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EUSS – computer model to evaluate emission uniformity for sloping surfaces under drip irrigation system

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Abstract

A computer model EUSS (Emission Uniformity on Sloping Surfaces) has been developed to design and evaluate the system capacity under operating conditions for drip irrigation system. And achieve the desired value of emission uniformity that is not significantly different according to the recommended values by applying it in field experiment located at Al-Slahia city, Egypt. The model has the ability to design the system by all of the common design techniques and have ability to customize any of them.

EUSS model includes two main parts: crop water requirements, and hydraulic calculations of the system using metric unit system. It developed in graphical user interface of the programming language C-sharp (C#) by using Microsoft Visual Studio. The model database is containing the equations, tables and reference values to get more rapid and accurate results, and gives the opportunity for selecting some parameters such as: soil properties, characteristics of the corresponding crop, and climatic data. EUSS model allows the user to assume or set definite values, for example plot layout, land slopes and topography, the emitter characteristics and operating conditions.

Key words: *computer model, drip irrigation system, emission uniformity, EUSS model, slope*

INTRODUCTION

Increasing of freshwater demand is associated globally with increasing of the population. By 2025 almost 29 countries are expecting to face water crisis, the majority of these countries located in the Middle East and northern Africa [HOFWEGEN, SVENDSEN 2000]. Rising population expected to associate with increasing 70% more food production globally in 2050 [FAO 2011].

The maximum water utilization is used primarily for agricultural intensification to cover the need requirements [BREMERE *et al.* 2001]. The main water supply in Egypt is the Nile River with a flow rate of 55.5 bln m^3 per year, 83.4% from the total water supply in Egypt used in agriculture [EL-FELLALY, SALEH 2004]. In coming decades Egypt is expected to face a substantially increasing population. Consequently, increasing demand on agriculture crops and irrigation water. Therefore, Egypt is encouraged to use a limited amount of water with a more efficient way. Pressurized irrigation systems (PIS) offer the most efficient and productive way for applying water and nutrients to crops specially in drip irrigation system, on the contrary of wasteful surface irrigation method [KELLER, BLIESNER 1990].

Designing and developing of the main components of drip irrigation system such as emitters, valves and control equipment were studied by several researches [FAO 2000]. The lateral and manifold pipelines in drip irrigation system costs from 30% to 40% of the total pipeline cost [MOSTAFA 2004]. So it must design and manage very precisely to achieve the required function successfully. This design and development need more complicated calculations by system designer. Recently, computer considered a good solution to solve the hard calculations by developing suitable programs for the target proposes and can perform and model hydraulic calculations of irrigation system.

In comparison with non-computer help, results in less error frequency and more comprehensive analysis could be obtained. There are several popular and commercial irrigation computer models used for this propose and aims to simplify the design and planning of laterals and Manifolds in sub-unit such as:

- OSSD – a computer software developed to predict emission uniformity for odd-shaped and design sub-unit by dealing with emitter characteristics and sub-unit geometry [MAHROUS *et al.* 2008];
- MicroCad – a computer software to simulate soil-water-plant relations, system hydraulics and cost analysis to achieve the optimum design [ISMAIL *et al.* 2000];
- SPRINKMOD – a computer model to simulate both flow rate distribution and pressure along Manifold and lateral lines [ALLEN 1999].
- There was a computer model offered a convenient way to design of small scale drip irrigation systems with an area up to 10 ha [PHILIPOVA *et al.* 2012].
- Determination of discharge of trickle emitters based on wetted soil profile and developing a methodology for the design of micro-irrigation laterals to obtain required average discharge from the emitters done by a software and accordingly the micro-irrigation sub-unit designed [JAIN 2001].
- RZWQM2 “Root Zone Water Quality”– a computer Model to predict crop water stress then the timing of irrigation [GU *et al.* 2017].

There are some variables influences on irrigation system design like land slopes and the emission uniformity [SWAMEE, RATHIE 2005]. To overcome these limitations and get more rapid and accurate results, computer models carried out.

The main objective of this research was developing a computer model for designing and evaluating of drip irrigation system on sloping surfaces to achieve the highest value of emission uniformity and overcoming the limitations and get more rapid and accurate results.

MATERIALS AND METHODS

PROGRAM FLOW-CHART

EUSS computer model has been developed in graphical user interface of the programing language C-sharp (C#) using Microsoft Visual Studio. EUSS is clarifying the process of drip irrigation system design based on Emission Uniformity equation’s [KELLER, BLIESNER 1990] and allowable pressure variation equation’s [SWAMEE, RATHIE 2005; USDA 1984].

A flowchart is a type of diagrammatic representation of an algorithm, a step-by-step approach to solving a task. It shows the steps as boxes of various kinds, and their order by connecting the boxes with arrows. A flowchart represents a workflow or process and used in analysing, designing, documenting or managing a process or program in various fields.

The required data to predict the actual emission uniformity were added into the program based on the design criteria. The data could be added simply by the program user who has a good experience otherwise the data will be added automatically. The developed software flow chart is illustrated in Figure 1.

HYDRAULIC CALCULATIONS AND MODEL DESCRIPTION

Sub-unit (plot) layout

As shown in Figure 2 the main interface describes the main element of the model as: plot layout, crop-soil-*ETo*, emitters, Manifold design, laterals design and design emission uniformity. The detailed description for each element in EUSS model illustrated in Figures 2, 3, 4 and 5. The plot layout includes plot data (number of plots, plots length and width), Manifold and lateral data (numbers, flow direction and elevation difference). The outlet data (plot area, lateral and Manifold lengths) will calculate by EUSS model and after that the Manifold and lateral run length will be determined.

Crop type, soil type and evapotranspiration rate

Row spacing (S_r), plant spacing (S_p), soil type and crop type could be input simply into EUSS model by the designer. The program will use automatically the available database related to crop and soil type such as wetted diameter [MIRZAEI *et al.* 2009] and crop factor (*CR*) [LAMM *et al.* 2007].

