevenka Djurović[1] and Ružica Stričević[1]**

**Abstract:** The aim of this work is to present some pecularity of Kirkham's method applied in drain spacing determination in steady state water flow in eugley soil type. The analysis was based on data obtained by measuring water discharge from drains and water table depth. Measurements was carried out on drainage field with drain spacing of 10 m, 20 m and 30 m, representing drainage treatments I, II and III, respectively. The estimation of drain spacing is moved to lower value in all treatments. The results of analysis show meaningful limitation of method, especially in the treatments with wider drain spacing as well as in the cases of deeper ground water.

**Key words:** drainage system, drain spacing, outflow, steady state flow, Kirkham's method.

## Introduction

Methods for drain spacing determination are divided into two groups:

a) Methods applied in steady state water flow
b) Methods applied in unsteady state water flow

The first group consists of methods based on the assumption that flow of water to the drain occurs under unchanged pressure, therefore water table depth is constant and then discharge is equal to recharge. In this case, velocity of water flow at any point of cross section has the same value. That is so-called steady state water flow. One of the methods from this group is Kirkham's method. This method will be applied for drain spacing determination in eugley type of soil.

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## Materials and Method

Experimental field was set up in Radmilovac near Belgrade. It occupies the area of 1.5 ha. The type of soil is eugley. The field is divided into three plots. Each plot is drained by subsurface pipe drains. Treatment I, II and III represent plots with drain spacing 10 m, 20 m and 30 m, respectively. The depth of drains is 0.9 m on average, and mean hydraulic conductivity of the experimental field is 0.6 m·day$^{-1}$. The equivalent drain depths by treatments I, II and III are $d_1$=0.45 m $d_2$= 1.06 m $d_3$=1.51 m, respectively.The experiment was carried out during three successive seasons out of vegetation from 1995 – 1997. (Djurović, 1999).

The measurements of water table depth and drain discharge shown in Table 1 were selected being considered as representative measurements in steady state water flow conditions.The absence of groups of data around different values during the whole study period was found by the previous analysis (Djurović, 2000). There is no group of data more frequent than others, therefore the assumptions on moving of statistics (mean value, median or mode) during successive seasons out of vegetation is not sustainable. Then, the data are considered as a part of one unit of time series.

