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

Manual PRESUD for drip irrigation

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

OBJECTIVE

Matlab software named PRESUD (Pressurized subunit Design) was developed to identify the optimum microirrigation 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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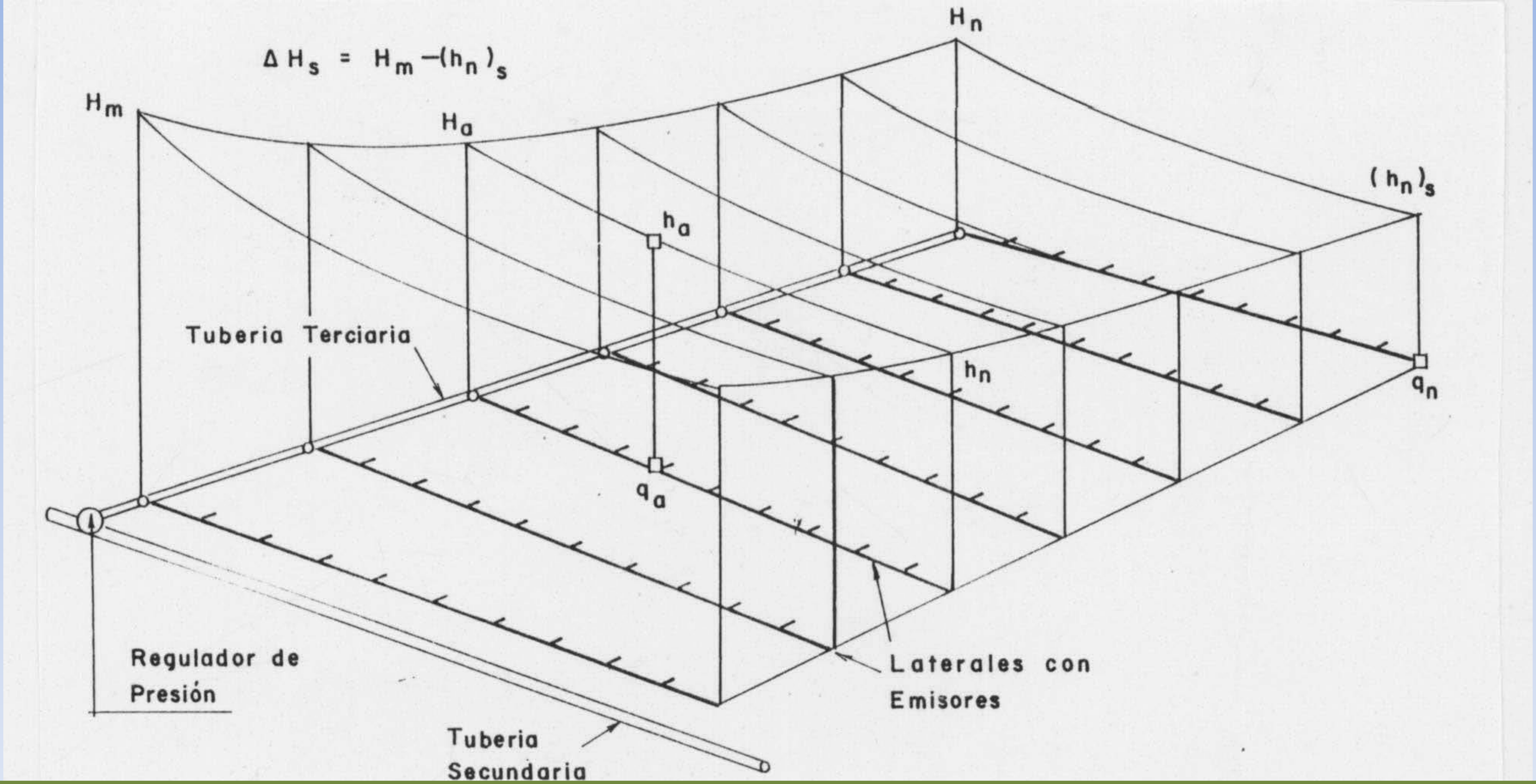
Pressure distribution in an irrigation subunit in a flat area



