SUPROMED: Sustainable production in water limited environments of Mediterranean agro-ecosystem

Manual PRESUD sprinkler irrigation

The PRIMA programme is supported under Horizon 2020, the European Union's Framework Programme for Research and Innovation

SUPR MED

PRIMA

Manual PRESUD of sprinkler irrigation

Design of sprinkler irrigation subunit of minimum cost with proper operation.

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OBJECTIVO

Matlab software named PRESUD (PREssurized SUBunit Design) was developed to identify the optimum solid set sprinkler irrigation rectangular subunit design minimizing the annual water application cost per unit of irrigated area (CT), calculated as the sum of investment, maintenance, energy, and water costs,

Water cost include the cost to transport water from the source to the subunit inlet.

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METRHODOLOGY

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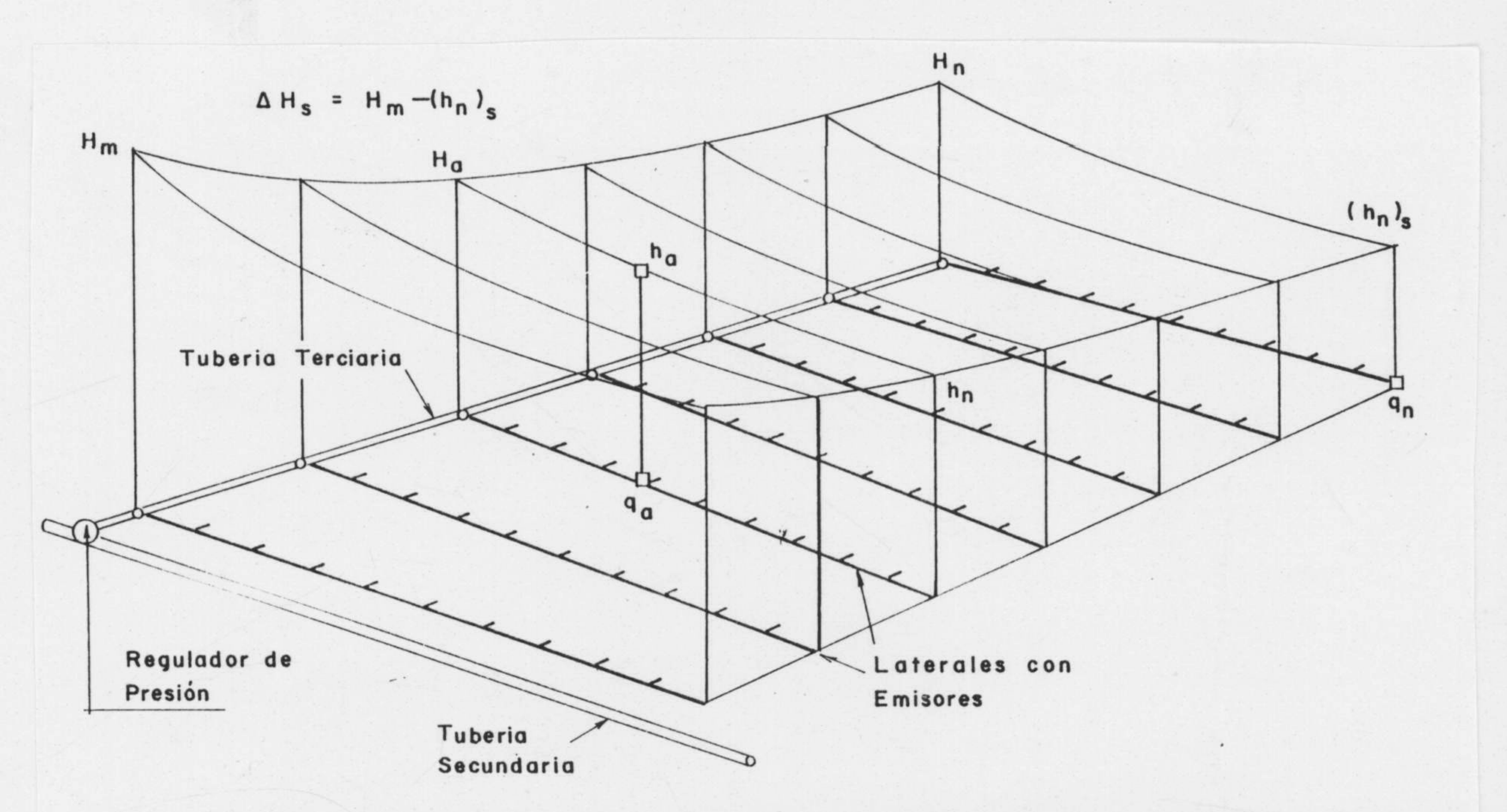
Pressure distribution in an irrigation subunit in a flat area