T a b.1.- Measurements in steady state water flow

| Index of measurements | $h_1$ (m) | $q_1$ (m/day) | $h_2$ (m) | $q_2$ (m/day) | $h_3$ (m) | $q_3$ (m/day) |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 0.5 | 0.01718 | 0.64 | 0.01537 | 0.71 | 0.01542 |
| 2 | 0.52 | 0.01715 | 0.59 | 0.01406 | 0.68 | 0.01421 |
| 3 | 0.46 | 0.01804 | 0.57 | 0.0121 | 0.65 | 0.01191 |
| 4 | 0.42 | 0.01612 | 0.51 | 0.01103 | 0.65 | 0.01124 |
| 5 | 0.41 | 0.01424 | 0.51 | 0.0116 | 0.6 | 0.0107 |
| 6 | 0.41 | 0.01101 | 0.5 | 0.00943 | 0.58 | 0.00907 |
| 7 | 0.4 | 0.01062 | 0.54 | 0.01067 | 0.65 | 0.0114 |
| 8 | 0.43 | 0.01331 | 0.46 | 0.00601 | 0.48 | 0.00542 |
| 9 | 0.39 | 0.01102 | 0.49 | 0.01111 | 0.58 | 0.00867 |
| 10 | 0.43 | 0.01226 | 0.5 | 0.01197 | 0.62 | 0.00941 |
| 11 | 0.35 | 0.00807 | 0.49 | 0.00761 | 0.52 | 0.00645 |
| 12 | 0.444 | 0.01231 | 0.48 | 0.00754 | 0.52 | 0.00602 |
| 13 | 0.,45 | 0.01204 | 0.48 | 0.00812 | 0.78 | 0.01542 |
| 14 | 0.35 | 0.00811 | 0.5 | 0.00974 | 0.78 | 0.01587 |
| 15 | 0.35 | 0.00823 | 0.51 | 0.01076 | 0.76 | 0.01423 |
| 16 | 0.35 | 0.00892 | 0.65 | 0.01656 | 0.77 | 0.01489 |
| 17 | 0.43 | 0.01134 | 0.63 | 0.01623 | 0.86 | 0.02014 |
| 18 | 0.44 | 0.01208 | 0.65 | 0.01684 | 0.87 | 0.02064 |
| 19 | 0.51 | 0.01738 | 0.64 | 0.01611 | 0.88 | 0.02152 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 20 | 0.51 | 0.01818 | 0.65 | 0.02001 | 0.44 | 0.00342 |
| 21 | 0.53 | 0.01806 | 0.76 | 0.02259 | 0.42 | 0.00412 |
| 22 | 0.51 | 0.01695 | 0.69 | 0.02008 | 0.41 | 0.00417 |
| 23 | 0.54 | 0.01844 | 0.79 | 0.02423 | 0.34 | 0.00401 |
| 24 | 0.67 | 0.02479 | 0.59 | 0.01411 | 0.41 | 0.00492 |
| 25 | 0.57 | 0.0223 | 0.56 | 0.01227 | 0.41 | 0.00417 |
| 26 | 0.68 | 0.02906 | 0.51 | 0.01055 | 0.48 | 0.00612 |
| 27 | 0.15 | 0.00632 | 0.51 | 0.01109 | 0.48 | 0.00591 |
| 28 | 0.1 | 0.00515 | 0.5 | 0.00824 | 0.49 | 0.00666 |
| 29 | 0.11 | 0.00211 | 0.5 | 0.00897 | 0.45 | 0.00593 |
| 30 | 0.67 | 0.01114 | 0.51 | 0.01024 | 0.45 | 0.00571 |
| 31 | 0.56 | 0.01045 | 0.56 | 0.01241 | 0.45 | 0.00555 |
| 32 | 0.57 | 0.01112 | 0.56 | 0.01294 | 0.45 | 0.00428 |
| 33 | 0.51 | 0.0159 | 0.59 | 0.01317 | 0.45 | 0.00516 |
| 34 | 0.48 | 0.00904 | 0.57 | 0.01203 | 0.09 | 0.00081 |
| 35 | 0.52 | 0.01752 | 0.58 | 0.0121 | 0.07 | 0.00062 |
| 36 | 0.56 | 0.01112 | 0.57 | 0.01218 | 0.03 | 0.00044 |
| 37 | 0.54 | 0.01009 | 0.56 | 0.01203 | 0.01 | 0.00007 |
| 38 | 0.54 | 0.01712 | 0.55 | 0.01206 | | |
| 39 | 0.56 | 0.01254 | 0.51 | 0.01019 | | |
| 40 | 0.56 | 0.00965 | 0.48 | 0.00896 | | |
| 41 | 0.57 | 0.00994 | 0.44 | 0.00642 | | |
| 42 | 0.56 | 0.00714 | 0.4 | 0.00514 | | |
| 43 | 0.56 | 0.00715 | 0.42 | 0.00573 | | |
| 44 | 0.52 | 0.00617 | 0.42 | 0.00601 | | |
| 45 | 0.48 | 0.00706 | 0.48 | 0.00827 | | |
| 46 | 0.39 | 0.01326 | 0.5 | 0.01073 | | |
| 47 | 0.4 | 0.01423 | 0.11 | 0.0011 | | |
| 48 | 0.35 | 0.0108 | 0.1 | 0.00131 | | |
| 49 | 0.36 | 0.00921 | 0.08 | 0.00096 | | |
| 50 | 0.06 | 0.00099 | 0.08 | 0.00109 | | |
| 51 | 0.11 | 0.00161 | | | | |
| 52 | 0.1 | 0.00162 | | | | |
| 53 | 0.1 | 00059 | | | | |
| 54 | 0.1 | 00051 | | | | |