The proper selection of C_R is important to determine the crop water requirements as well as the system capacity. Evapotranspiration rate (*ET*) is automatically selected by EUSS model from the input climate data [ALLEN *et al.* 1998], as in Figure 3.

Emitters

In order to calculate the irrigation water requirements and all design parameters, the designer will provide EUSS model with the emitter specifications such as emitter flow rate (Q_e), emitter inlet pressure (P_e), number of emitters per plant (n_e), the emitter exponent (x), manufacturing variation coefficient (C_V) and the emitter’s type (online or inline) and accordingly the irrigation efficiency (η_i) for both type shall be estimated as 0.9 [IRMAK *et al.* 2011]. Also the daily available working time (T_{AV}), number of shifts (N_s), required design emission uniformity ($EU_{D.req}$) and allowable pressure variation sharing factor (*SF*) will be added as shown in Figure 4.

EUSS model will calculate the water requirement (W_{req}) – Equation (1) [PHOCAIDES 2007], emitter precipitation rate (Pr_e) – Equation (2) [PHOCAIDES 2001], the maximum duration of water application (t_{Ap}, $\mathrm{h \cdot day^{-1}}$) – Equation (3) [USDA 1984], and system capacity (Q_{Sys}, $\mathrm{m^3 \cdot h^{-1}}$) – Equation (6) [USDA 2013]:

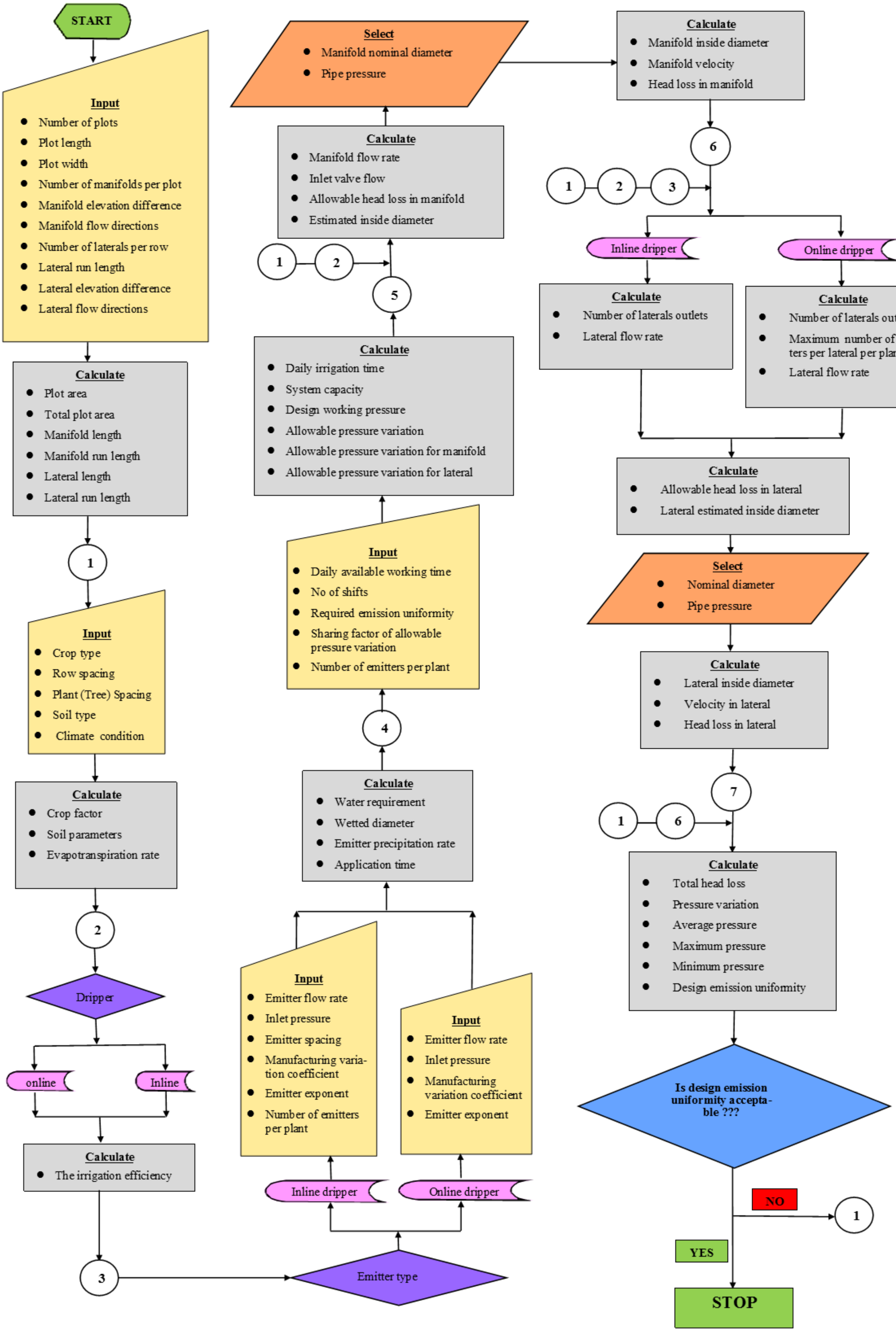
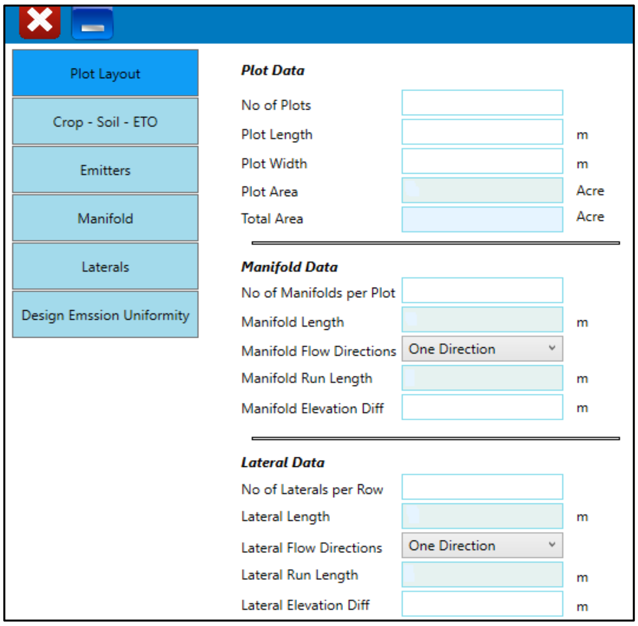