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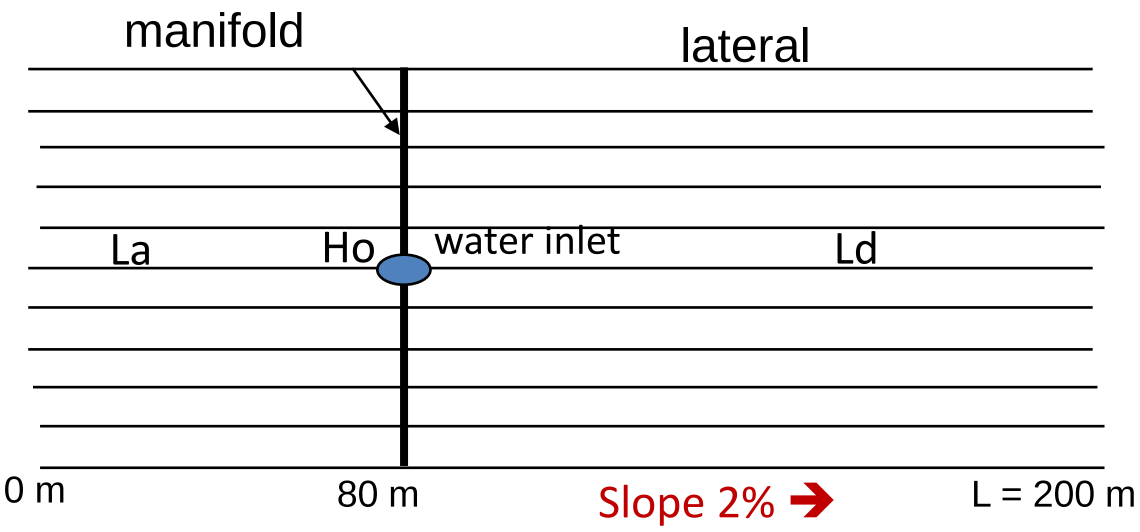
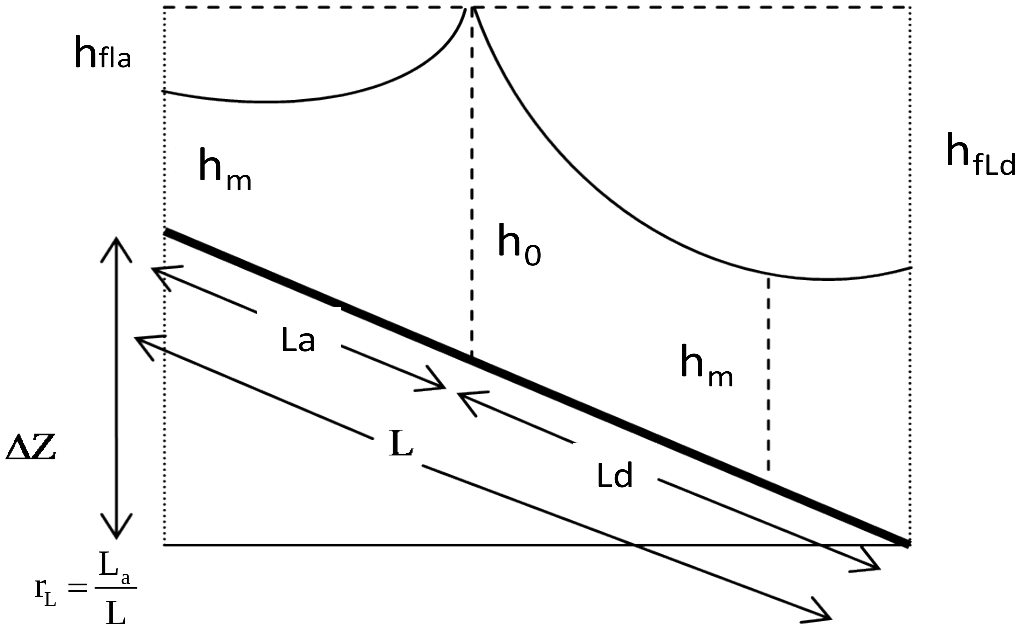
METHODOLOGY

Identification of the inlet point in paired lateral or manifold pipes

Emitter equation $\boxed{q_e = K\, h_e^{x}}$

q_e = emission rate; K = emission coefficient;
x = emission exponent; he = inlet pressure head of the sprinkler.





So= lateral slope
m= 1.8 in Veronese Datey for head loss equation
q_u = emission rate by unit of length
L = length of the paired lateral pipe
La = lateral length uphill of the manifold pipe
D = inner diameter of lateral pipe
The relationship $\Psi(r_L)$ <==> r_L in table

Equation used to calculate La

$$\Psi(r_L) = \frac{0{,}5\ S_0\ (1+m)}{0.74\ \ 0{,}426 D^{-(3+m)} q_u^m L^m}$$

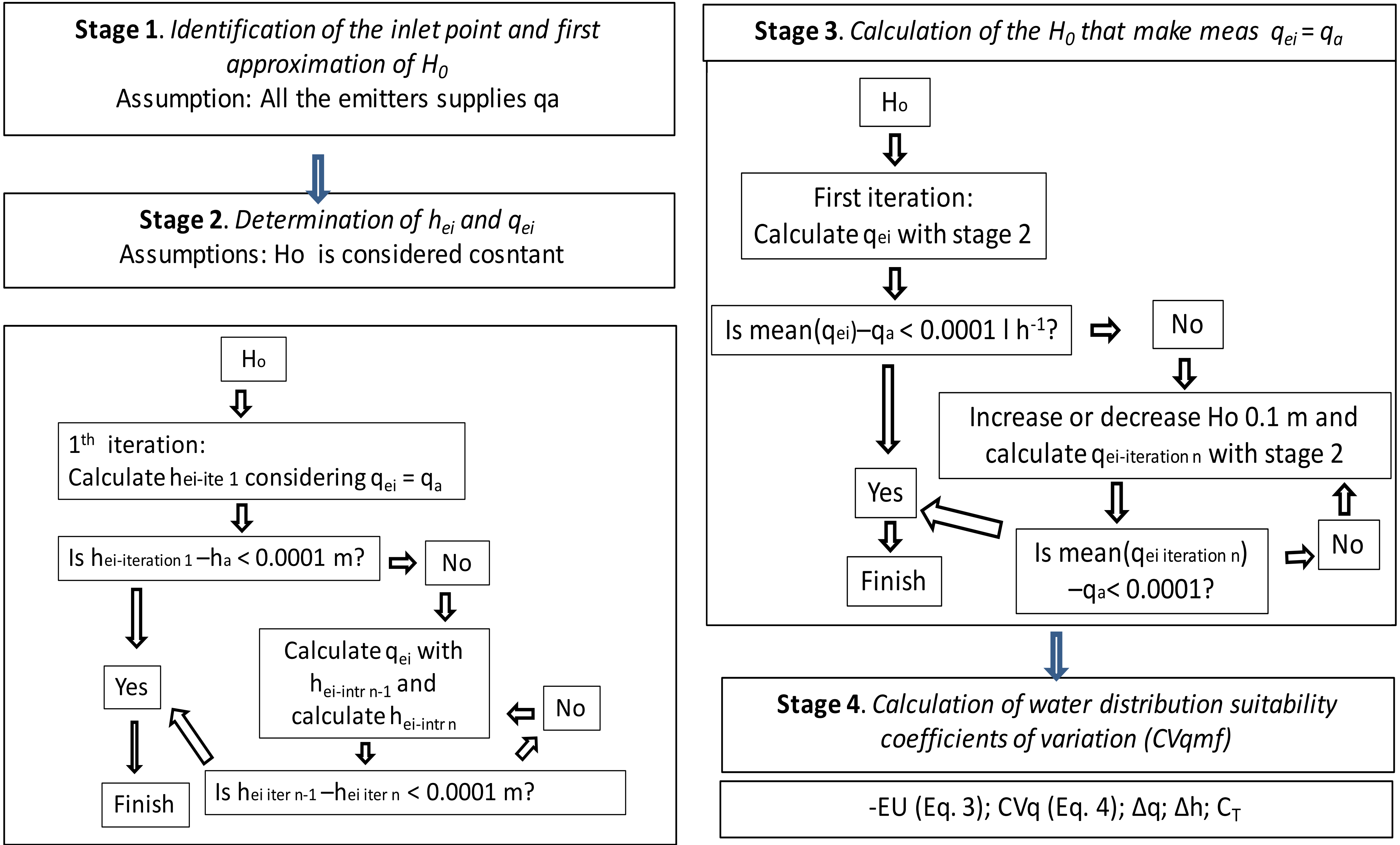
Carrión F, Tarjuelo J.M., Hernandez D., Moreno M.A.2013. Design of microirrigation subunit of minimum cost with proper operation. Irrigation Science. 31, 1199-1211:. DOI 10.1007/s00271-013-0399-8

