

# Comparing drain and well spacings in deep semi-confined aquifers for water table and soil salinity control

R.J. Oosterbaan, 16-09-2019. On [www.waterlog.info](http://www.waterlog.info) public domain

## Abstract

For the control of the water table in a thick soil layer with low hydraulic conductivity underlain by a deep aquifer with high hydraulic conductivity, it may be recommendable to use a pumped well drainage system (vertical drainage) instead of a horizontal subsurface drainage system by ditches, tiles or pipes owing to the relatively large well spacings compared to the drain spacings. The drainage by wells can also help in soil salinity control.

This article shows the calculation of the required well and drain spacings in the kind of semi confined aquifer described.

In those aquifers the drainage by wells may be more economical due to the large spacings, but when the horizontal drainage can be done by gravity, the well drainage system has the disadvantage of pumping costs.

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## 1. Introduction

Subsurface drainage systems are used for the control of the water table in otherwise waterlogged soils. They are also used to control the soil salinity by evacuating saline soil moisture.

Subsurface drainage is usually done by horizontally placing drain pipes at some depth below the soil surface, often around 1 to 1.2 m depth, but sometimes also shallower or deeper than that. The water removed by the drainage system may have a gravity outlet, but in low lands pumping may be required to evacuate the drainage water.

Subsurface drainage by pumped wells is not frequently done because it is usually more expensive. However, in some cases drainage by wells (vertical drainage) may be economically advantageous, especially in cases of a thick topsoil layer with low hydraulic conductivity underlain by a deep aquifer with high hydraulic conductivity. Under such conditions, the required spacing of the horizontal drains are small while that of well may be large, so that the installation costs of the wells are relatively small.

When the horizontal drainage system evacuates the water by gravity, the costs of pumping the water from wells may reduce the economical advantage of the wider spacings.

The "Revelle Report" states that subsurface drains (horizontal drains) are used in controlling the watertable and the build up of salinity in many regions of the world. In the Punjab, however, the report states that such horizontal drains are not only much more expensive than tubewells (vertical drains) for eliminating waterlogging and salinity, but they do not provide the advantages of regulation of the irrigation supply [Ref. 1]. (Ref. Gulam Mohmmad, 1965. *Waterlogging and Salinity in the Indus plain: A Critical Analysis of the Major Conclusions of the Revelle Report*. <http://www.pide.org.pk/pdf/PDR/1964/Volume3/357-403.pdf> ).

Mohammad Valipur has felt the necessity to compare the required spacings of horizontal and vertical drains as a basis for cost comparison between the two drainage methods. His well spacings, however, are relatively small, because he did not use an aquifer with high hydraulic transmissivity (the product of hydraulic conductivity and thickness of the aquifer), while the use of tube wells only advisable when aquifers with high transmissivity are present, because in that situation the well spacing can be very wide making the constructing of a vertical drainage system relatively cheap [Ref. 2] (Ref. Mohammad Valipour, 2012. *A Comparison between Horizontal and Vertical Drainage Systems in Anisotropic soils*. IOSR Journal of Mechanical and Civil Engineering, Vol. 4, Issue 1 (Nov.-Dec. 2012), PP 07-12.

<http://iosrjournals.org/iosr-jmce/papers/vol4-issue1/B0410712.pdf>

In this article, the required spacing of horizontal and vertical drains will be calculated for the conditions of a semi confined aquifer. A comparison will be made and the results will be discussed.

## 2. Horizontal drainage

Horizontal drainage equations are given by Ritzema [Ref. 3]. Of these, the Hooghoudt equation is the most widely used. He also described the adjustment of the Hooghoudt equation for entrance resistance and sloping land [Ref. 4]. The application of the energy balance of groundwater flow is explained in [Ref. 5]. Software for horizontal subsurface drainage can be downloaded from [Ref. 6]. This software uses the energy balance of groundwater flow with the hydraulic equivalent of the law of Joule in electricity [Ref. 7]. The program, called EnDrain, will be used for the following calculation. The parameters used in this program are shown in the next figure.