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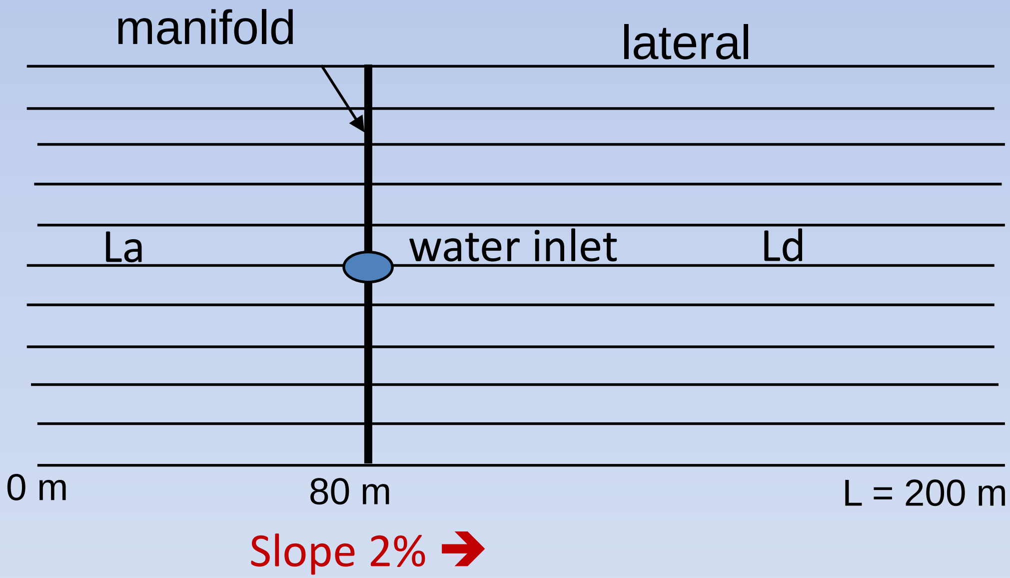
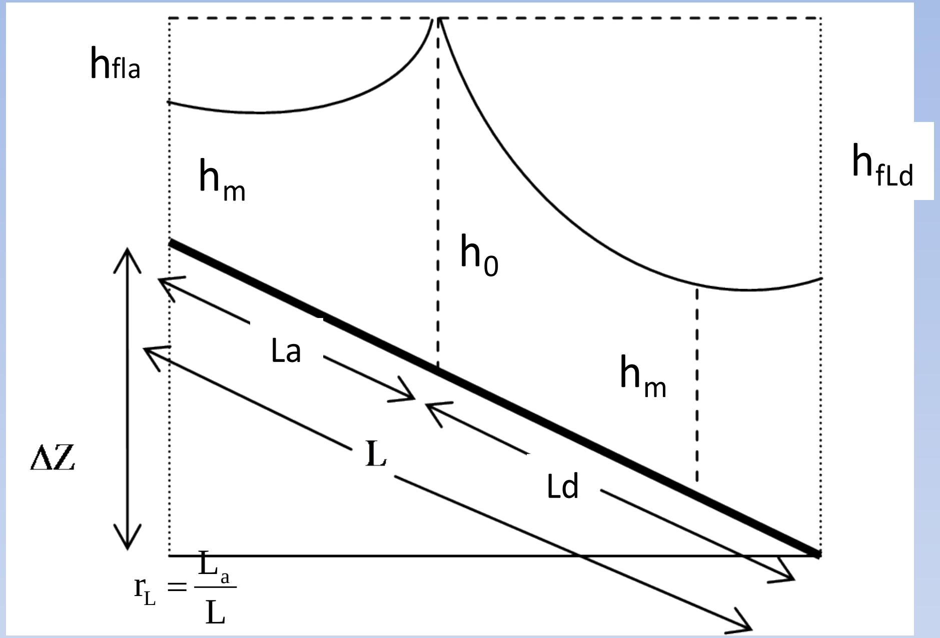
METHODOLOGY