METHODOLOGY

The procedure uses the following calculation stages:

- Stage 1. **Identification of the inlet point and first approximation of H_0:** The procedure begins by identifying a point of supply with for the previously selected diameter of lateral or manifold pipes. It assumes that all sprinklers discharge is the average required flow (q_a) (design data), calculates the flow distribution in all pipes, and makes a first estimate of the pressure head in the inlet subunit (H_0)
- Stage 2. **Determination of pressure (h_{ei}) and discharge (q_{ei}) of each sprinkler within the subunit for H_0 in stage 1:** An iterative process begins calculating q_{hi}, keeping the same H_0 value to facilitate convergence. The distribution of flows and pressures in each pipe is calculated. The process is repeated until the difference in sprinkler pressure between two consecutive iterations is lower than 0.0001 m.
- Stage 3. **Calculation of H_0 value that matches $q_{ei\ average} = q_a$:** This stage repeats Stage 2, but changing the value of H_0 until ($q_{ei\ avr} - q_a$) < 0.001 L h^{-1}.
- Stage 4. **Calculation of : EU, CT, Δq** (difference of sprinkler flow)**,and Δh** (difference of pressure heads) extreme in the irrigated subunit

Diagram of the calculus process of PRESUD tool



METODOLOGY

Total cost of irrigation water application :

$$C_T = C_a + C_e + C_w + C_m$$

1) Investment

$$C_a = \frac{A}{S} = \frac{CRF.C_i}{S}$$

2) Energy

$$C_e = \frac{P.O_t.En_c}{S}$$

$$P = \frac{9{,}81.Q_{0s}.H_0}{E_p}$$

$$O_t = \frac{R_n S}{3600\, E_a Q_{0s}}$$

3) Water

$$C_W = R_g P_W \qquad R_g = \frac{R_n}{Ea}$$

Ca = Investment annuity per unit of area (€ ha^{-1} $year^{-1}$)
Ce = Energy annuity per unit of area (€ ha^{-1} $year^{-1}$)
Cw = Cost of irrigation water per unit of area (€ ha^{-1} $year^{-1}$)
Cm = Energy annuity (5% de Ca)
A = Investment annuity (€ $year^{-1}$)
S = Irrigated area (ha)
CRF = Capital recovery factor
C_i = Total investment cost (€)
P = Power to give pressure to the water at subunit inlet (kW)
O_t = Annual operating time (h $año^{-1}$)
Q_{os}= Flow rate at subunit inlet ($m^3 s^{-1}$)
En_c = Energy rates (€ kWh^{-1})
Rg = Gross annual irrigation water requirement (m^3 ha^{-1} $año^{-1}$)
Pw = Water price (€ m^{-3})
Rn = Net annual irrigation water requirement (m^3 ha^{-1} $año^{-1}$)
Ep = Pumping efficiency (≈ 0,65)
Ea = General application efficiency Ea= EDa 0,92
a= Proportion of properly irrigated area (%)
CUs= Uniformity coefficient of water in the soil (%)

E_a = EDa=(100+(606-24.9*a + 0.349*a^2-0.00186*a^3)*(1-CUs/100))/100

METODOLOGIA

Table 1. Average prices of different manufacturers and distributors in Spain

Concept	External (inner) diameter (mm)	Price (€ m^{-1}) (1)
Sprinkler		10 €/unit
Riser pipe		0.30
Lateral pipe PVC 0.6 MPa (mm)	50 (46.4)	0.65
	63 (59.2)	0.97
	75 (70.6)	1.34
Manifold pipe PVC 0.6 MPa (mm)	140 (131.8)	3.52
	160 (150.6)	4.45
	180 (168.4)	5.63
	200 (188.2)	6.78
Riser coupler		0.6 €/unit

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METODOLOGIA

Table 2. Summary of the reference parameter considered in the study

Parameter		Value in reference conditions
Slope in lateral (S_{0l})		0%
Slope in manifold (S_{0m})		0%
Emission exponent (x)		0.5
Coefficient of variation of sprinkler manufacturer CV_{qm}		0.03
Lateral diameter D_l		50 (46.4 mm) PVC 0.6 MPa
Nº of lateral pipes in the subunit		12
Water price (P_w) (€ m^{-3})		0.10
Energy price (En_c) (€ kWh^{-1})		0.10
Annual crop irrigation water requirement (N_n) (mm Y^{-1})		650
Sprinkler spacing (m x m)		18 x 18 and 15 x 15
Working pressure (kPa)		300 and 350
Riser of sprinkler (m)		2.5

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METHODOLOGY

Uniformity coefficients of water discharged by the irrigation system

1. Emission uniformity (EU)

$$EU = \left(1 - \frac{1{,}27CV_{qmf}}{\sqrt{e}}\right)\frac{q_{mh}}{q_{ah}}100$$