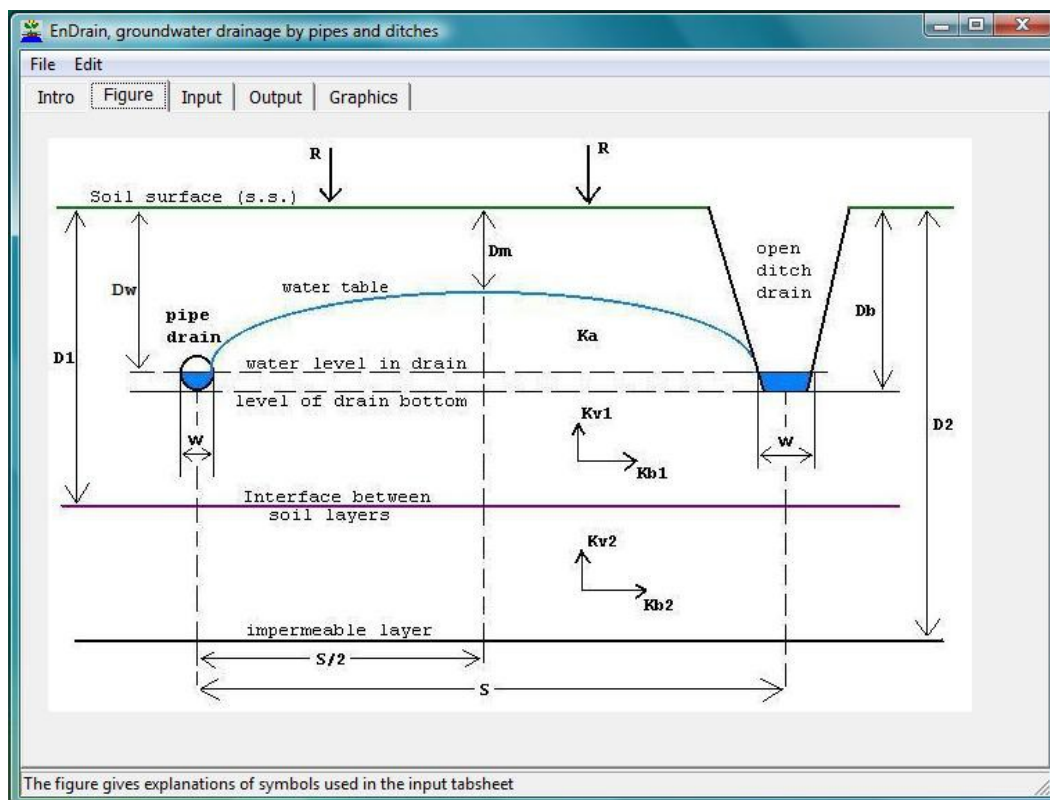


Figure 1. Parameters used in the EnDrain model.  $R$ =net recharge,  $K_v$ =vertical hydraulic conductivity,  $K_h$ =horizontal hydraulic conductivity,  $K_a$ =uniform hydraulic conductivity above drain level.

In this case it is assumed that the depth of the water table midway between the drains ( $D_m$ ) should not be shallower than 0.5 below soil the soil surface when the discharge reaches a value of 2 mm/day (0.002 m/day). Further, the soil profile consists of a first layer of 5 m. thickness having a hydraulic conductivity of 0.5 m/day, underlain by a second layer, the aquifer, of 95 m. thickness having a hydraulic conductivity of 2 m/day.

The input data used can be seen in figure 2.