Kirkham (1958) (cit ILRI IV, 1980, Wesseling, 1977) gave analytical solution for drainage problem for the same conditions that had been used by Hooghoudt

- Two dimensional flow
- Regular distribution of rainfall
- Vertical flow without loss above the drain

Kirkham's equation can be written in the form:

$$h = \frac{qL}{K} F_K \qquad (1)$$

Note: $K$ – hydraulic conductivity (m·day$^{-1}$); $h$- water table depth (m), $q$- drain discharge (m/day), $L$- drain spacing (m) where:

$$F_K = \frac{1}{\pi}\left[\ln\frac{L}{\pi r_0} + \sum_{n=1}^{\infty}\frac{1}{n}\left(\cos\frac{2n\pi r_o}{L} - \cos n\pi\right)\left(\cosh\frac{2n\pi D}{L} - 1\right)\right] \qquad (2)$$

The values of $F_k$ are shown in Table 2 (cit. Wesseling, 1977).

In his later papers (1960) Kirkham took into account head loss due to vertical flow above the drains. When drains are set up in the interfaces of two soil layers, general equation which includes vertical recharge of water is as follows:

$$h = \frac{qL}{K_b}\frac{1}{1-\frac{q}{K_a}}F_K \qquad (3)$$

where: $K_a$ – hydraulic conductivity above the drain (m·day$^{-1}$);
$K_b$ - hydraulic conductivity below the drain (m·day$^{-1}$)

Drain spacing calculation by Kirkham's method is based on equation 1. The values of $F_k$ are shown in Table 2 (cit. Wessiling) and the values of function for the facts corresponding to drainage treatments I, II and III obtained by interpolation are: $F_{k(10)}$=2.8714, $F_{k(20)}$=2.4414, $F_{k(30)}$=*2.5364.*

## Results and Discussion

The obtained results of drain spacing determination by applying Kirkham's method for treatment I (*L = 10 m*) are shown in Figs. 1 – 4. In the cluster of measurements, shown in fig. 1 two segments single out. The first segment is for k< 28 and the second one for k>28. The first interval is characterised by deeper ground water, whereas the second one for shallow water table. Kirkham's method generates more precisely the estimation in the second interval, admittedly with a bit increased spreading out that will be reflected in higher standard deviation. Histogram is one type of estimation of density probability function which, in fact, contains maximal information of random variable (Fig. 2). Statistics such as mean value, variance or moments of higher order are very often insufficient to identify the nature of some variables. Histogram in itself shows the magnitude of measured data, and it is very simple to show mean value, dispersion around mean value, but much more. Histogram clearly shows the most frequently measured data (so-called mode which exactly means the point of maximum in the function of density probability) but a realm of possible value with the highest concentration or most frequent occurrence (Vukadinović, 1986; FAO, 1976). Mean value of error for the treatment I is –1.518 m, median –2.42 m, mode of error –5.05 m, which is very high value considering the exact drain spacing of 10 m. The standard deviation of error is 3.36 m.

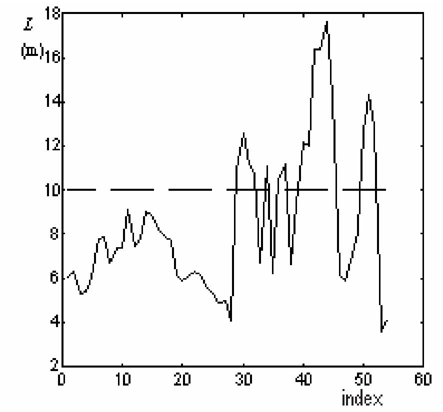


Fig. 1.- Drain spacing estimation by applying Kirkham's method in treatment I ($L$=10 m)