Identification of the inlet point in paired lateral or manifold pipes

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

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





$r_L = \frac{L_a}{L}$

So= lateral slope
m= 1.75 in Blasius for head loss equation for PE
q_u = emission rate by unit of length
L = length of the paired lateral pipe
La = length uphill of lateral or 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

Table 1. Values of r_L for paired lateral and manifold pipes

r_L	$\Psi(r_L)$	r_L	$\Psi(r_L)$	r_L	$\Psi(r_L)$	r_L	$\Psi(r_L)$
0.01	0.973	0.14	0.656	0.27	0.394	0.40	0.165
0.02	0.946	0.15	0.634	0.28	0.375	0.41	0.148
0.03	0.920	0.16	0.613	0.29	0.357	0.42	0.132
0.04	0.894	0.17	0.591	0.30	0.339	0.43	0.115
0.05	0.868	0.18	0.570	0.31	0.321	0.44	0.098
0.06	0.843	0.19	0.550	0.32	0.303	0.45	0.082
0.07	0.818	0.20	0.529	0.33	0.285	0.46	0.065
0.08	0.794	0.21	0.509	0.34	0.267	0.47	0.049
0.09	0.770	0.22	0.489	0.35	0.250	0.48	0.033
0.10	0.747	0.23	0.470	0.36	0.233	0.49	0.016
0.11	0.723	0.24	0.450	0.37	0.216	0.50	0.000
0.12	0.701	0.25	0.431	0.38	0.199		
0.13	0.878	0.26	0.412	0.39	0.182		

Table 2. Tr values based on soil texture and root depth

Profundidad radicular	Textura del suelo			
	Muy gruesa	gruesa	media	fina
< 0.8 m	1.10	1.10	1.05	1.00
0.8 to 1.50 m	1.10	1.05	1.00	1.00
> 1.50 m	1.05	1.00	1.00	1.00

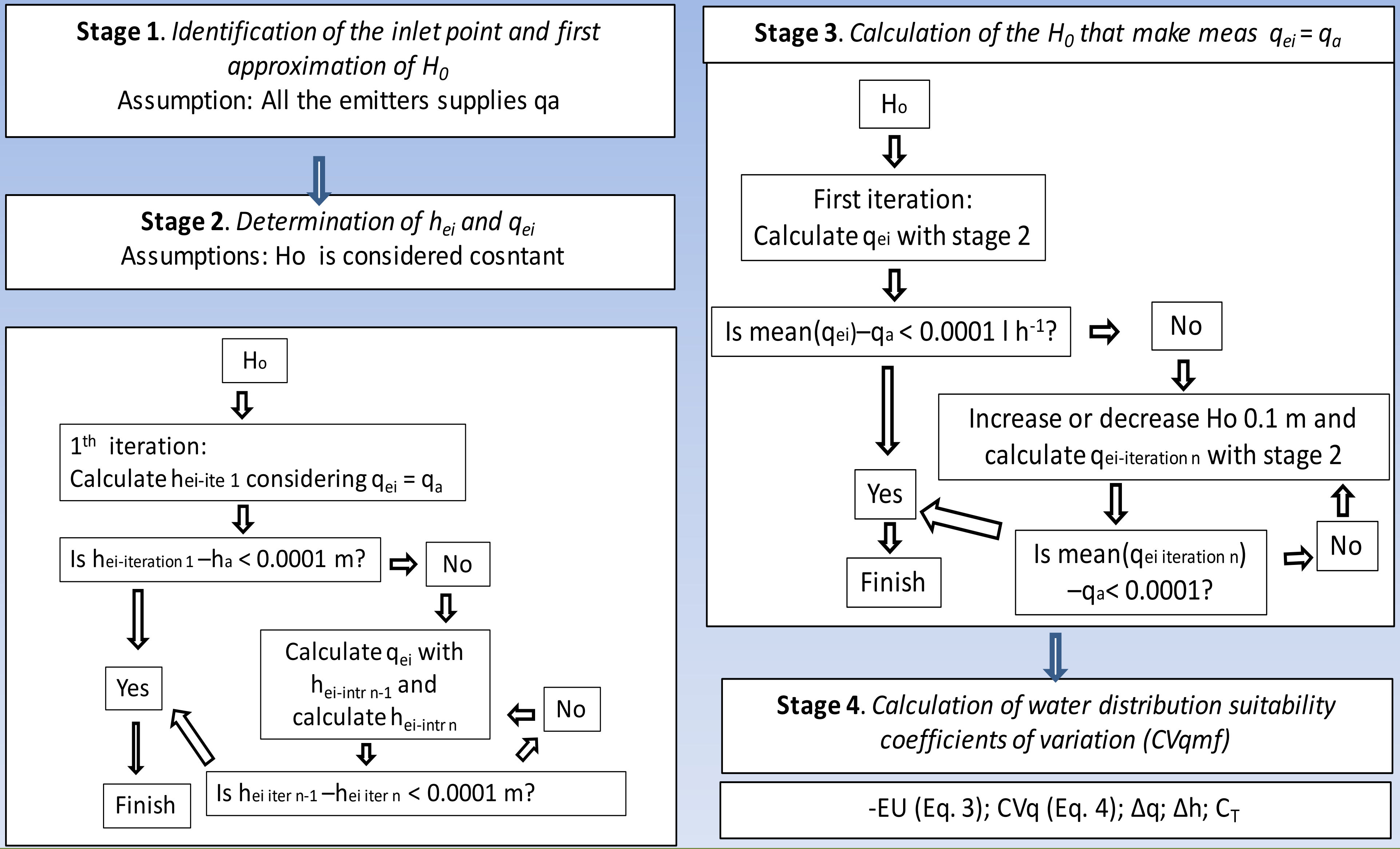
For micro sprinkling add 0.05 to Tr in humid climates and 0.10 in arid climates to account for evaporation