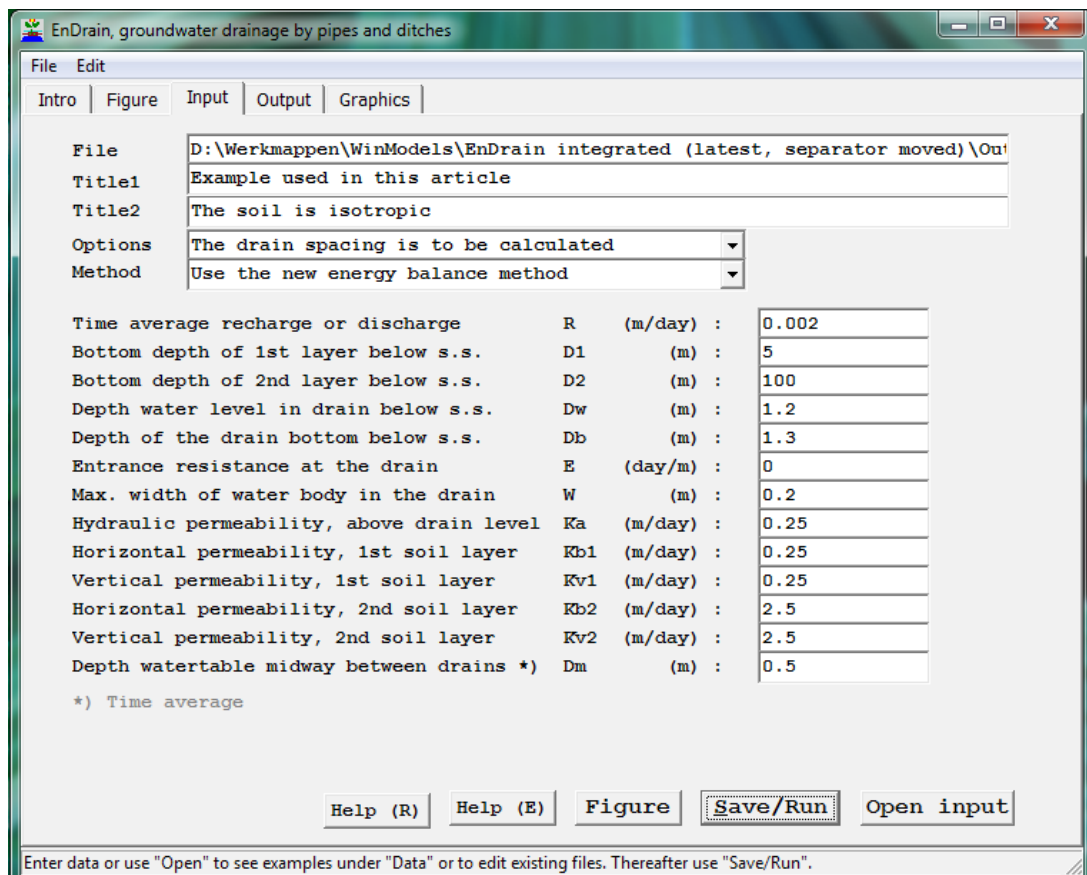


Figure 2. Screen print of the input tab sheet of the EnDrain program

Figure 2 shows that the drain depth ( $D_w$ ) is 1.2 m and the drain width ( $W$ ) is 0.2 m, making the drain radius 0.1 m.

The results of the calculations are depicted in figure 3.