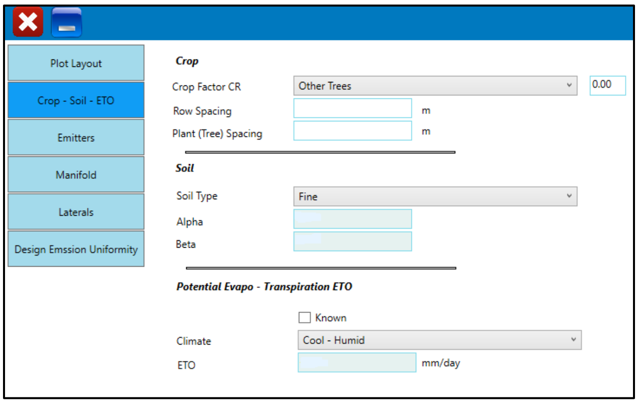
Fig. 1. Emission Uniformity on Sloping Surfaces (EUSS) model flow-chart; source: own elaboration



Manifold Flow Directions: One Direction

Lateral Flow Directions: One Direction

Fig. 2. The main program interface of Emission Uniformity on Sloping Surfaces (EUSS) model; source: own elaboration



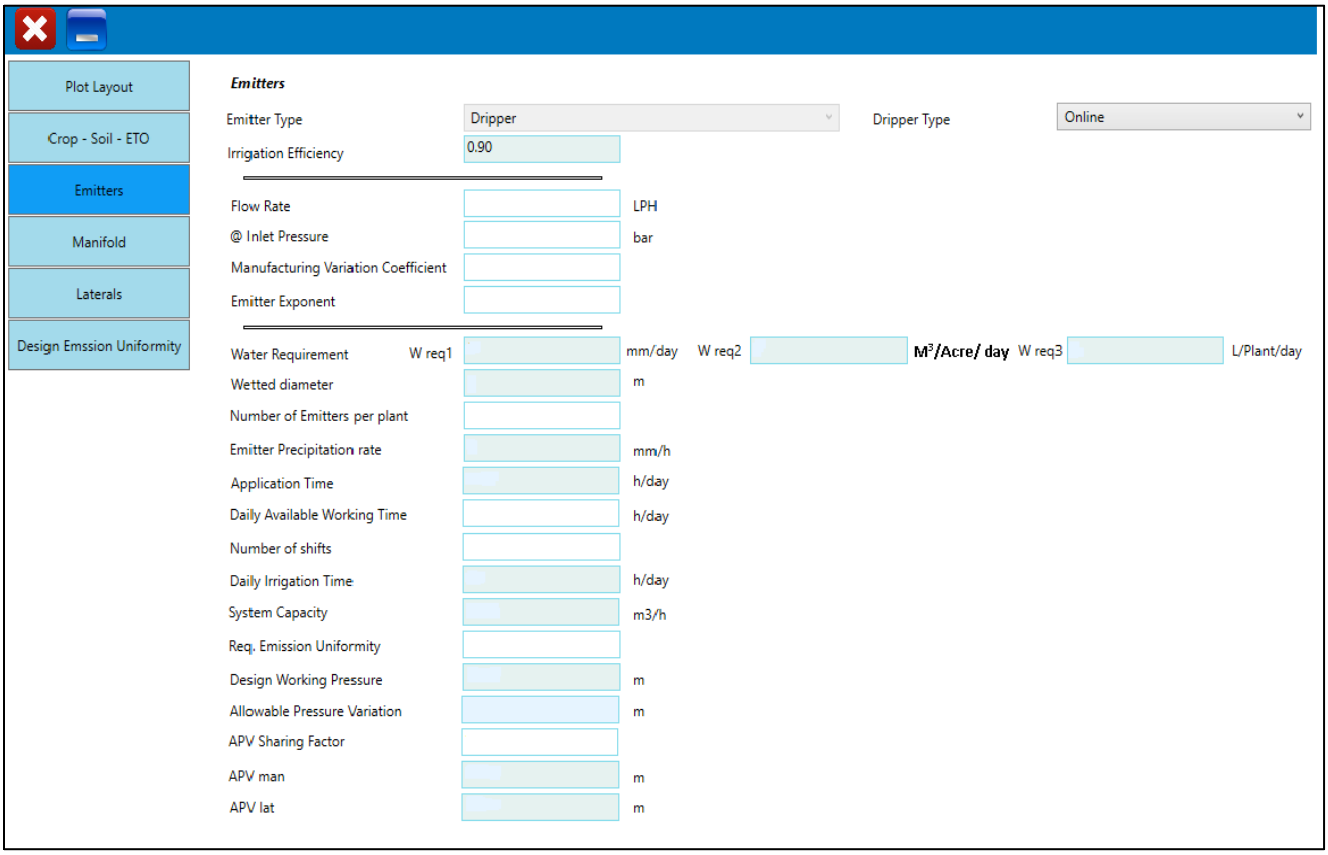
Crop Factor CR: Other Trees 0.00

Soil Type: Fine

☐ Known

Climate: Cool - Humid

Fig. 3. Interface for crop, soil and potential evapotranspiration rate inputs; source: own elaboration



Emitter Type: Dripper

Dripper Type: Online

Irrigation Efficiency: 0.90

Fig. 4. Interface for emitters and the design parameter; source: own elaboration

$$W_{\text{req}} = \frac{ET\ C_R}{\eta_i} \tag{1}$$

Where: W_{req} = water requirement (mm·day^{-1}), ET = evapotranspiration rate (mm·day^{-1}), C_R = crop factor, η_i = irrigation efficiency.

