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DETERMINING OPTIMIZED DISTANCE AND DEPTH OF SUBSURFACE DRAINS UNDER UNSTEADY FLOW CONDITIONS AT MULTIPLE CROPPING PATTERN

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ABSTRACT The study area was located in central part of Khuzestan province, Iran. Soil survey and land classification conducted in the area indicated that from total area of 41,855 hectares, about 36,430 hectares (87.0%) was affected by water logging as well as poor internal drainage conditions. These problems were usually associated with shallow and saline to extremely saline groundwater tables. Also, about 14,100 hectares (33.7%) of the studied area was faced with soil Salinity and Alkalinity. The pre-request of soil desalinization and land reclamation of such problematic conditions, are subsurface drainage installation and soils salt leaching, by making use of suitable and available surface water resources of the area. The main objective of this study was to obtain the optimal subsurface drain spacing and depth, considering the new suggested idea for decreasing the installation depth. Calculation and optimizations were done with "Dynamic Equilibrium Method", by making use of computer simulation technique, for unsteady drainage conditions. The obtained results indicated that the optimum tile drain spacing of 35-50 meters, together with 2.0 meter depth of installations, is the most effective, practical and economical alternative. The mentioned condition responds properly for application of 1.0 meter depth for leaching water in four 0.25 meter intervals intermittently. Also a cropping pattern with 100% intensity for irrigated crops production and with 53% irrigation efficiency is suggested to be practiced after soil desalinization in the same study area.

Keywords: Subsurface drainage, Drain depth, Drain spacing, Unsteady drainage models, Land reclamation.

INTRODUCTION The region under study is located in Khuzestan plains and in southern part of Shoushtar city, between 32˚3'North latitude and 48˚50' East longitude. The regions average elevation from the sea level is 67m, and covers an area of about 41,855 hectares. The climate is arid and semi-arid with long and hot summers and short and relatively temperate winters. The average annual rainfall reaches 322mm, and average annual temperature of the region is 26.26 degrees Celsius, while the hottest and coolest months of the year are July and January, with 32.9 and 20.23 degrees Celsius, respectively. Additionally, the annual evaporation from the class (A) pan in this region is 3721 mm/year. Hence, the studied region irrigation water quality supplied from Shotait and Gargar rivers (branches of Karoun River) was ranged between minimum of C_1-S_1 to maximum C_3-S_1 according to USSL [9]. The surveys indicate that the soils of the regional are in three physiographic units: high plateau and hills, river alluvial plains and miscellaneous lands.

The irrigation, potable and industrial water resources originated from the semi-elevated mountains located at the north and east (Zagros and Bakhtiari mountains) of the Khuzestan province, provide the permanent rivers of Karoun, Dez, Karkhe, Jarahi (Maroun) and Hendijan (Zohreh), which enter the Khuzestan plains and are potential sources of water supply of the Khuzestan plains. Shavour River is a permanent river, but is the natural drains of the Dez and Karkhe rivers. In fact, instead of river, it shall be considered as a natural drain.

The geological formation of Khuzestan Province dates back to *Cenozoic* geological period, the respective north and east parties of the province have become in the form of fractures during the orogenensis changes in the *Tertiary* geological formation and includes faults and synclines which are in parallel with the Zagros fractures. During the *quaternary* geological formation, the south and western parts of these fractures have gradually become as plain lands, resulted from accumulation of river alluvium. These fractures parent materials are mainly from lime, marl, sand, gypsum and salt, and the plain regions sediments are the result of such fractures degradation. The studied region geological formations are formed mainly from Karoun and Dez river sediments, these rivers originate from Zagros Mountains[1], and enter into Khuzestan plains [4].