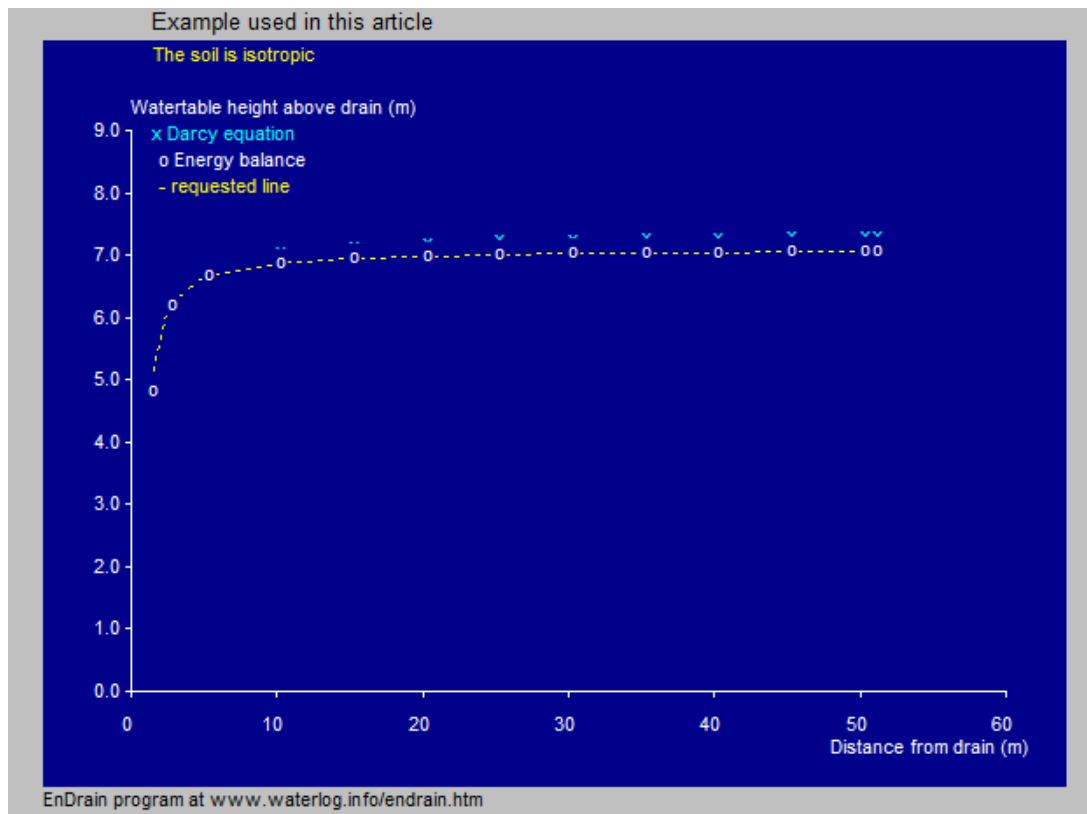


Figure 3. Graph of the shape of the water table produced by EnDrain on the basis of the input data described before.

Figure 3 shows that the water table rises steeply near the drain due to the small hydraulic conductivity in its vicinity and the large radial flow of the groundwater towards the drain. Further away the water table becomes almost flat, as the groundwater flow reduces at larger distances away from the drain and it makes use of the more permeable underground.

The required drain spacing is 102 m. For 1 ha the drain length required is  $10000/102=98$  m.

### 3. Vertical drainage

Vertical drainage equations are given [Ref. 8]. Software for vertical subsurface drainage can be downloaded from [Ref. 9]. The program, called WellDrain, will be used for the following calculation. The parameters used in this program are shown in the next figure.