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 emitter 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 emitter pressure (hei) and discharge (qei) of each emitter within the subunit for Ho 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 emitter 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, CU, CVq, CT, Δq** (difference of emitter flow),and **Δh** (difference of pressure heads) extreme in the irrigated subunit

Diagram of the calculus process of PRESUD tool



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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

$$C_w = R_g P_w$$

$$R_g = \frac{R_n}{Ea}$$

$$E_a = \frac{EU_q}{Tr}$$

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
Ci = Total investment cost (€)
P = Power to give pressure to the water at subunit inlet (kW)
Ot = Annual operating time (h $año^{-1}$)
Qos= Flow rate at subunit inlet ($m^3 s^{-1}$)
Enc = 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= EUq Tr^{-1} (decimal)
EUq= Emission Uniformity EUq = q_{25}/q_a
q_{25}= mean of 25% emitters with lower flow values
q_a = mean of all emitter flow values
Tr= Transpiration ration in peak period (dimensionless, Table2)

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

2. Christiansen emission uniformity coefficient (CU)

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

n = number of emitters in the subunit; q_i = discharge of each emitter in the subunit,
q_a = mean discharge of all emitter

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

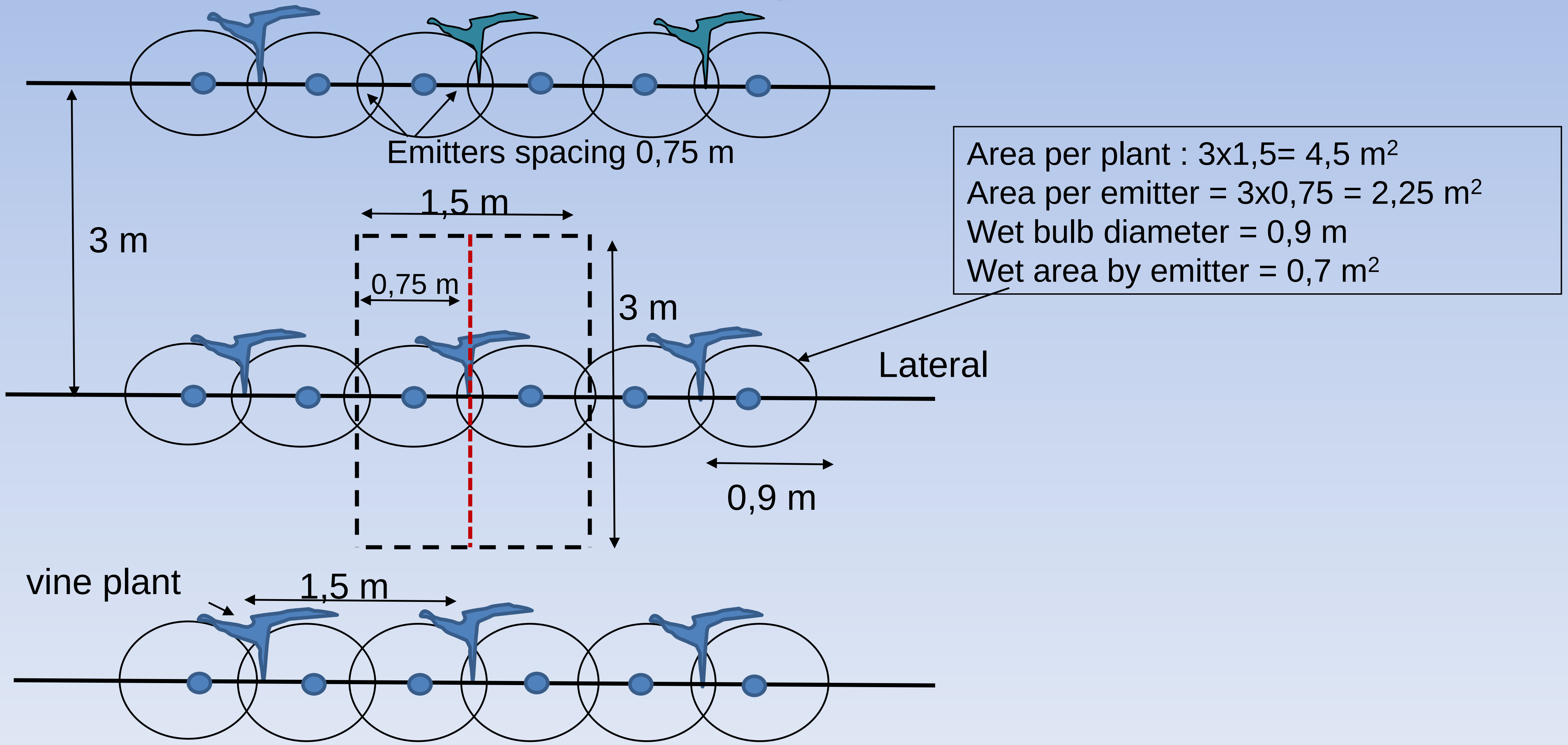
$$CV_q \cong \sqrt{CV_{qmf}^{\ 2} + x^2\, CV_h^{\ 2}}$$

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

RESULTS

Example of PRESUD tool for subunit drip irrigation design

Example of 0.76 ha (120 m x 63m) of vineyard at 3m x 1,5m (22 lines of 120m vine plant) using emitters of $q_a = 2\ L\ h^{-1}$, working to a pressure of 10m