$$Pr_e = \frac{n_e\ Q_e}{S_r\ S_p} \tag{2}$$

Where: Pr_e = emitter precipitation rate (mm·h^{-1}), n_e = number of emitters per plant, Q_e = emitter flow rate (dm^3·h^{-1}), S_r = row spacing (m), S_p = plant (tree) spacing (m),

$$t_{Ap} = \frac{W_{\text{req}}}{Pr_e} \tag{3}$$

If t_{Av} is the total operation time available during one day, the number of shifts N_S will be the integer value according to Equation (4):

$$N_S = \frac{t_{Av}}{t_{Ap}} \qquad (4)$$

Hence the total operating hours of the system (t_{Op}, h·day^{-1}) will calculate using Equation (5):

$$t_{Op} = N_S \cdot t_{Ap} \qquad (5)$$

$$Q_{\text{Sys}} = \frac{4\, W_{\text{req}} \cdot A_{\text{PLT}}}{t_{Op}} \qquad (6)$$

Where: A_{PLT} is the total plots area in acres (1 acre = 4046.86 m^2).

In any micro-irrigation system, the friction losses in pipelines and the elevation differences will cause pressure variations and consequently variations in the emitter's flow rates. The allowable pressure variation between emitters in a sub-unit (APV_{Sub}) can be easily derived from emission uniformity equation (Eq. 14) [SWAMEE, RATHIE 2005; USDA 1984] as described in Equation (7):

$$APV_{\text{Sub}} = 200\, P_{\text{ave}} \left[1 - \left\{ \frac{EU_D}{1 - \frac{1.27 C_V}{\sqrt{n_e}}} \right\}^{1/x} \right] \qquad (7)$$

Where: P_{ave} = design pressure (average pressure in a sub-unit) (kPa), EU_D = design emission uniformity, C_V = emitter's coefficient of manufacturing variation, n_e = number of emitters per plant, x = the emitter exponent.

The effect of APV_{Sub} reflected on the emission uniformity especially at difference levels between the Manifold and lateral as presented in USDA [2013].

APV_{Sub} divided into APV_{Man} for the Manifold and APV_{Lat} for the lateral, so EUSS model could calculate both APV_{Man} and APV_{Lat} using Equation (8) [KELLER, BLIESNER 1990]:

$$APV_{\text{Sub}} = APV_{\text{Man}} + APV_{\text{Lat}}. \qquad (8)$$

Sharing factor (SF) is the ratio between APV_{Sub} and APV_{Man} as shown in Equation (9) and subsequently APV_{Lat} is calculated using Equation (10) [ALI 2016]:

$$SF = APV_{\text{Man}} : APV_{\text{Sub}} \qquad (9)$$

$$APV_{\text{Lat}} = (1 - \text{SF}) \cdot APV_{\text{Sub}} \qquad (10)$$

SF value varies between 0.4 and 0.6 and inversely proportional with Manifold and lateral diameters [ALI 2016].

Manifold design

In order to realize the desired EU_D, the pressure variation among the Manifold should not exceed the APV_{Man}. Applying Bernoulli's equation on the Manifold from point 1 to point 2 as shown in Figure 5, the Manifold head loss $h_{L,\text{Man}}$ will be estimated in Equation (11):

$$h_{L,\text{Man}} = APV_{\text{Man}} - \Delta Z_{\text{Man}} \qquad (11)$$

Where: $h_{L,\text{Man}}$ = the Manifold head loss (m), ΔZ_{Man} = Manifold elevation difference (m) "ΔZ (–) going uphill and ΔZ (+) going downhill".

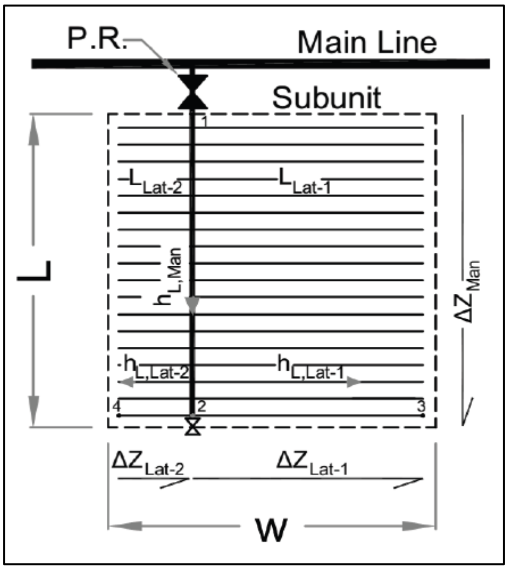


Fig. 5. Manifold design and layout; own elaboration; L = subunit length (m), W = subunit width (m), P.R. = pressure regulator, L_{Lat} = lateral length (m), $h_{L,\text{Lat}}$ = the head loss in lateral (m), ΔZ_{Lat} = lateral elevation difference (m), ΔZ_{Man} = Manifold elevation difference (m); source: own elaboration

Friction loss changes when pipeline flow rates change because of diverging flows. However, multiple outlet pipes such as Manifolds and laterals typically have uniformly spaced and uniformly discharging outlets. Pipes head loss can be modified using the Christiansen multiple outlet reduction factor, rf in Equation (12).

Head loss reduction factor can be estimated for various outlet numbers and two outlet configurations as in Table 1 and Figure 6 [LAMM *et al.* 2007].

Table 1. Christiansen multiple outlet reduction factor (rf)

Number of outlet	Christiansen multiple outlet reduction factor, rf	
	A (full space)	B (half space)
1	1.00	1.00
2	0.64	0.52
3	0.53	0.44
4	0.49	0.41
5	0.46	0.40
6	0.44	0.39
7	0.43	0.38
8	0.42	0.38
9	0.41	0.37
10–11	0.40	0.37
12–14	0.39	0.37
15–20	0.38	0.36
21–35	0.37	0.36
>35	0.36	0.36

Explanations: column A values are used when the first outlet is a full space from the pipe inlet, and column B values are used when the first outlet is a half space from the pipe inlet.
Source: own elaboration.