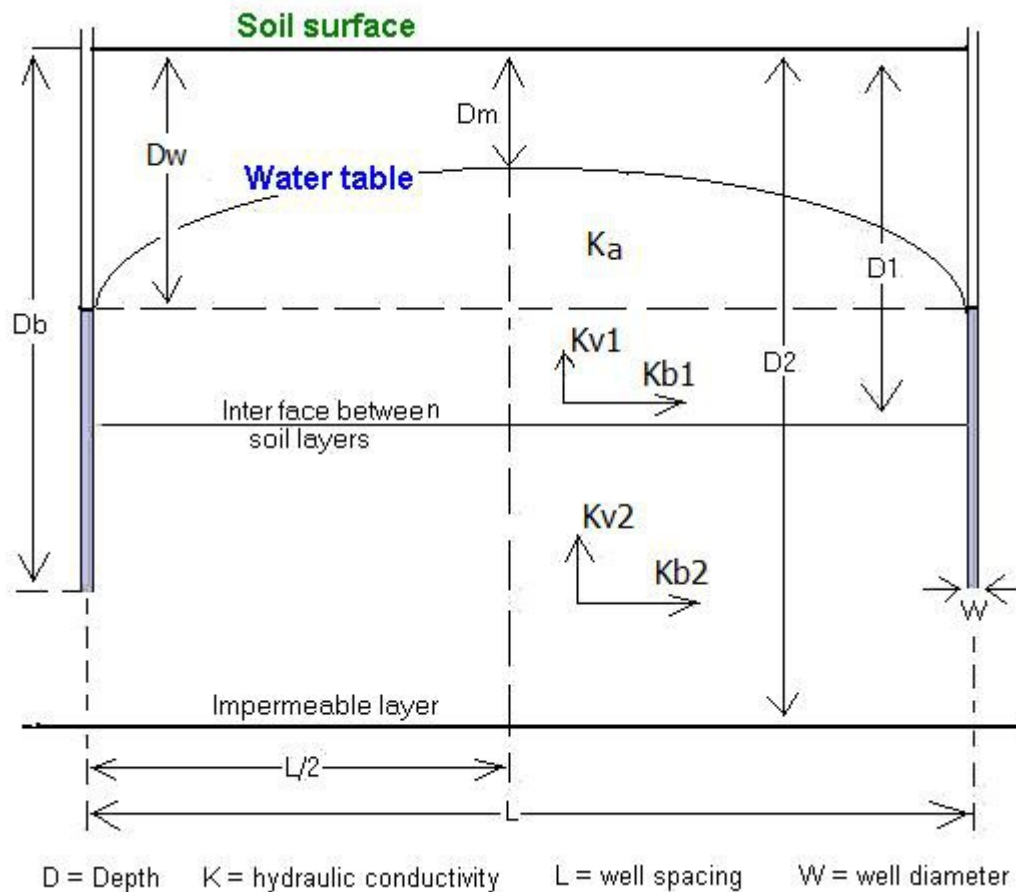


Figure 4. Parameters used in the WellDrain model.  $K_v$ =vertical hydraulic conductivity,  $K_h$ =horizontal hydraulic conductivity,  $K_a$ =uniform hydraulic conductivity above drain level.

Like in the example of the EnDrain program, in it is assumed that the depth of the water table midway between the wells ( $D_m$ ) should not be shallower than 0.5 below soil the soil surface when the discharge reaches a value of 2 mm/day (0.002 m/day). Further, in all cases, the soil profile consists of a first layer of 5 m. thickness having a hydraulic conductivity of 0.5 m/day, underlain by a second layer, the aquifer, of 95 m. thickness having a hydraulic conductivity of 2 m/day.