CV_{qmf} =Coefficient of variation of emitter manufacturer; q_{mh} = minimum emitter flow in the subunit due to the pressure,
q_{ah} = mean of all emitter flow values due to variations in pressure ; e = number of emitters per plant,

2. Christiansen emission uniformity coefficient (CU) and Discharge Uniformity (UD)

$$CU = \left(1 - \frac{\sum_{i=1}^{n} |q_i - q_a|}{q_a\, n}\right)100$$

$$UD = 100\, q_{25}/q_a$$

n = number of emitters in the subunit; q_i = discharge of each emitter in the subunit,
q_a = mean discharge of all emitter; q_{25}= 25% of lowest discharge in the irrigation subunit

3. Total variation coefficient of flow rate in the subunit (CV_q)

$$CV_q \cong \sqrt{CV_{qmf}^{\ 2} + x^2\, CV_h^{\ 2}}$$

CV_h = coefficient of variation of pressure; X = Emission exponent of the emitter

METODOLOGIA

Table 3. Values of the different parameter related with the sprinkler that can be considered for Castilla-La Mancha (Spain) conditions.

Spacing of sprinklers (m x m)	Working pressure (kPa)	CUC (%)	a (%)	ED_a (decimal)	Pef (decimal)	Ea (decimal)	ARa (mm h^{-1})	Diameter of Nozzles (mm)
18 x 18	300	85	80	0.84	0.92	0.77	5.90	4,8+2.4
	350	87	80	0.86	0.92	0.79	6.33	4,8+2.4
	350	87	80	0.86	0.92	0.79	7.30	5.2+2.4
15 x 15	300	86	80	0.85	0.92	0.78	6.33	4.0+204
	300	87	80	0.86	0.92	0.79	7.30	4,4+2.4
	350	90	80	0.89	0.92	0.82	8.00	4,4+2.4

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Example of PRESUD tool for subunit sprinkler irrigation design

Example of 4.54 ha of onion (252 m x 180 m, corresponding to 10 laterals and 14 sprinkler in the lateral , with spacing 18m x 18m), using sprinklers whit nozzles 4,8+2.4 mm, working to a pressure of 35 m, ARa = 6.5 mm h^{-1}, slope in lateral 3% and 0% in manifold.

DATOS usados

Pendiente terciaria	0 %	Distancia entre ramales	18 m	Adequately irrigated area (a)	80 %
Pendiente	3%	Nº de ramales	10	Nº of sprinkler per plant	2
Terciaria	Alimentada por punto intermedio	Distancia desde la entrada hasta el 1º ramal	0	Pumping efficiency	65 %
Ramal	Alimentado por punto intermedio	Distancia desde la entrada hasta el 1º aspersor	0	Water price	0.1 € m-3
Exponente del aspersor (X) y CV_{qmf}	X= 0.5 CV_{qmf} = 3 %	Spacing between sprinklers	18 m	Lateral price	0.65 € m-1
Presión de trabajo	35 m	Sprinkler height	2 m	Manifold price	2.74 € m-1
Pluviometría media	6.5 mm h-1	Nº sprinkler in lateral	14	Energy rate	0.1 € kWh-1
Entrada en terciaria	Entre 2 ramales	Net crop irrigation water requirement	5500 m3 ha-1 year -1	Sprinkler price	10 € ud-1
Entrada en ramal	Entre 2 aspersores	Application uniformity CUa	87	Riser and coupler	1.2 € ud-1

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RESULTS

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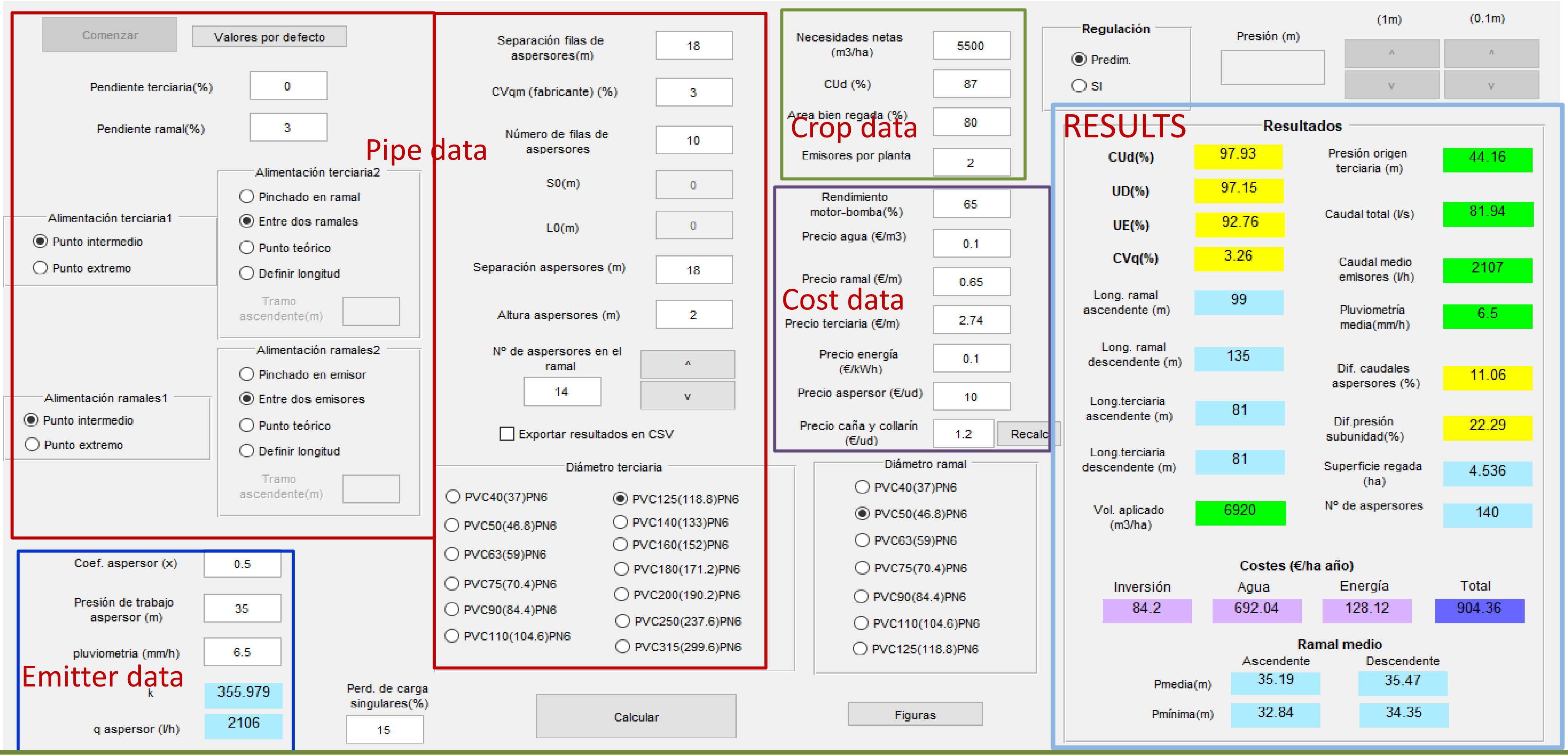