Based on previous calculations and user choices, EUSS model will calculate the Manifold flow rate, allowable head loss, and estimated inside diameter (ID_{Man}) using Hazen–William's Equation (12) [KELLER, BLIESNER 1990; USDA 2013]:

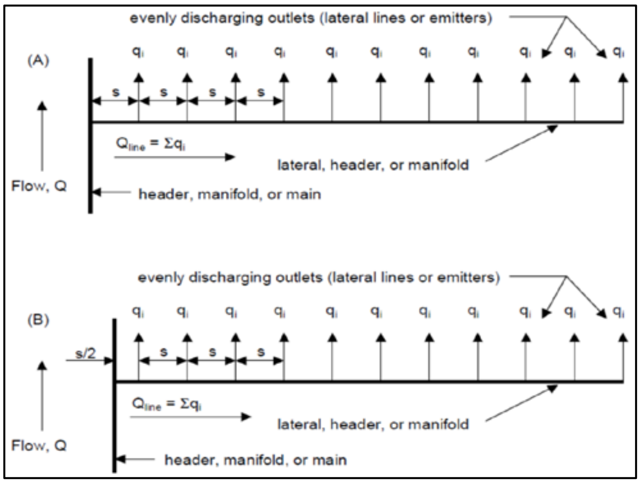


Fig. 6. Discharging outlet orientation for the multiple outlet factor: A = case of full space, B = case of half space; source: own elaboration

$$h_L = rf \cdot 10.675 \left(\frac{Q}{c}\right)^{1.852} \frac{L}{ID^{4.8704}} \tag{12}$$

Where: h_L = the head loss in (m), rf = Christiansen multiple outlet reduction factor, n = The number of outlets along the pipe, Q = pipe flow rate ($\text{m}^3 \cdot \text{s}^{-1}$), L = the pipe length (m), ID = the inside diameter of the pipe (m), C = friction coefficient of the pipe.

Accordingly, the user can select the nominal diameter at the required pipe pressure as shown in Figure 7 and correlate it with the nearest standard diameter according to ASTM standard. Then, the Manifold flow velocity (v_{Man}) and the actual head loss ($h_{L,\text{Man}}$) in Manifold will be determined using Equation (12).

Lateral design

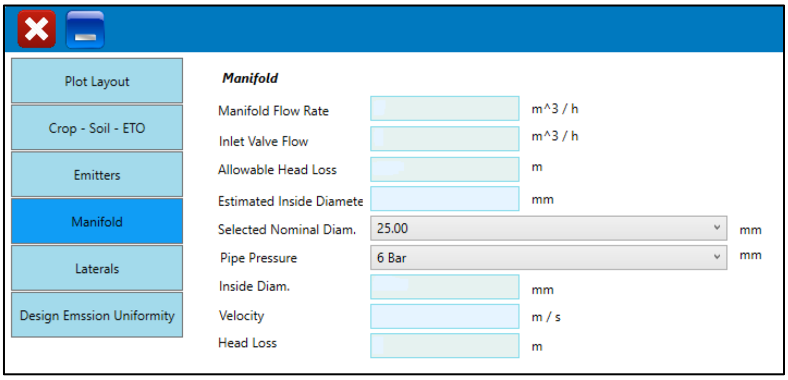
The lateral tubes made from polyethylene tubes (PE), and designed similar to Manifold as described in Manifold design. Then, the inside diameter of lateral tube (ID_{Lat}), the flow velocity (v_{Lat}) and the actual head loss ($h_{L,\text{Lat}}$) will be calculated as shown in Figure 8.

Designed emission uniformity

To evaluate the design performance, emission uniformity was recommended by JAMREY and NIGAM [2018] to be used as a major evaluation criteria. The predicted emission uniformity was compared with assumed values presented by previous literatures. Calculations of maximum pressure (P_{Max}) and minimum pressure (P_{Min}) were determined using both the Manifold and lateral head losses and average pressure. So, the design emission uniformity (EU_D) was calculated using Equation (13) as presented in USDA [1984], Figure 9.

$$EU_D = 100\left(1 - 1.27\frac{Cv}{\sqrt{n_e}}\right)\frac{Q_{e\,\text{min}}}{Q_{e\,\text{avg}}} \tag{13}$$

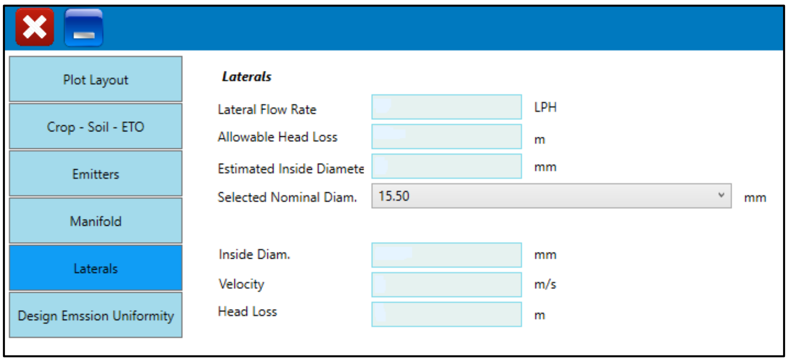
Where: EU_D = design emission uniformity (%), Cv = emitter's coefficient of manufacturing variation, n_e = number of emitters per plant, $Q_{e\,\text{min}}$ = the minimum emitter discharge rate for the minimum pressure in the sub-unit, ($\text{dm}^3 \cdot \text{h}^{-1}$), $Q_{e\,\text{avg}}$ = the average or design emitter discharge rate for the sub-unit ($\text{dm}^3 \cdot \text{h}^{-1}$).