The origin of the Khuzestan Province soils is general from the river sediments. Due to the region climatic conditions, extraordinary evaporation from the bare soil surface, high rate of plants evapotranspiration, result in significant concentration of salts in top soil layers in the soil profile. The other general factor which has provided the saline, sodic, drainage and water logging condition of the land in Khuzestan is the existence of shallow and extremely saline ground water table, Due to poor irrigation management and water use in the past and even present time, which have resulted in enhanced the aforementioned phenomena. According to the detailed studies conducted, in the Khuzestan region, causes leading to salinity or sodicity of the soil and land resources are subjected to the following reasons [4, 5]. Shallow saline groundwater table, existence of salts concentrated layers in the soil profile, poor irrigating water quality, destruction of natural vegetation and predominance of the evaporation to the rain fall, the effects of hot winds and sand storms, sediments resulted from rivers overflow, while to the aforementioned factors, some three

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[1] Zagros Mountains are located in the western and central Iran.

other factors, i.e. soil texture heaviness, soils improper internal drainage condition and involvement of the mankind, due to the improper management of satisfactory utilization of the provincial soil and water resources shall be added.

Materials and Methods

Completing the required measurements of the soil hydrodynamic coefficients and field surveys, control and review the maps and information resulted and completing the respective calculations have been made in two phases as follows:

- **Phase one:**
  According to the survey plan, it was proceeded with completing the field operations, by mean of bore holes to determine the soil layering status, determination the depths of impermeable or semi-impermeable layers in study area, measuring the soils saturated hydraulic conductivity (using the two methods of Ernest and Porschet), and finally measurement the infiltration rate of the soils in 40 locations of the studied region lands. In this phase, totally 41 observation wells were installed, while another 11 complementary observation wells were drilled to complete the saturated hydraulic conductivity and soils layering condition.

- **Phase two:**
  In order to complete the detail studies, the re-controlling of the unreasonable figures and results, eventually determination more precise ranges from the surveyed factors, some other filed studies were made. Some of the aforementioned operations were made simultaneously with completing the soils desalinization and desodification studies plan, during which some 21 observation wells were installed, while another 11 complementary observation wells were drilled to complete the result of saturated hydraulic conductivity and soils layering status. According to the results of soil hydraulic conductivity measurement and water level records in the observation wells. After completion of observations and analysis, indicate that those regions where there is the possibility of existence of artesian or semi-artesian conditions have been identified and some 39 series of compositional piezometer (each series include three piezometer units) have been considered to be installed in these regions.

  The relative ranking of the impermeable layer depth ranges (with respect to soil surface in meters) have also been made in five levels: very shallow (<2.0), shallow (2.0-3.0), moderate (3.0-4.0), deep (4.0-5.0) and very deep (>5.0), while the soils saturated hydraulic conductivity in this regard have been classified in seven levels of very slow (0.00-0.25), slow (0.25- 0.50), moderately slow (0.50- 1.0), moderate (1.00- 1.50), moderately rapid (1,50-2.00), rapid (2.00- 3.00) and very rapid (> 3.00) meters per day, obtained from the field measurement by Ernest and porschet. [1,8].

By choosing the appropriate cropping pattern with 100% intensity, and calculation the plants net and gross water requirements for surface irrigation method with 53% overall irrigation efficiency, considering 10% as water conveyance and distribution loss and 28% as water loss due to on farm application, it was seen that the maximum monthly deep percolation (for cropping pattern) was 4.57 mm/day for July, and maximum annual (for cropping pattern) based on calculated weighted averages was 2.26 mm/day, and also using the calculated values and applying the maximum rate for alfalfa annual deep percolation (as the most water consuming plant), the same was calculated as 2.96 mm/day [1]. Figure (1) shows the monthly deep percolation for cropping pattern of the studied region.