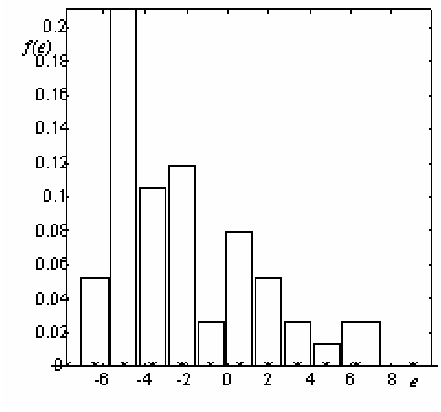


Fig. 2.- Histogram of error of estimation by applying Kirkham's method in treatment I ($L$=10 m)

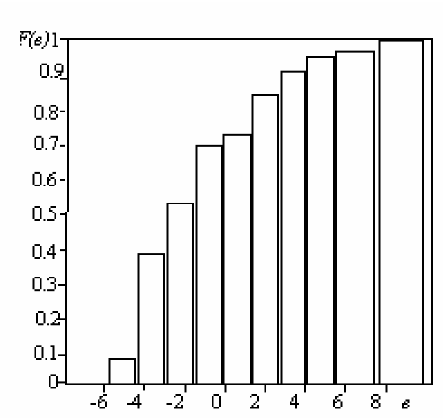


Fig. 3.- Function of error distribution by applying Kirkham's method in treatment I ($L$=10m)

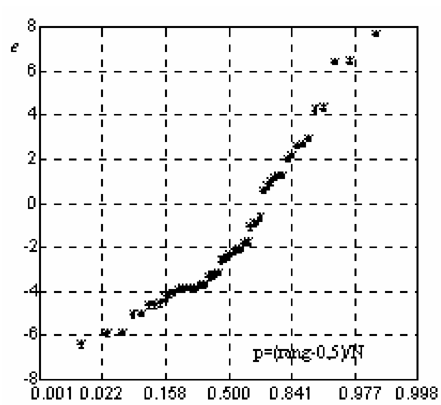


Fig. 4.- Error of estimation by applying Kirkham's method in treatment I ($L$=10 m) plotted on normal probability paper

Note: *f*(e)-probability density function of *e*; *F*(*e*)- distribution function of *e*

Histogram of error (Fig. 2) is utterly irregular with the highest concentration of data at point –5 m. The same trend of error normally distributed is shown in

Fig. 4. Some groups of data appeared but without clear linear or any other interconnection.

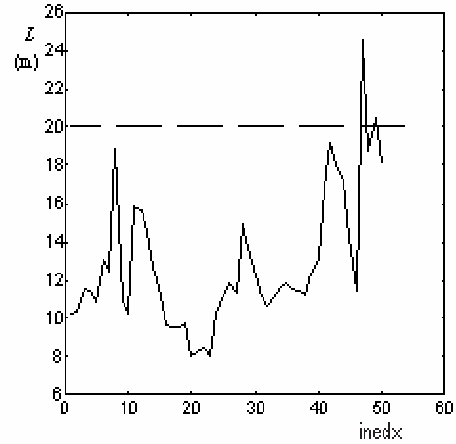


Fig. 5.- Drain spacing estimation by applying Kirkham's method in treatment II ($L$ = 20 m)

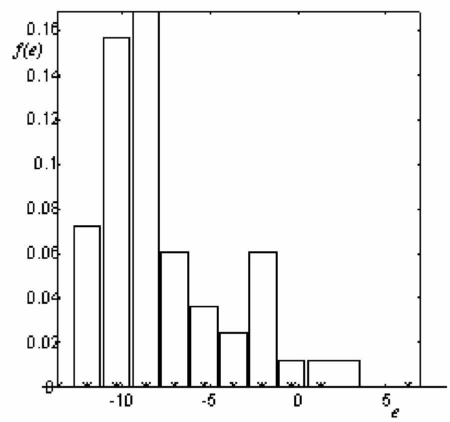


Fig. 6.- Histogram of error of estimation by applying Kirkham's method in treatment II ($L$ = 20 m)