Manifold

Manifold Flow Rate m^3 / h
Inlet Valve Flow m^3 / h
Allowable Head Loss m
Estimated Inside Diamete mm
Selected Nominal Diam. 25.00 mm
Pipe Pressure 6 Bar mm
Inside Diam. mm
Velocity m / s
Head Loss m

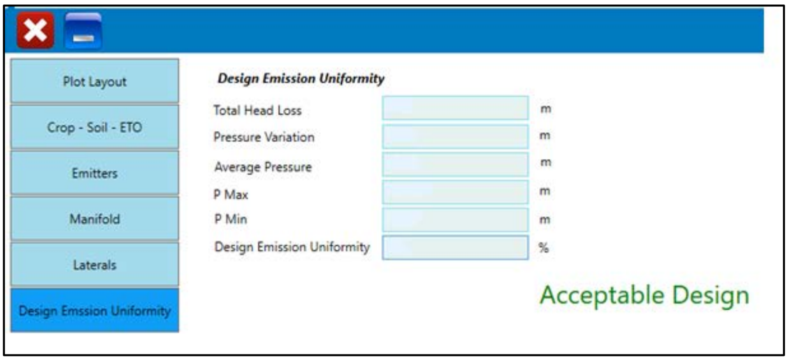
Fig. 7. Interface for Manifold design; source: own elaboration



Laterals

Lateral Flow Rate LPH
Allowable Head Loss m
Estimated Inside Diamete mm
Selected Nominal Diam. 15.50 mm
Inside Diam. mm
Velocity m/s
Head Loss m

Fig. 8. Interface for lateral design; source: own elaboration



Design Emission Uniformity

Total Head Loss m
Pressure Variation m
Average Pressure m
P Max m
P Min m
Design Emission Uniformity %

Acceptable Design

Fig. 9. Interface for designed emission uniformity; source: own elaboration

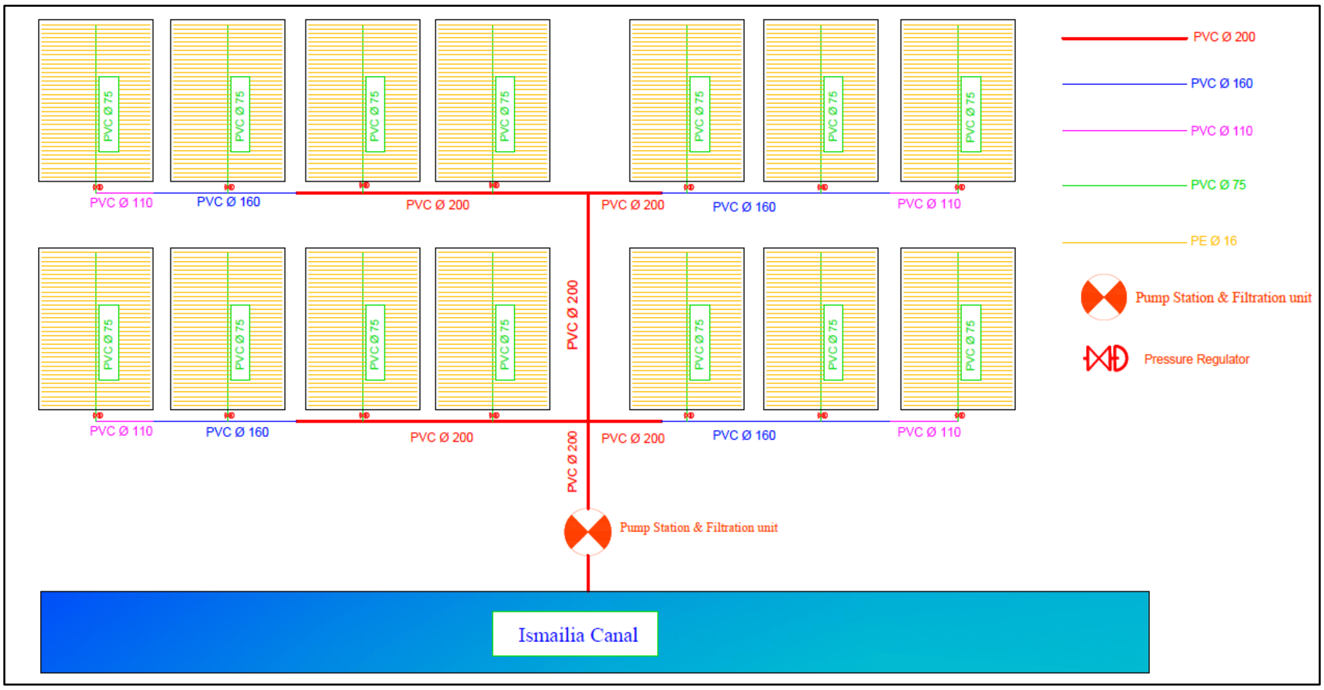


Fig. 10. The layout of the project, Al Slahia city, Egypt; source: own elaboration

The estimated emission uniformity by the model will be compared with the recommended ranges [ASAE 1999a] and accordingly the calculation will be accepted or rejected.

VALIDATION

Site description

The field experiments were conducted in a medium texture soil located at Al-Slahia city, Egypt during August 2019 in order to validate the EUSS model. The irrigation water was provided from Ismalia Channel under warm dry weather (Fig. 10)

One direction 75 mm PVC Manifold pipes (C = 140) with 36 outlets were used for the experimental sub-units at 600 kPa and –1.7 m (downhill) slope. Two directions 16 mm lateral tubes (C = 130) were used without slope in two lines per row. The daily irrigation was performed only in one shift at 6.5 h·day^{-1}. Five online drip emitters used per plant (n_e) with 4 dm^3·h^{-1} discharge, orifice flow (x = 0.5), 100 kPa pressure and Cv = 0.05. The sub-unit area was 8.42 acres (216 m as length × 156 m as width) and was cultivated with citrus 6 × 4 m with 0.65 crop factor (C_R). Field emission uniformity EU_{ACT} was estimated from 18 measurement points as illustrated in Figure 11 based on the measured actual discharge and pressure using catch cans (0.2 m diameter and 0.15 m height) and pressure gage respectively.

Hydraulic evaluation

There were several equations to calculate and evaluate the **emission uniformity** as following.