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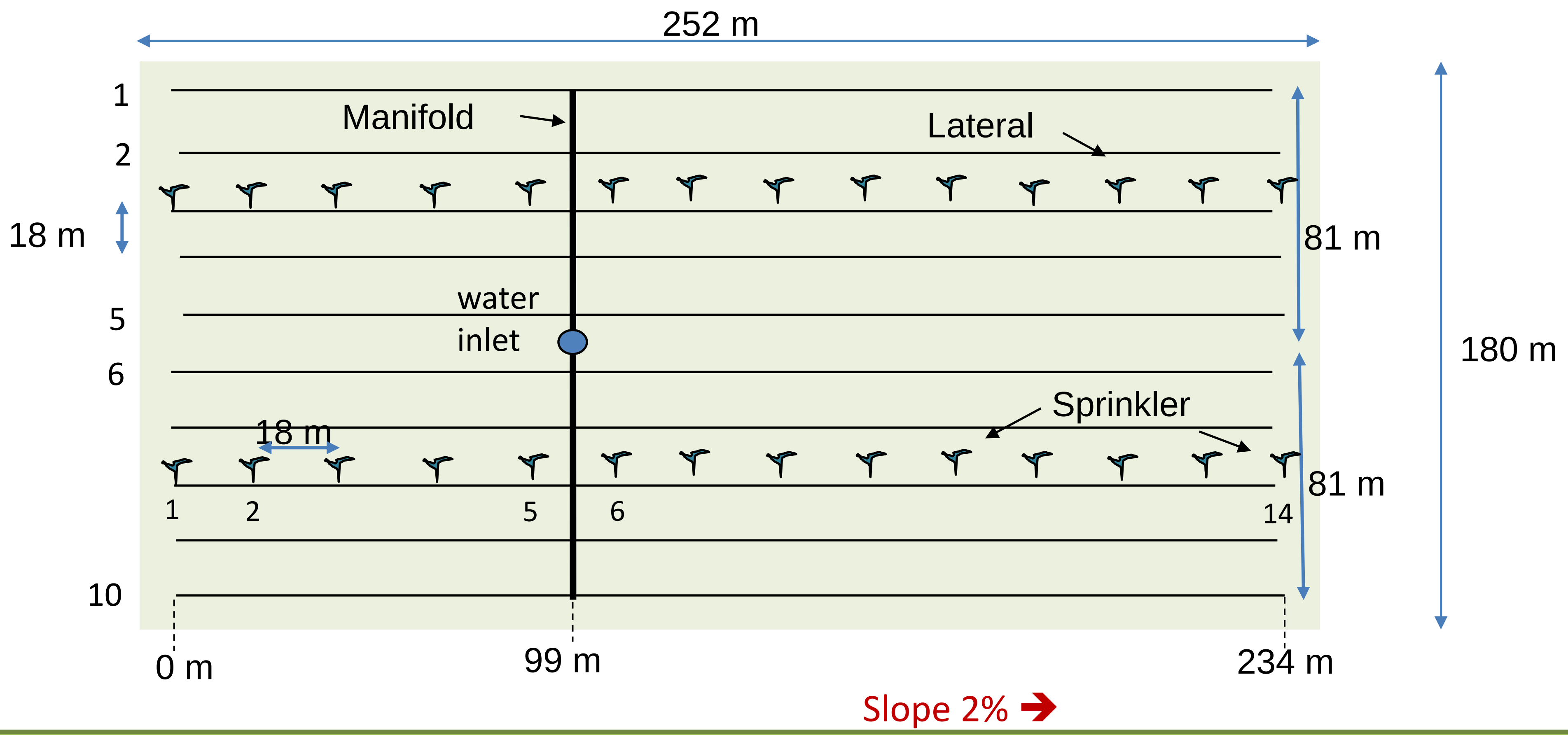

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RESULTS

CUd	97.93 %	Pressure in subunit inlet	44.16 m
UD	97.15%	Total inlet flow rate	81.94 L s^{-1}
EU	92.76	Average emitter discharge	2107 L h^{-1}
CV_q	3.26 %	Average application rate	6.6 mm h^{-1}
Ascending lateral length	99 m	Maximum discharge variation between sprinklers	11.06 %
Descending lateral length	135 m	Maximum pressure variation in the subunit	22.29 %
Ascending manifold length	81 m	Irrigated area	4.54 ha
Descending manifold length	81 m	Nº Sprinklers	140
Applied volumen	6900	Total cost (CT)	904.36 € ha^{-1} y^{-1}