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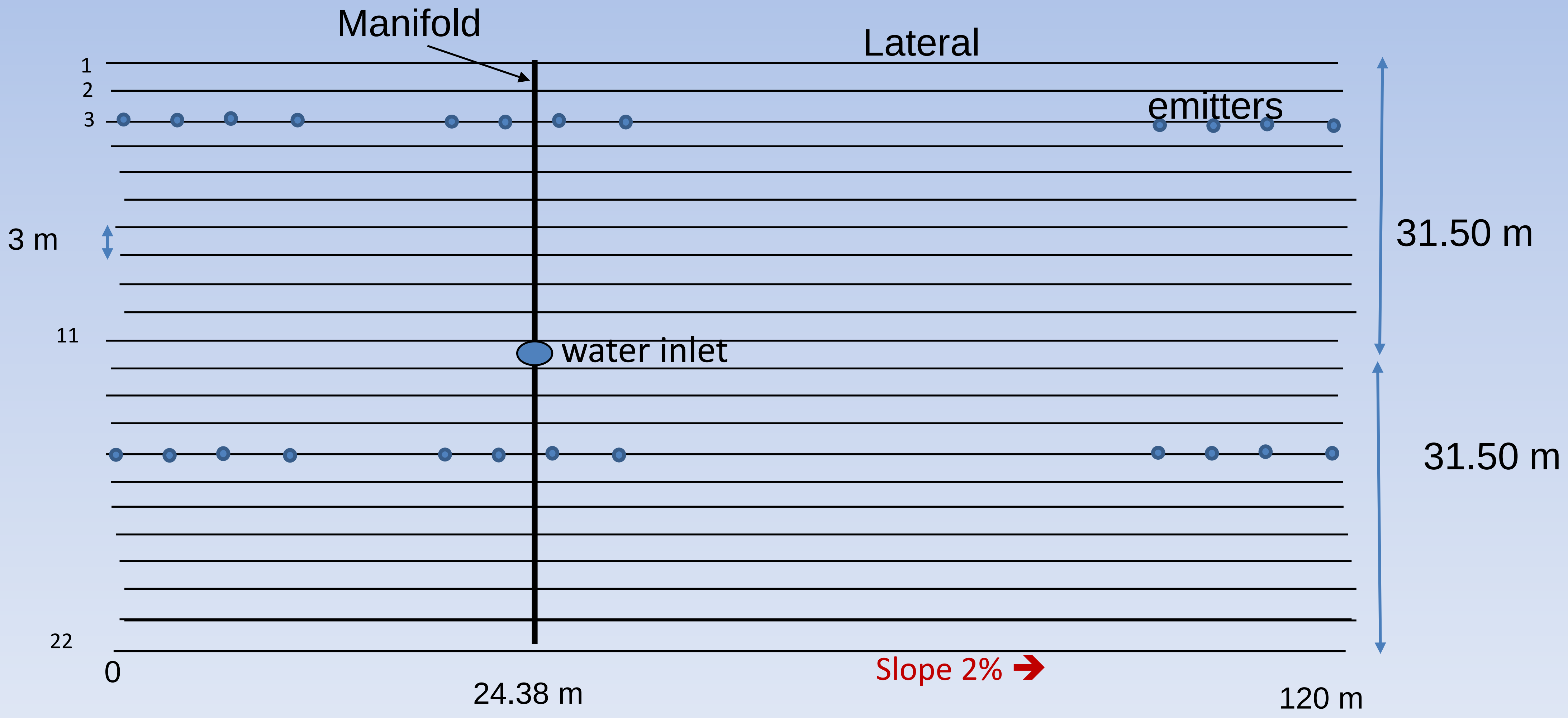

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DATA used

Manifold slope	0 %	Manifold inlet	Between tow laterals	Lateral length	120 m
Latera slope	2%	lateral inlet	Between tow emitters	Net crop irrigation water requirement	1500 m3 ha-1 year -1
Manifold inlet	paired manifold	Distance between to lines of plants	3 m	Transpiration relationship	Tr = 1
lateral inlet	paired lateral	CVqmf Coefficient	5 %	Pumping efficiency	65 %
emission exponent (x)	0.5	Distance from the inlet point to the firs lateral	0	Water price	0.1 € m-3
Working pressure	10 m	Distance from the inlet point to the firs emitter	0	Lateral price	0.13 € m-1
emission rate	2 L h-1	Spacing between emitters	0.75 m	Manifold price	0.48 € m-1
Equivalent length for minor singularity	emitter =0.15m lateral = 0,18m	Spacing between plants	1.5 m	Energy rate	0.1 € kWh-1