Field emission uniformity (EU_{ACT}). The field emission uniformity (EU_{ACT}) was calculated using Equation (14) [JAMREY, NIGAM 2018]:

$$EU_{\mathrm{ACT}} = Q_{e\ \mathrm{avg}\ (1/4\ \mathrm{low})} : Q_{e\ \mathrm{avg}} \cdot 100 \qquad (14)$$

Where: $Q_{e\ \mathrm{avg}\ (1/4\ \mathrm{low})}$ = the average discharge of the low quarter emitters (dm^3·h^{-1}), $Q_{e\ \mathrm{avg}}$ = the average or design emitter discharge rate for the sub-unit (dm^3·h^{-1}).

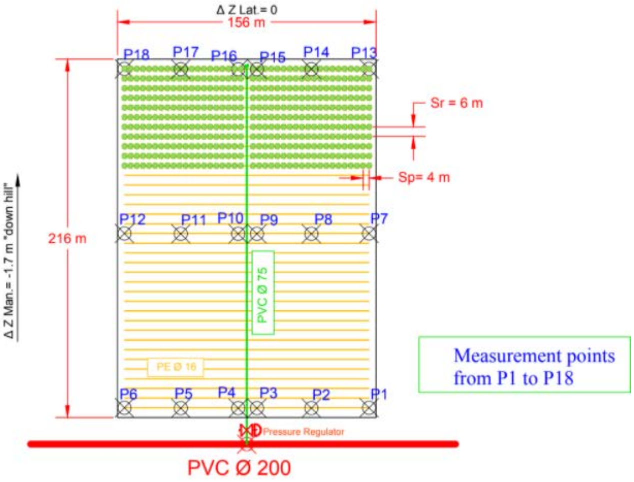


Fig. 11. The layout of the sub-unit (plot area); ΔZ_{Lat} = lateral elevation difference (m), ΔZ_{Man} = Manifold elevation difference (m), source: own elaboration

Design emission uniformity (EU_D). EUSS model used Equation (13) to calculate EU_D to evaluate the design performance as mention before.

Statistical emission uniformity (EU_S). The 18 observations were evaluated using "one sample T test" and accordingly the statistical uniformity (EU_S) for non-significant values were calculated by Equations (15) and (16) [LAMM *et al.* 2007] to evaluate *EU* for submain unit as shown in Table 2.

$$V_{qs} = \frac{S_q}{Q_{e\ \text{avg}}} \tag{15}$$

$$EU_S = 100\,(1 - V_{qs}) \tag{16}$$

Where $Q_{e\ \text{avg}}$ = the average or design emitter discharge rate for the sub-unit ($\text{dm}^3 \cdot \text{h}^{-1}$), S_q = standard deviation, V_{qs} = statistical coefficient of variation for a submain unit or system.

Table 2. Comparison of statistical uniformity (EU_S) and emission uniformity (EU_D), %

Method acceptability	EU_S	EU_D
	%	
Excellent	100–95	100–94
Good	90–85	87–81
Fair	80–75	75–68
Poor	70–65	62–56
Unacceptable	<60	<50

Source: LAMM *et al.* [1999].

Statistical analysis. The obtained data were analysed statistically using one sample T test. The significant differences between EU_D, EU_{ACT} and EU_S were identified by comparing the *EU* values with reference value (EU_{assumed}).

Assumed emission uniformity (EU_{assumed}). The recommended value of assumed emission uniformity will determine as presented in Table 3 [ASAE 1999a], according to the field conditions as emitter type, spacing, topography and land slop.

Table 3. Recommended ranges of design emission uniformity (EU_D)

Emitter type	Spacing	Topography	Slope (%)	*EU* rang (%)
Point source on perennial crops	>4	uniform	<2	90–95
		steep or undulating	>2	85–90
Point source on perennial or semi-permanent crops	<4	uniform	<2	85–90
		steep or undulating	>2	80–90
Line source on annual or perennial crops	all	uniform	<2	80–90
		steep or undulating	>2	70–85

Source: ASAE [1999a].

RESULTS AND DISCUSSION

HYDRAULIC EVALUATION RESULTS

Field emission uniformity (actual) (EU_{ACT}). The estimated EU_{ACT} value based on the measured $q_{\text{ACT.}}$ was 86.31% using Equation (14) and Table 4.

Table 4. Measured values of actual discharge q_{ACT} and actual pressure P_{ACT} for 18 measurements points

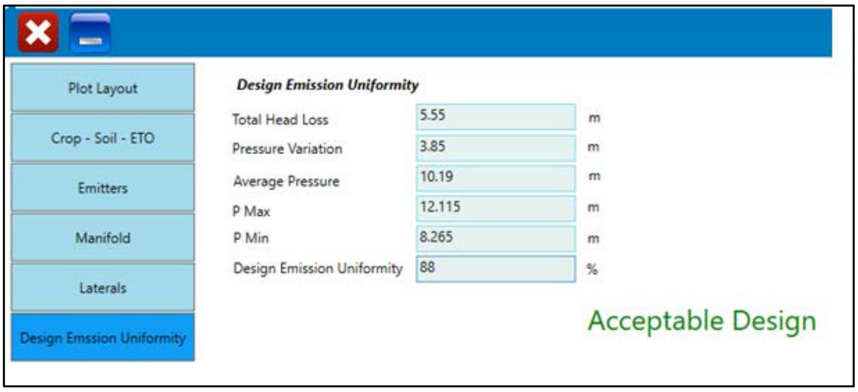
Measurement points	q_{ACT} ($\text{dm}^3 \cdot \text{h}^{-1}$)	P_{ACT} (kPa)
P1	4.6	130
P2	4.75	140
P3	5.0	150
P4	4.6	140
P5	4.8	140
P6	4.5	130
P7	4.3	110
P8	4.4	120
P9	4.6	130
P10	4.6	130
P11	4.35	120
P12	4.25	110
P13	3.68	90
P14	4.0	100
P15	3.9	100
P16	4.1	100
P17	3.7	90
P18	3.6	90

Source: own study.