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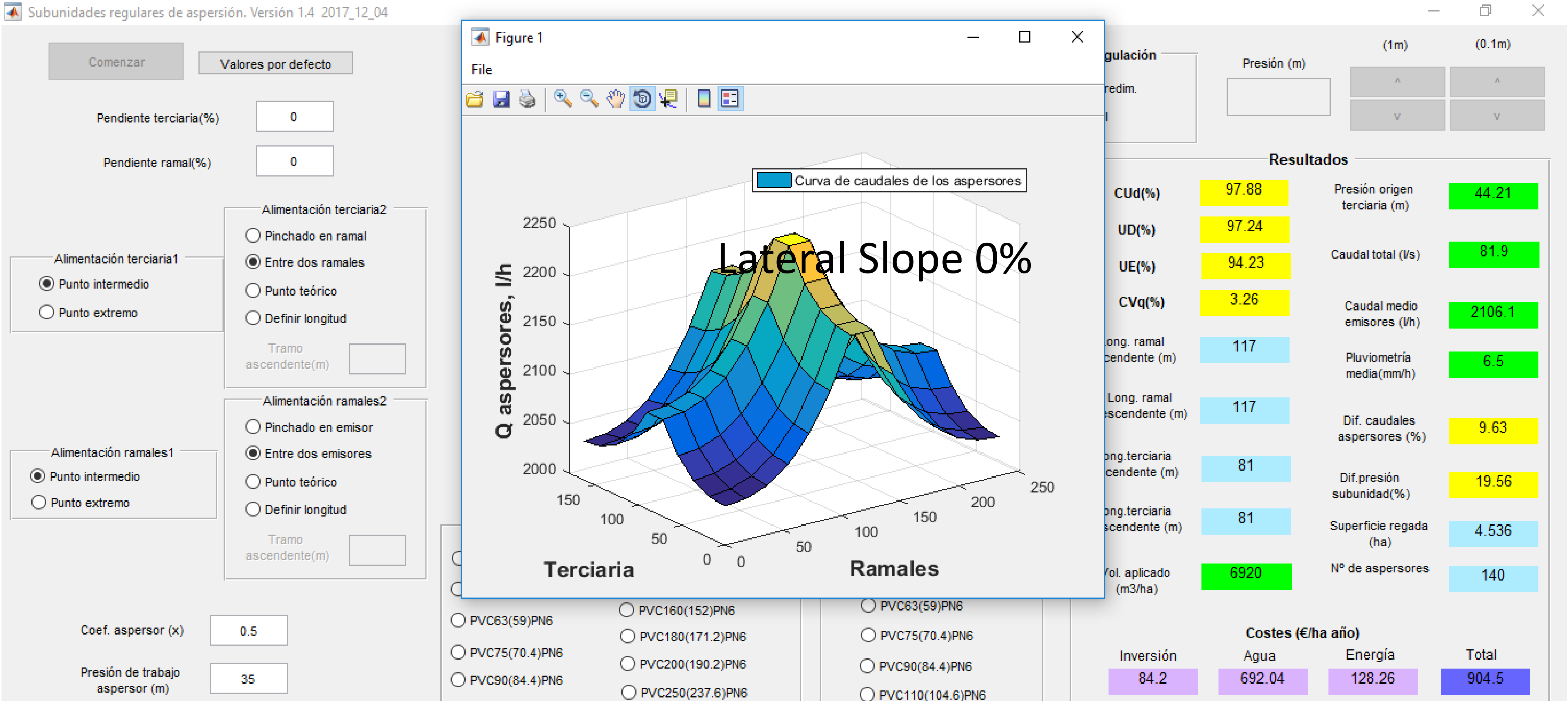

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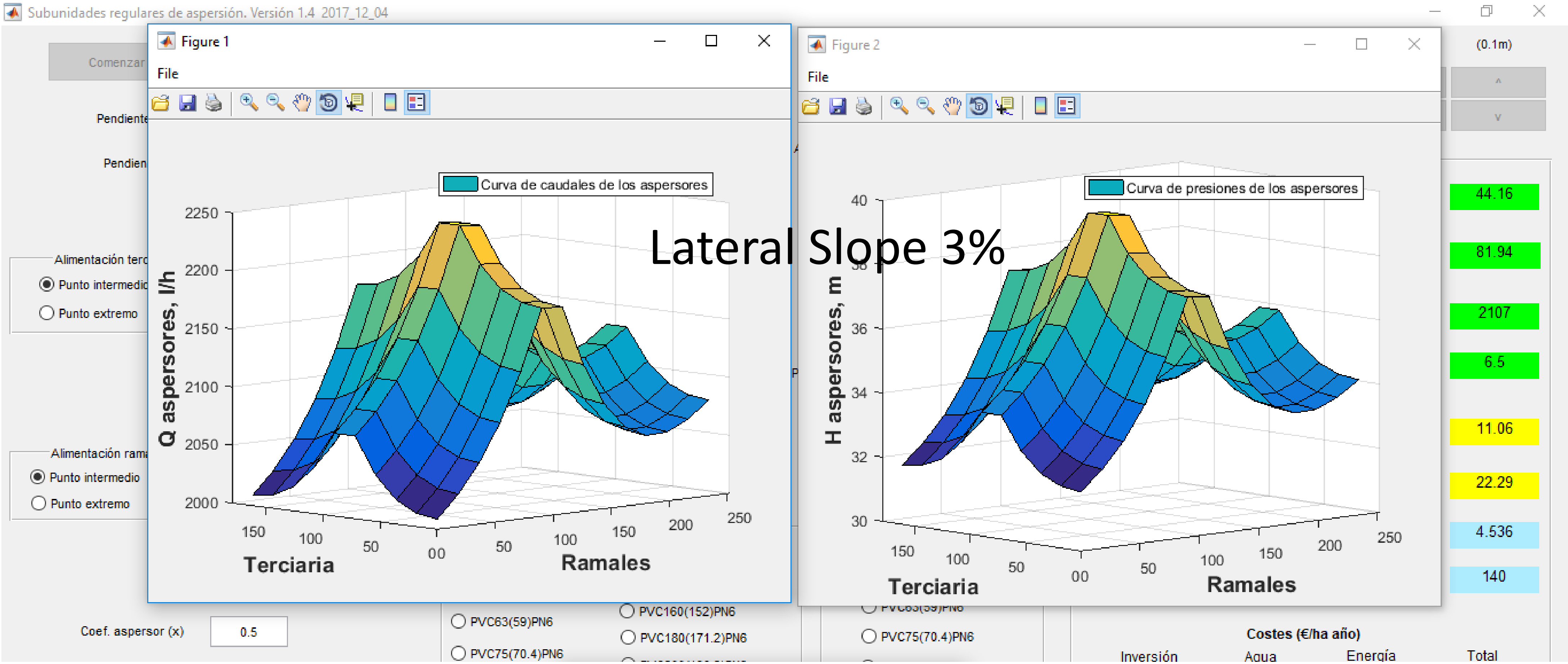