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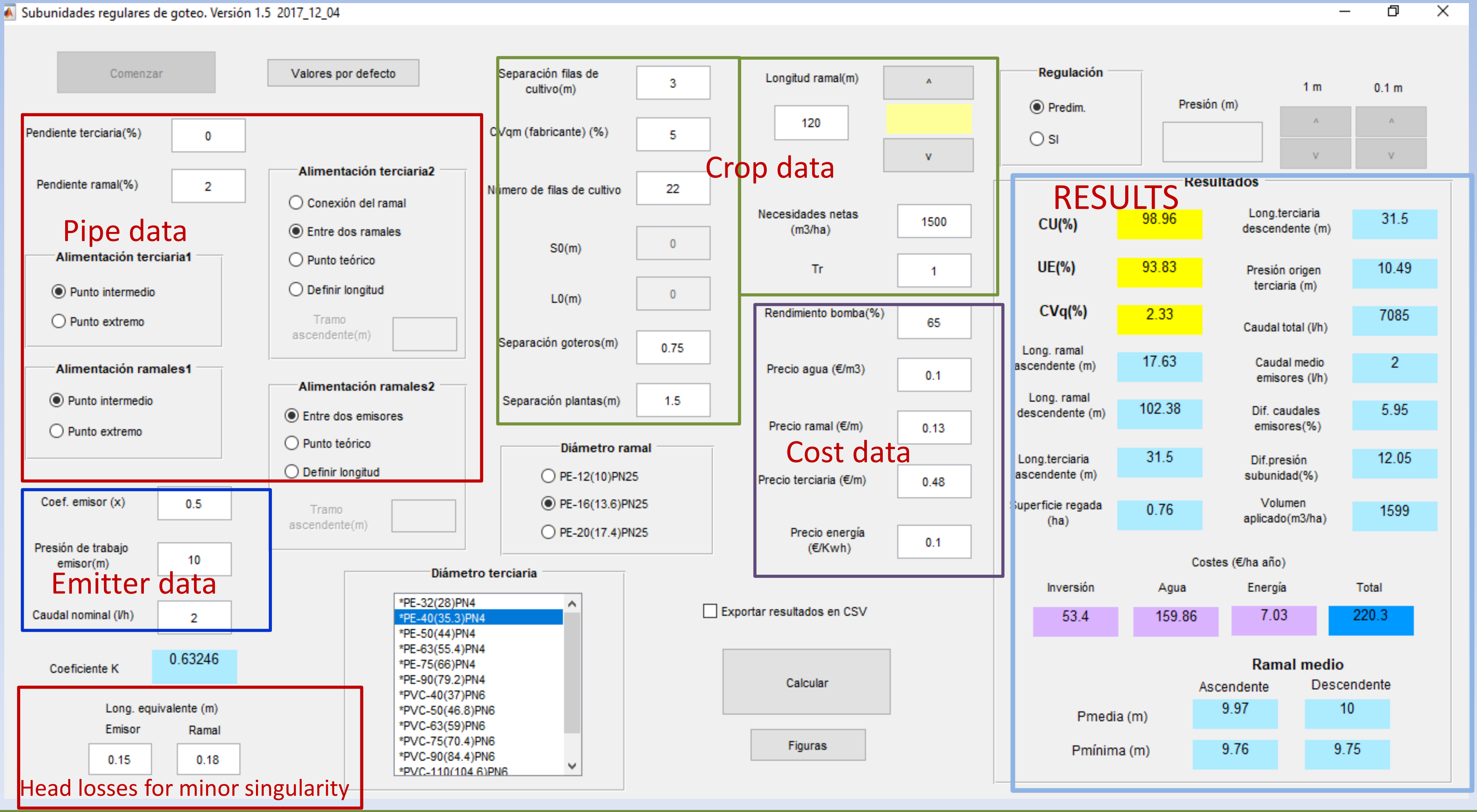