Design emission uniformity (EUD): "EUSS model result". The hydraulic parameters were calculated using EUSS model based on the entered data from the field experiment. Subsequently as shown in Figure 12, the EU_D value was 88% which is in the acceptable range as shown in Table 2.

Statistical emission uniformity (EU_S). The EU_S value based on the measured values of actual discharge (q_{ACT}) was 90.47%. One sample T test result shows that there is no significant difference was observed between the measured values of discharge.

Assumed emission uniformity (EU_{assumed}). According the site conditions and recommended rang in Table 2, the assumed emission uniformity were varied between 85 and 90%.



Design Emission Uniformity

Total Head Loss: 5.55 m
Pressure Variation: 3.85 m
Average Pressure: 10.19 m
P Max: 12.115 m
P Min: 8.265 m
Design Emission Uniformity: 88 %

Acceptable Design

Fig. 12. Emission Uniformity on Sloping Surfaces (EUSS) model result; source: own study

STATISTICAL ANALYSIS RESULT

One sample T test analysis was applied on the different values of *EU* (EU_D, EU_{ACT} and EU_S) by comparing with recommended value (EU_{assumed}).The test result showed that there is no significantly different between the *EU* values as shown in Table 5.

Consequently, the validity of the EUSS model was showed when the statistical analysis proved that there was no significantly different between EU_D which calculated by the model and the other values of *EU*.

Table 5. Statistical analysis result

Emission uniformity values			Reference value (EU_{assumed})	Significant difference
EU_D "EUSS model result"	EU_{ACT}	EU_S		
88%	86.31 %	90.47%	85–90%	*EU* values is not significantly different

Explanations: EU_D = design emission uniformity, EU_{ACT} = field emission uniformity (actual), EU_S = statistical emission uniformity, EU_{assumed} = assumed emission uniformity.
Source: own study.

CONCLUSIONS

An interactive program is developed for drip irrigation system design. It is accomplished in the computer language C# with graphical interface. The program consists of two parts: determine crop water requirements, and hydraulic calculations of lateral and manifold to achieve the desired value of emission uniformity. It allows the user to input or select site conditions such as soil, crop, climatic data and the basic parameters for hydraulic calculations. The program has been compiled to work in windows to enable engineers inexperienced in programming to use it easily.

The field experiment and statistical analysis proved the accuracy of the EUSS model to achieve the highest value of emission uniformity and evaluate it especially on sloping surfaces.

EUSS model has some limitations as listed below:

1) EUSS model deals with drip irrigation system;
2) EUSS model not related to a specific area, it is applied to small or large areas;
3) EUSS model can simulate the regular sub-units (square and rectangular) only;
4) EUSS model includes simulating of sloping and non-sloping surfaces;
5) EUSS model is specialized in field crops and palms.

List of symbols

PIS	pressurized irrigation systems
EUSS	emission uniformity on sloping surfaces
ASAE	American Society of Agricultural Engineers
ASTM	American Society for Testing and Materials
NEH	National Engineering Handbook
FAO	Food and Agriculture Organization of the United Nations
ET	evapotranspiration rate in (mm·day^{-1})
S_r	row spacing (m)
S_p	plant spacing (m)
A_{PLT}	total plots area in acres
C_R	crop factor
Q_e	emitter flow rate (dm^3·h^{-1})
P_e	emitter inlet pressure (kPa)
x	emitter exponent
C_V	emitter's coefficient of manufacturing variation
η_i	the irrigation efficiency
T_{AV}	daily available working time (h·day^{-1})
t_{AP}	maximum duration of water application (h·day^{-1})
t_{OP}	total operating hours of the system (h·day^{-1})
$EU_{D\,\mathrm{req}}$	required design emission uniformity
N_s	number of shifts
W_{req}	water requirement (mm·day^{-1})
Pr_e	emitter precipitation rate (mm·h^{-1})
Q_{Sys}	system capacity (m^3·h^{-1})
P_{avg}	average pressure, or design pressure in a sub-unit (kPa)
EU_D	design emission uniformity
n_e	number of emitters per plant
APV_{Sub}	the allowable pressure variation between emitters in a sub-unit (kPa)
SF	allowable pressure variation sharing factor
APV_{Man}	the allowable pressure variation in Manifold (kPa)
APV_{lat}	the allowable pressure variation in lateral (kPa)
$h_{L,Man}$	the head loss in Manifold (m)
ΔZ_{Man}	Manifold elevation difference (m)
ID_{Man}	estimated inside diameter (mm)
$h_{L\,\mathrm{Lat}}$	The head loss in lateral (m)
ΔZ_{Lat}	Lateral elevation difference (m)
h_L	The head loss (m)
rf	Christiansen multiple outlet reduction factor
n	the number of outlets along the pipe
Q	pipe flow rate (m^3·s^{-1})
L	pipe length (m)
ID	the inside diameter of the pipe (m)
C	pipe friction coefficient
v_{Man}	Manifold flow velocity (m·s^{-1})
PVC	polyvinyl chloride
PE	polyethylene
ID_{Lat}	the inside diameter of lateral tube
v_{Lat}	lateral flow velocity (m·s^{-1})
P_{Max}	maximum pressure (kPa)

P_{Min}	minimum pressure (kPa)
$Q_{e\ \text{min}}$	the minimum emitter discharge rate for the minimum pressure in the sub-unit ($\text{dm}^3\cdot\text{h}^{-1}$)
$Q_{e\ \text{avg}}$	the average or design emitter discharge rate for the sub-unit ($\text{dm}^3\cdot\text{h}^{-1}$)
EU_{ACT}	field emission uniformity (actual)
$Q_{\text{avg (1/4 low)}}$	the average discharge of the low quarter emitters ($\text{dm}^3\cdot\text{h}^{-1}$)
EU_S	statistical emission uniformity
q_{ACT}	actual discharge for measuring points ($\text{dm}^3\cdot\text{h}^{-1}$)
P_{ACT}	actual pressure for measuring points (kPa)
S_q	standard deviation for measuring points
V_{qs}	statistical coefficient of variation for a submain unit or system
EU_{assumed}	assumed emission uniformity

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