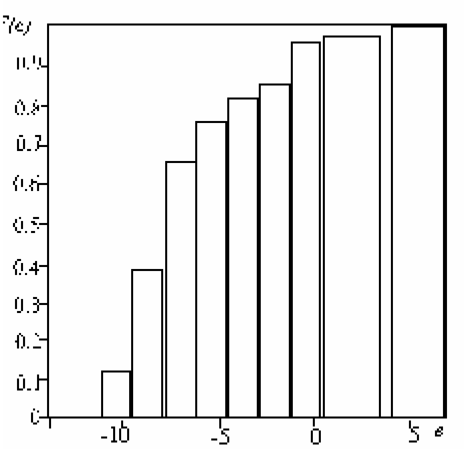


Fig. 7.- Function of error distribution by applying Kirkham's method in treatment II ($L$ = 20 m)

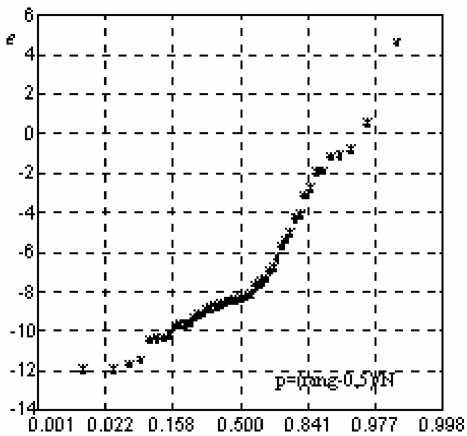


Fig. 8.- Error of estimation by applying Kirkham's method in treatment II ($L$=20 m) plotted on normal probability paper

The obtained results of drain spacing determination by applying Kirkham's method for treatment II (L = 20 m) are shown in figs. 5 – 8. Figure 5 clearly shows significantly moved estimation (with negative movement) illustrated through the negative value of mean error estimation (– 7.16 m), median error of – 8.38 m and mode of error –8.68 m. Standard deviation of error is 3.56 m. Histogram of error shows a high negative error, considering that the most concentration of data are in the realm of around –10 m. Error of estimation plotted on normal probability paper (Fig. 8) is not linear due to concavity of data trend.

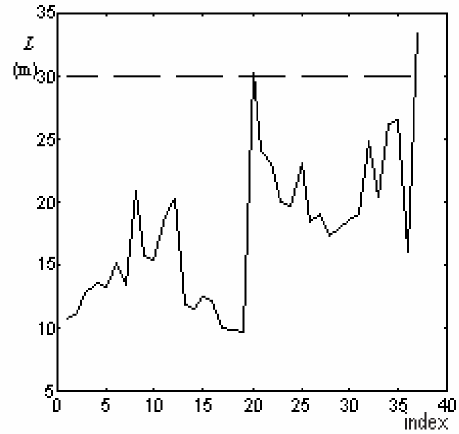


Fig. 9.- Drain spacing estimation by applying Kirkham's method in treatment III ($L$ = 30 m)

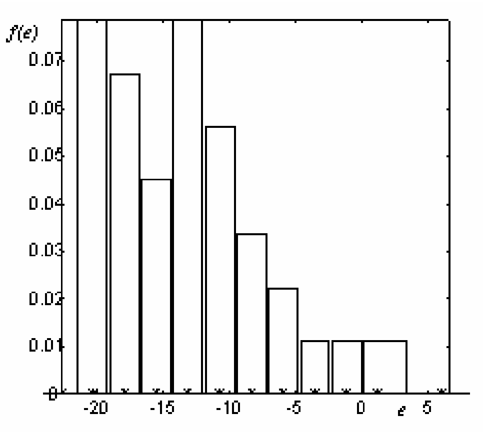


Fig. 10.- Histogram of error of estimation by applying Kirkham's method in treatment III ($L$ = 30 m)