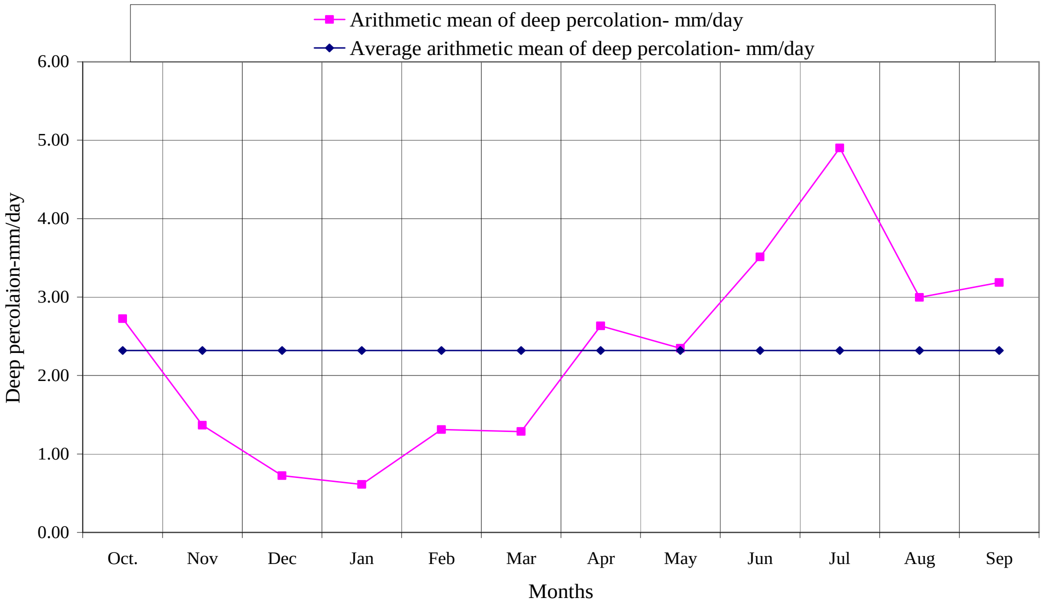

Figure (1) the monthly deep percolation for cropping pattern of the studied region.

Later on, and by making use of Hooghoudt (steady state) and Glover-Dumm (unsteady state) equations, it was possible to calculate the subsurface drains distances within the region under study. Hooghoudt method is one of the most common calculation methods of the drains distances in the steady state condition, for which the general formula is as follows [7]:

$$L^2 = \frac{8K_2 d_e h}{q} + \frac{4K_1 h^2}{q} \qquad (1)$$

Where:

L = drains distance- m

q= drainage coefficient- m/day

K1, K2= hydraulic conductivity in the upper and lower layers of drain installation- m/day

h= water height in the middle of the drain line- m

de = Hooghoudt’s equivalent depth-m

Regarding the unsteady state flow towards condition the drains it should be mentioned that the flows entering into the soil are variable in respected to time, and eventually the drainage flow will always fluctuate. Although, according to the foregoing in the previous sections, the presumption of flow steadiness results in application of a simpler equation, but as in the studied region the entering (percolation) flows into the soil profile are unsteady, thus the Glover- Dumm equation has been used under such state to determine the drain distances, which is as follows [7]:

$$L^2 = \frac{\pi^2 \cdot K \cdot d_e \cdot t}{S \cdot \ln\left(1.16 \frac{Y_0}{Y_t}\right)} \tag{2}$$

Where:

L = subsurface drains distance- m

K = soil hydraulic conductivity - m/day

d_e = Hooghoudt’s equivalent depth-m, when the drains are installed above the impermeable layer (some resistance is resulted from the radial flows adjacent to the drains, for which the equivalent depth shall be used)

S= soil drainable porosity [which may be found by having the soil hydraulic conductivity, and using the $S = 0.1\sqrt{K(m/day)}$ empirical relation.]

Y_0= water table level in the middle of two drains, from the drain installation, promptly after irrigation or rainfall- m

Y_t = water table level in the middle of the drains, from the drain installation, after time "t" from irrigation or rainfall- m

T= time interval between two irrigation or rainfalls- days

In fact, equation (3) is the final and adjusted form of Glover- Dumm equation, which may be expressed as follows [7]:

$$L = \pi\left(\frac{K \cdot D \cdot T}{S}\right)^{\frac{1}{2}} \times \left(Ln1.16\frac{Y_0}{Y}\right)^{-\frac{1}{2}} \tag{3}$$

Where:

D= average thickness of water-bearing layer-m

K.D= soil transmissivity coefficient - m^2/day, while other symbols have the previous meaning assigned to them.