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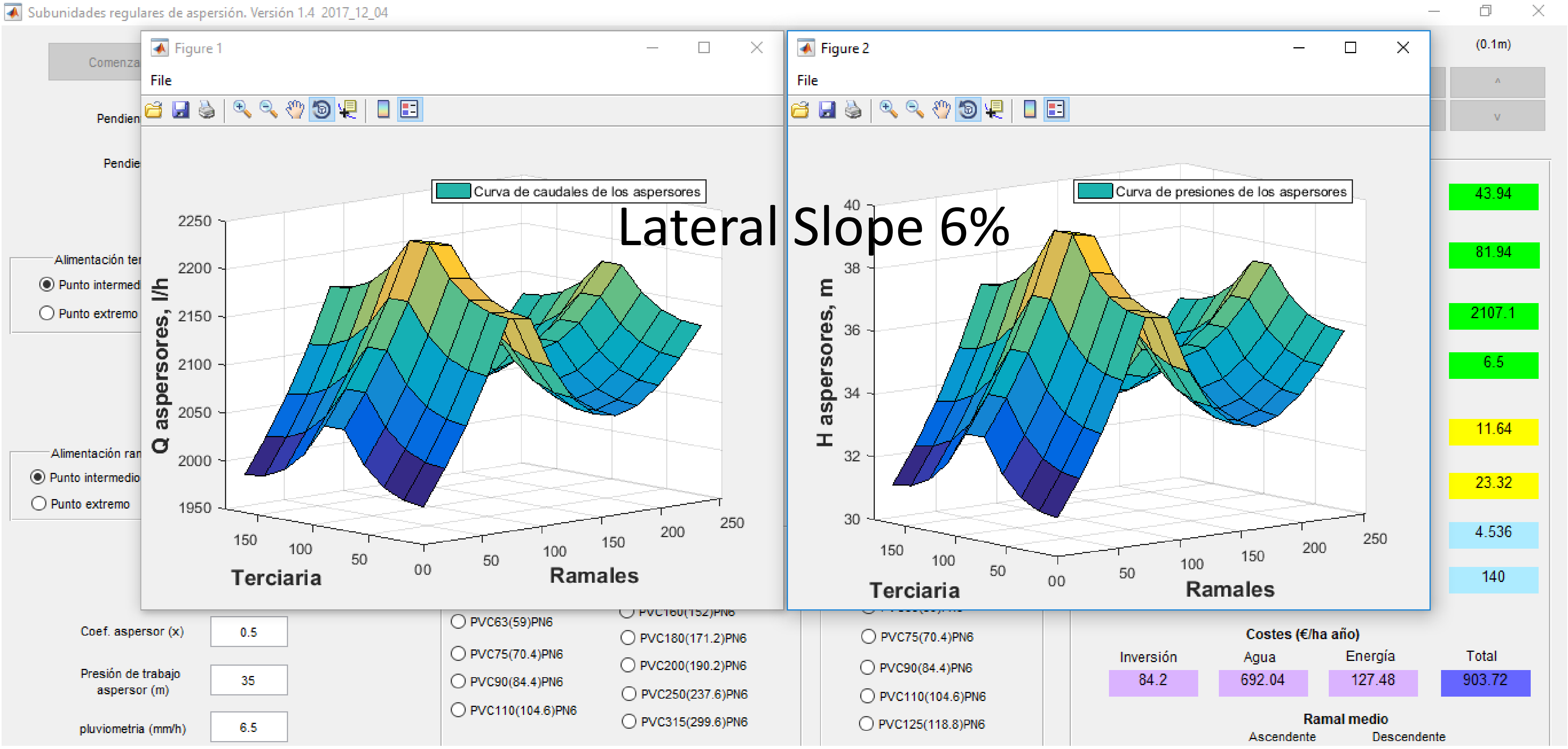

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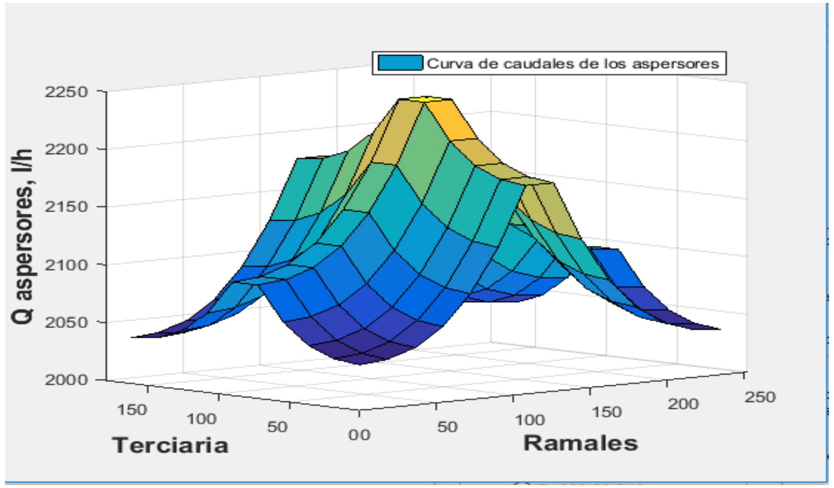
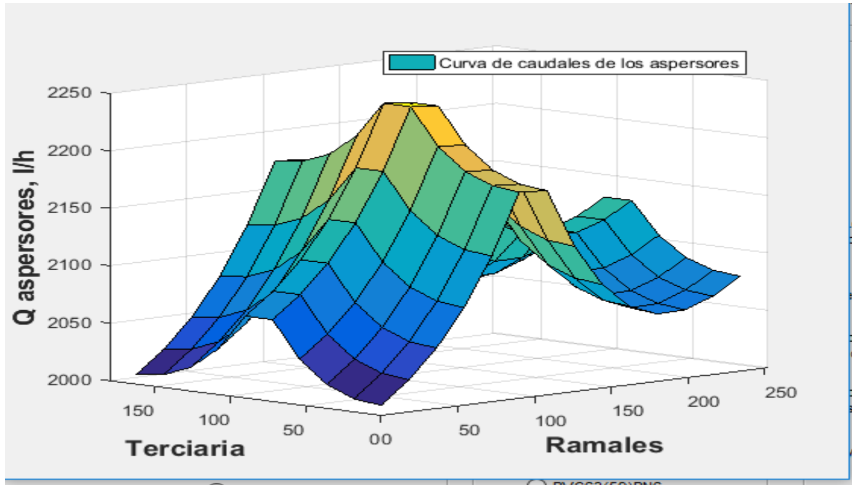