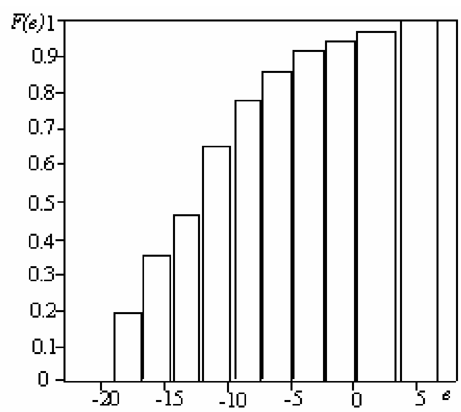


Fig. 11.- Function of error distribution by applying Kirkham's method in treatment III ($L$ = 30 m)

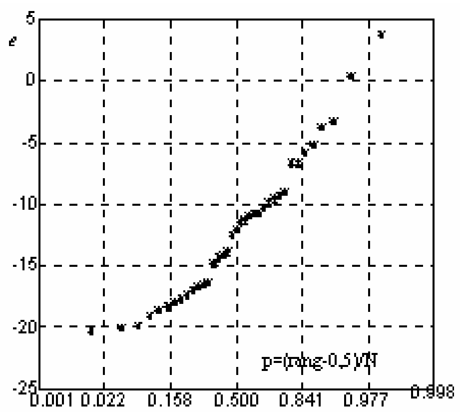


Fig 12.- Error of estimation by applying Kirkham's method in treatment III ($L$=30 m) plotted on normal paper

Very similar trend of negative value of error has been observed in treatment III. The results of this analysis are shown in figs. 8 – 12. Mean value of error is much higher according to the absolute value of mode (–20.35 m). However, it should be pointed out that on histogram of error estimation (Fig. 10) two peaks exist, therefore the mentioned value of mode is under question.

## Conclusion

Kirkham's method, as one of the representative methods for drain spacing determination in steady state water flow in marshy–clay type of soil on the experimental field with three drainage treatments, estimated better drain spacing in treatment I with narrower drains (L= 10 m). In treatment III, Kirkham's method more precisely generates estimation in the case of shallower ground water. In all drainage treatments estimations of drain spacing are moved toward lower values. Histogram of error explicates high negative value of error as well. Moving toward lower values is illustrated through the negative values of mean, median and mode of error of estimation.

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# NEKE OSOBINE METODE KIRKHAMA ZA ODREDJIVANJE RASTOJANJA IZMEĐU DRENOVA NA MOČVARNO-GLEJNOM ZEMLJIŠTU

**Nevenka Djurović[1] i Ružica Stričević[1]**

R e z i m e

Metode za određivanje rastojanja izmedju drenova dele se na dve grupe: metode primenljive u uslovima stacionarnog režima filtracije i metode primenljive u uslovima nestacionarnog režima filtracije.

U prvu grupu spadaju metode koje polaze od predpostavke da se priticanje vode u drenove odvija pod istovetnim pritiskom, tj. nivo podzemnih voda je konstantan, pa je i isticanje jednako priticanju. Jedna metoda za odredjivanje rastojanja izmedju drenova u stacionarnom režimu filtracije je metoda Kirkhama. Cilj ovog rada je da prikaže neke osobenosti primene metode Kirkhama-a za odredjivanje rastojanja izmedju drenova u stacionarnom režimu filtracije na zemljištu tipa euglej. Analiza je zasnovana na merenjima drenažnog isticanja i dubine podzemne vode na drenažnom sistemu sa tri varijante medjudrenskog rastojanja:10, 20 i 30 metara. Na svim varijantama ogleda procena je značajno pomerena ka manjim vrednostima. Rezultati analize pokazuju značajna ograničenja primene metode, naročito na drenažnim sistemima sa većim drenažnim rastojanjima, kao i u slučajevima većih dubina podzemnih voda.

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