Also, in order to determine the proper depth of subsurface drains installation, in comparison with the conventional methods, and believing that decreasing the installation depth of subsurface drains result in achieving some features such as: provision of a part of the plant water requirements from the water table, acquire of relative dilution in the subsurface water quality, establishment of faster equilibrium conditions of water and salt balance within the respective plants roots zone [4,7] and economical explicability of the pricelist regarding non payment of additional costs for installation of drains deeper than 2meters, it was proceeded with choosing the 2.0m equal installation depth, so that the maximum water table level may keep the soil under the steady and unsteady relations application conditions and in depths of 1.2m and 1.0m, respectively.

Calculation the subsurface drains distance based on the dynamic equilibrium concept, which has been presented by the U.S Bureau of reclamation. In this method, the gradual rise of the water table level will be provided during the irrigation period, so that by the end of irrigation season, or the end of the maximum water requirement period of the cultivations, the water table level reaches the maximum level (designed level), and during the rotation periods the expressed water table level will be declined approximately to the subsurface drains location of installation. Hence, it is presumed that the subsurface water reservoir annual recharge to be equal with its discharge. Otherwise, in a couple of years the water table level rise will reach to a certain equilibrium which will have negative effect on the plants growth.

In the dynamic equilibrium method, during the irrigation period (mainly) and during the maximum water requirements period of the plants (especially), the subsurface drains discharge from the deep percolation is less than the water utilization losses (deep percolation), for which the result of such conditions- though causes the water table level rise of the farm but such water table level range shall be less than the designed criteria (permitted water table level depth). Also the following points have been considered:

- In this method, the water table permitted depth level has been chosen as 1.2m (with respect to the surveys made and the issues specified) in most of the cases
- The subsurface drains distances values calculated by the Glover-Dumm relations (unsteady state) have been used temporarily and to commence the calculations
- After the completion of calculations, the acceptable values have been adjusted or modified using the dynamic equilibrium method
- Finally, the equivalent depth applied in this calculating method has been as followed:

$$d' = d_e + \frac{Y_0}{2} \qquad (4)$$

Where:

d' = applied equivalent depth

de = Hooghoudt’s equivalent depth (as calculated or extracted from the respective graphs, tables or equations)

Additionally, and apart from equation (4), the following relations have been used for numerical solving of equation (2) [3]:

$$\frac{Y}{Y_0} = \frac{1}{1.16} e^{\left(\frac{\Pi^2 Kdt}{SL^2}\right)} \qquad (5)$$

$$Y = 1.16 Y_0 e^{-a \cdot t} \qquad (6)$$

$$a = \frac{\pi^2 \cdot K \cdot d'}{SL^2} \qquad (7)$$

Where:

a= reaction factor, day^{-1}, while the other symbols had the previous meaning assigned to them.

Comparing values calculated by Glover-Dumm relation and dynamic equilibrium indicates that in subsurface drains distances in the latter method in the maximum plant water requirements stage and in different conditions (with similar water table level with respect to the ground water) is a little higher.

CONCLUSIONS The results indicate February and October are the highest rise and draw down of water table level (ground water) within the region under study, respectively. Also, studying the infiltration rate values resulted from tests implementation indicated that from a total 25 cases, 9, 7, 7, and finally 2 cases had very rapid, rapid, moderate and slow rate (final) of infiltration rate, respectively. Whereas among the features measured, the two factors of hydraulic conductivity and impermeable layer establishment depth are highly significant in determination the proper depth and distance of installation the subsurface drains [8], the respective items have been merged and given in Table (1).