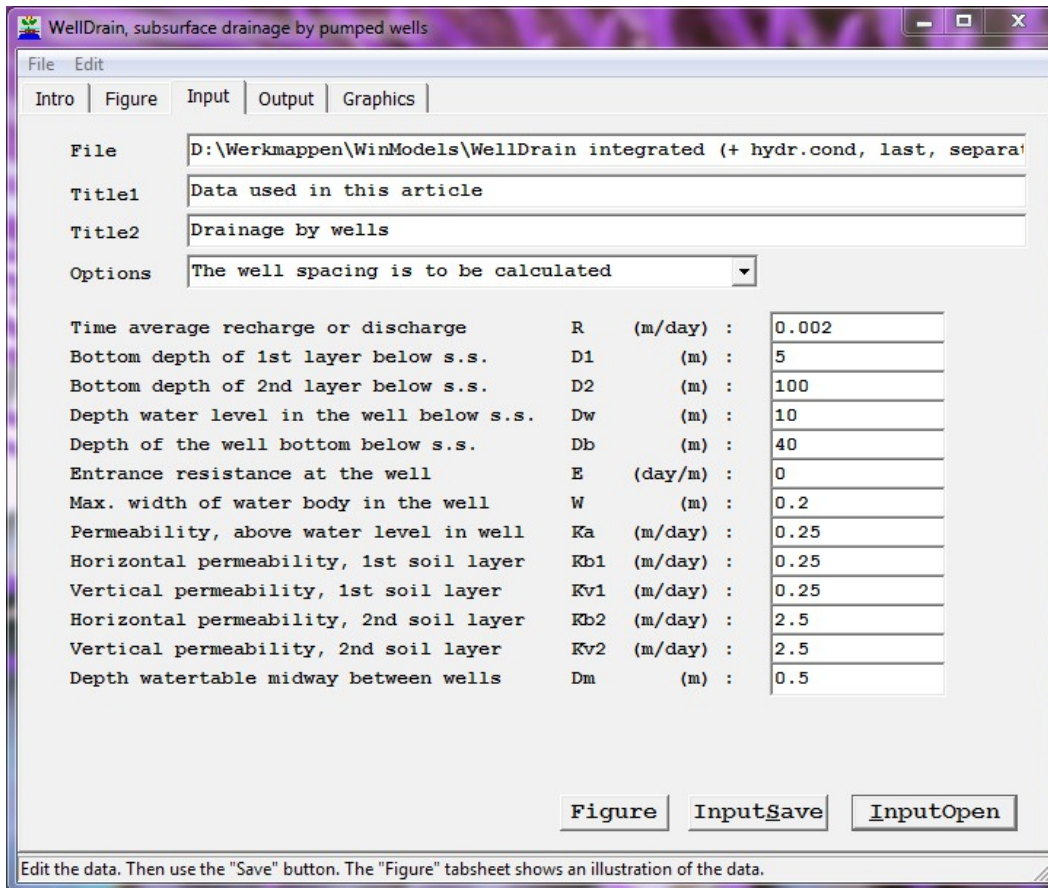


Figure 5. Screen print of the input tab sheet of the WellDrain program

Figure 2 shows that the water level in the well ( $D_w$ , drain level) is 10 m and the well is 40 m deep ( $D_b$ ). The width of the water body in the well is 0.2 m, making the well radius 0.1 m. The well are partially penetrating.

The results of the calculations are depicted in figure 6.

The well spacing is 683 m. The well discharge is  $0.002 \cdot 683^2 = 933$  m<sup>3</sup>/day originating from  $6.83^2 = 47$  ha,

The tube length is  $40 / 47 = 0.85$  m / ha.

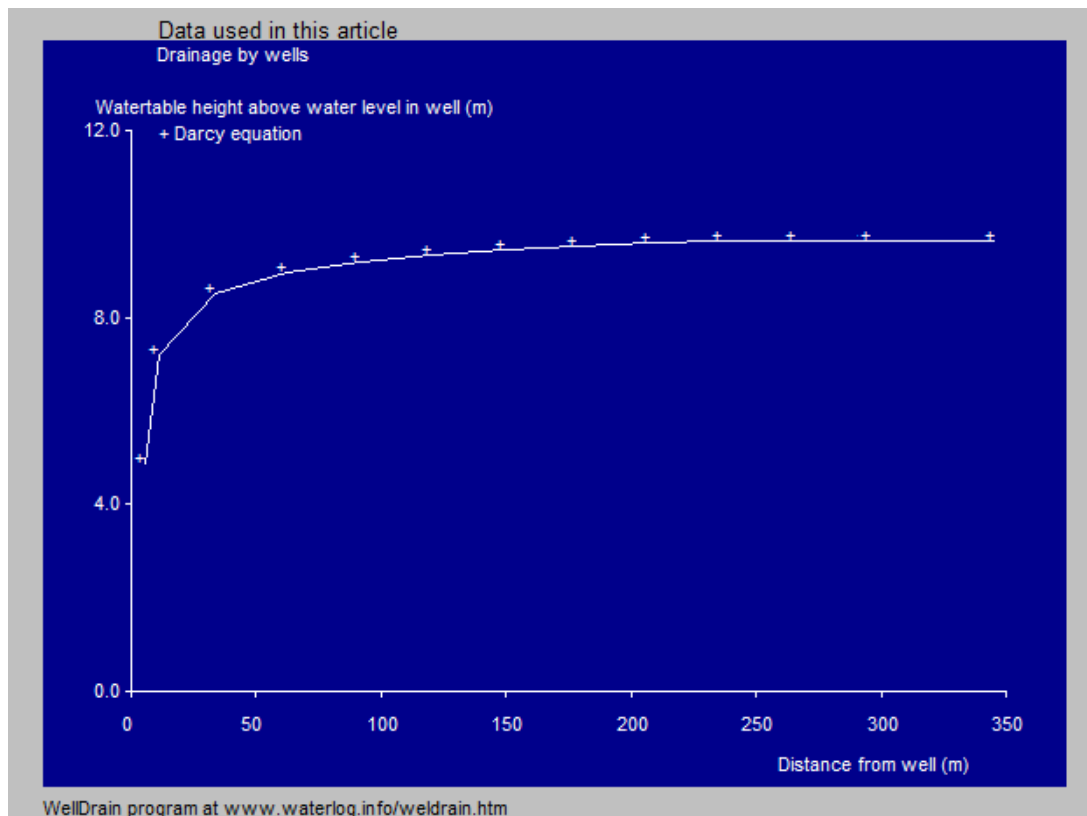


Figure 6. Graph of the shape of the water table produced by WellDrain on the basis of the input data described before.