Lateral slope 0%

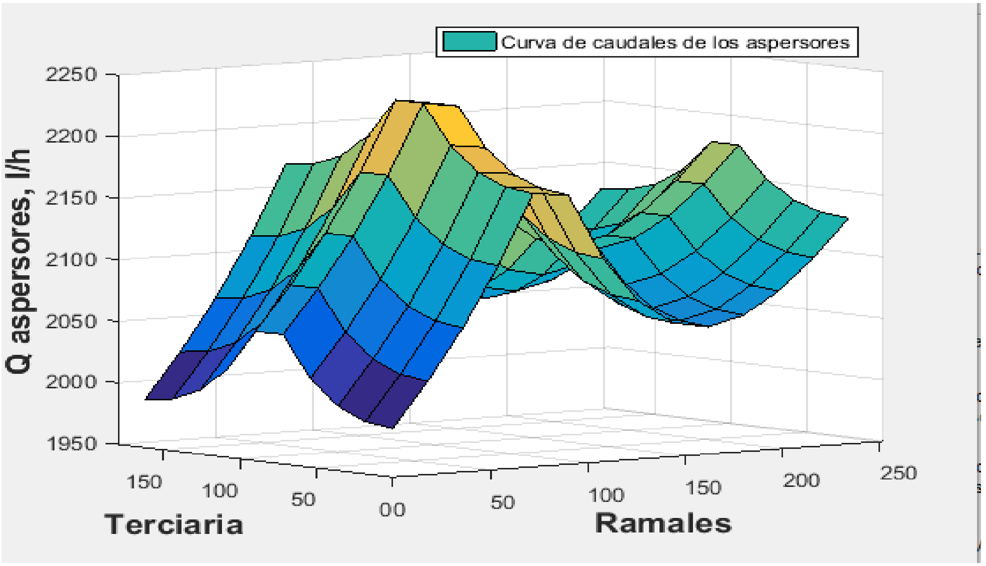
CU %	97.9
UE %	94.2
CV_q %	3.3
C_T (€ ha^{-1} $year^{-1}$)	904.5

Discharge distribution



Lateral slope 3%

CU %	97.9
UE %	92.8
CV_q %	3.3
C_T (€ ha^{-1} $year^{-1}$)	904.4



Lateral slope 6%

CU %	97.9
UE %	91.9
CV_q %	3.3
C_T (€ ha^{-1} $year^{-1}$)	903.7

Results for 18m x 18 m spacing

Subunit area (ha)	Lateral length (m)	Manifold length (m)		C_a (€ $ha^{-1}Y^{-1}$)	H_0 (m)	EU (%)	Δq (%)	Δh (%)
	Lateral diameter (mm)	Manifold diameter (mm)						
	50 (46.4)	140 (131.8)	160 (150.6)					
Sprinkler spacing 18m x 18m, h_a= 300 kPa and AR_a= 5.9 mm h^{-1}								
1.56	198	54		86.4	35	95.9	4.2	8.4
2.33	198	90		87.8	35.1	95.9	4.4	8.8
3.11	198	126		88.6	35.4	95.7	4.7	9.5
3.89	198	162		89.0	35.8	95.5	5.4	10.8
4.67	198	198		89.3	36.3	95.3	6.3	12.8
5.44	198	234		89.5	37.1	94.9	7.7	15.5
6.22	198		270	94.0	36.6	95.1	6.9	14.0
7.00	198		306	94.2	37.2	94.8	8.1	16.4
7.78	198		342	94.3	38.0	94.4	9.5	19.4
Sprinkler spacing 18m x 18m, h_a= 350 kPa and AR_a= 6.3 mm h^{-1}								
1.56	198	54		86.4	40.4	96.0	4.1	8.2
2.33	198	90		87.8	40.5	95.9	4.2	8.5
3.11	198	126		88.6	40.8	95.8	4.6	9.3
3.89	198	162		89.0	41.2	95.6	5.2	10.5
4.67	198	198		89.3	41.8	95.3	6.2	12.5
5.44	198	234		89.5	42.7	95.0	7.5	15.1
6.22	198		270	94.0	42.1	95.2	6.7	13.6
7.00	198		306	94.2	42.8	94.8	7.9	16.0
7.78	198		342	94.3	43.7	94.4	9.3	18.9

Results for 15m x 15m spacing (Carrión et al. 2013)

Subunit area (ha)	Lateral length (m)	Manifold length (m)		C_T (€ $ha^{-1}Y^{-1}$)	H_0 (m)	EU (%)	Δq (%)	Δh (%)
	Lateral diameter (mm)	Manifold external (inner) diameter (mm)						
	50 (46.4)	140 (131.8)	160 (150.6)					
Sprinkler spacing 15m x 15m, h_a = 350 kPa and AR_a = 8.0 mm h^{-1}								
1,26	195	45		110.9	40.3	95.9	4.3	8.6
1,89	195	75		112.4	40.5	95.9	4.4	8.9
2,52	195	105		113.2	40.7	95.8	4.7	9.6
3,15	195	135		113.6	41.1	95.6	5.3	10.7
3,78	195	165		113.9	41.6	95.4	6.1	12.3
4,41	195		195	114.1	42.3	95.5	7.3	14.8
5,04	195		225	114.3	41.9	95.3	6.6	13.3
5,67	195		255	114.4	42.5	95.0	7.6	15.4
6,3	195		285	114.5	43.3	94.6	8.8	17.9

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