Table (1) - area and percentage from total area resulted from merging the soils saturation hydraulic conductivity ranking surveys results and impermeable layer establishment depth within the studied region

		Area- hectare (percentage from total area)							
No.	Hydraulic conductivity m/day / Impermeable layer-m	0.25	0.50	1.00	1.50	2.00	3.00	4.00	Total
1	2	177 (0.6)	827 (2.8)	856 (2.9)	-	-	-	-	1860 (6.2)
2	3	1241 (4.2)	1537 (5.2)	3162 (10.7)	565 (1.9)	-	-	-	6505 (22.0)
3	4	-	1065 (3.6)	650 (2.2)	-	-	-	-	1715 (5.8)
4	> 5	709 (2.4)	2660 (9)	8333 (28.2)	3605 (12.2)	1093 (3.7)	1093 (3.7)	1980 (6.7)	19473 (66.0)
Total		2127 (7.2)	6089 (20.6)	13001 (44.0)	4170 (14.1)	1093 (3.7)	1093 (3.7)	1980 (6.7)	29553 (100.0)

As it can been seen from the above table, there have been 16 states or combinations from the impermeable later establishment and soils saturation hydraulic conductivity parameters. Due to the studies made and by focusing on the extension of such states within the region under study, first of all it was proceeded with calculating the subsurface drains distances using steady method for each of the combinations, and then with respect to the necessity of considering other factors for the two combinations, the 1m/day hydraulic conductivity and impermeable layer depth equal to 5m representing the largest area, the final calculation of the subsurface drains distances was completed using the unsteady method, while the results were controlled by the dynamic equilibrium method. Also, in order to adjust the proper depth of installation the subsurface drains in comparison with the common methods, and believing that reducing the subsurface drains installation depth results in achieving some features such as: provision of a part of the plant water requirements from the water table level, acquire of relative dilution in the first subsurface ground water, establishment of faster equilibrium conditions of water and salt balance within the respective plants roots zone [6,7], it was proceeded with choosing the equal installation depth of 2.0m, the maximum water table wave level may keep the soil level under the steady and unsteady relations application conditions and in depths of 1.2m and 1.0m, respectively.

Due to the studies made and application of the aforementioned cases, finally two distances of subsurface drains installation distances for the whole region under study, i.e. 35m and 50m, with 2.0m installation depth may be effective for the respective cropping pattern and mentioned irrigation efficiency. A sample of the subsurface water level fluctuations hydrographs during one year for the 50m subsurface drains distance has been given in Fig. No.2. Reviews on other studies made all over Iran, especially other regions of Khuzestan Province, emphasize the results of this study.

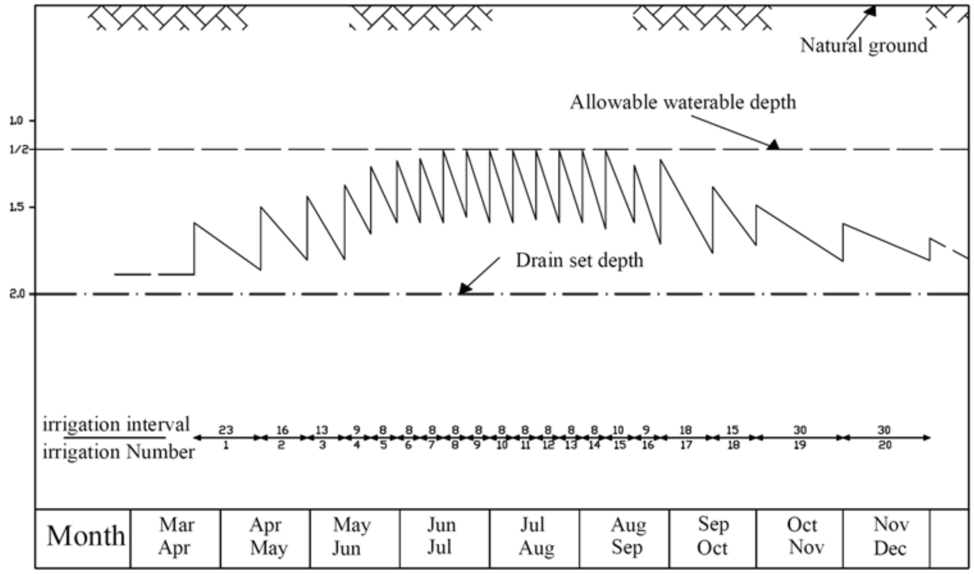

Figure 2. Hydrograph of subsurface water table during the farm irrigation period for maximum monthly proper cropping pattern

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