## 5. Comparison

Type of drainage system	Spacing between tubes (m)	Tube length (m/ha)
Horizontal	102	98
Vertical	683	0.85

In the table it is shown that the spacing of the horizontal drains is 102 m so that per ha 98 m of drain tubes are needed. The spacing of the vertical drains (wells) is much larger: 683 m. With the depth of the well being 40 m, one finds that per ha only 0.85 m of tube is needed.

## 5. Conclusion

It is found that for subsurface drainage of the soil with deep semi-confined aquifers the required length of horizontal drains (pipe drains) is much larger than that of vertical drains (wells).

Economically the well drainage option is worth to consider, taking into account that wells need pumps and energy for uplifting the drainage water

## 6. References

[Ref. 1] Gulam Mohammad, 1965. *Waterlogging and Salinity in the Indus plain: A Critical Analysis of the Major Conclusions of the Revelle Report*. On line:

<http://www.pide.org.pk/pdf/PDR/1964/Volume3/357-403.pdf> ).

[Ref. 2] Mohammad Valipour, 2012. *A Comparison between Horizontal and Vertical Drainage Systems in Anisotropic soils*. IOSR Journal of Mechanical and Civil Engineering, Vol. 4, Issue 1 (Nov.-Dec. 2012), PP 07-12. On line:

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[Ref.3] H.P. Ritzema, Subsurface flow to drains. On line:

[https://www.researchgate.net/publication/272483377\\_Subsurface\\_flow\\_to\\_drains](https://www.researchgate.net/publication/272483377_Subsurface_flow_to_drains)

[Ref. 4] Hooghoudt's drainage equation, adjusted for entrance resistance and sloping land

[https://www.researchgate.net/publication/272507723\\_Hooghoudt's\\_drainage\\_equation\\_adjusted\\_for\\_entrance\\_resistance\\_and\\_sloping\\_land](https://www.researchgate.net/publication/272507723_Hooghoudt's_drainage_equation_adjusted_for_entrance_resistance_and_sloping_land)

[Ref. 5] The energy balance of groundwater flow applied to subsurface drainage in anisotropic soils by pipes or ditches with entrance resistance. On line:

<https://www.waterlog.info/pdf/enerart.pdf>

[Ref. 6] Free software for calculations of horizontal subsurface drainage system. Download from: <https://www.waterlog.info/endrain.htm>

[Ref. 7] The hydraulic equivalent of the law of Joule in electricity. On line:

[https://www.researchgate.net/publication/335229941\\_hydraulic\\_equivalent\\_of\\_Joule](https://www.researchgate.net/publication/335229941_hydraulic_equivalent_of_Joule)

[Ref. 8] Subsurface land drainage by tube wells, well spacing equations for fully and partially penetrating wells in uniform or layered soils with or without anisotropy and entrance resistance. On line:

[https://www.researchgate.net/publication/332470338\\_SUBSURFACE\\_LAND\\_DRAINAGE\\_BY\\_TUBE\\_WELLS\\_WELL\\_SPACING\\_EQUATIONS\\_FOR\\_FULLY\\_AND\\_PARTIALLY\\_PENETRATING\\_WELLS\\_IN\\_UNIFORM\\_OR\\_LAYERED\\_AQUIFERS\\_WITH\\_OR\\_WITHOUT\\_ANISOTROPY\\_AND\\_ENTRANCE\\_RESISTANCE](https://www.researchgate.net/publication/332470338_SUBSURFACE_LAND_DRAINAGE_BY_TUBE_WELLS_WELL_SPACING_EQUATIONS_FOR_FULLY_AND_PARTIALLY_PENETRATING_WELLS_IN_UNIFORM_OR_LAYERED_AQUIFERS_WITH_OR_WITHOUT_ANISOTROPY_AND_ENTRANCE_RESISTANCE)

[Ref. 9] Free software for calculations of drainage by wells. Download from:

<https://www.waterlog.info/welldrain.htm>