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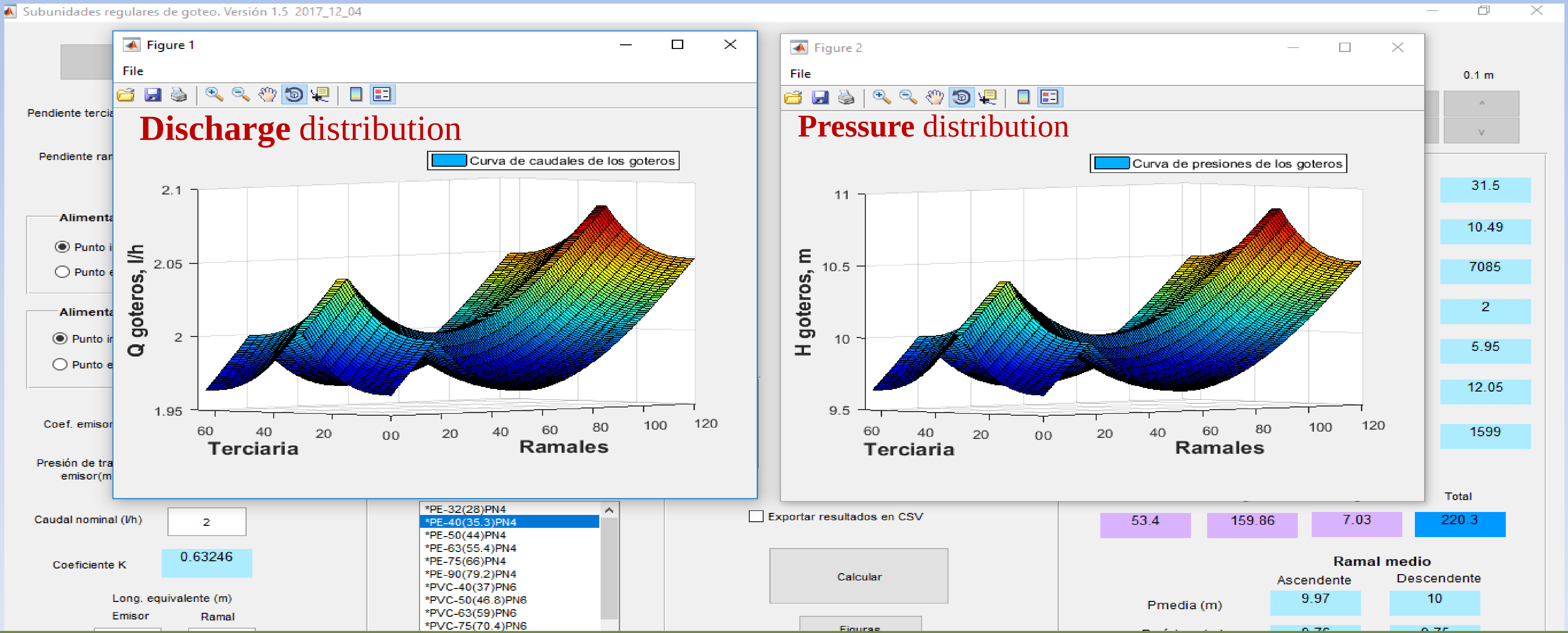
RESULTS of PRESUD tool for subunit drip irrigation design

Example of 0.76 ha subunit (120 m x 63m) of vineyard at 3m x 1,5m (22 lines of 120 m vine plant) using emitters of q_a = 2 L h^{-1}, working to a pressure of 10 m, and with slope 2% in lateral and 0% in manifold



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RESULTS of PRESUD tool for subunit drip irrigation design

Example of 0.76 ha subunit (120 m x 63m) of vineyard at 3m x 1,5m (22 lines of 120 m vine plant) using emitters of q_a = 2 L h^{-1}, working to a pressure of 10 m, and with slope 2% in lateral and 0% in manifold

CU	98.96 %	Descending manifold length	31.50 m
UE	93.83%	Pressure in subunit inlet	14.9 m
CV_q	2.33 %	Total inlet flow rate	7085 L h^{-1}
Ascending lateral length	17.63 m	Average emitter discharge	2 L h^{-1}
Descending lateral length	102.38 m	Maximum discharge variation between emitter	5.95%
Ascending manifold length	31.50 m	Maximum pressure variation in the subunit	12.05 %
Irrigated area	0.76 ha	Total applied volume	1599 m^{-3} ha^{-1}

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Example of PRESUD tool for subunit drip irrigation design

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Additional RESULTS

TOTAL COSTS in the irrigated subunit	**(€ ha^{-1} $year^{-1}$)**
Investment	53.40
Water	159.86
Energy	7.03
TOTAL	**220.30**

	Working conditions of the middle lateral	
	Ascending lateral	Descending lateral
Average pressure (m)	9.97	10
Minimum pressure (m)	9.76	9.75

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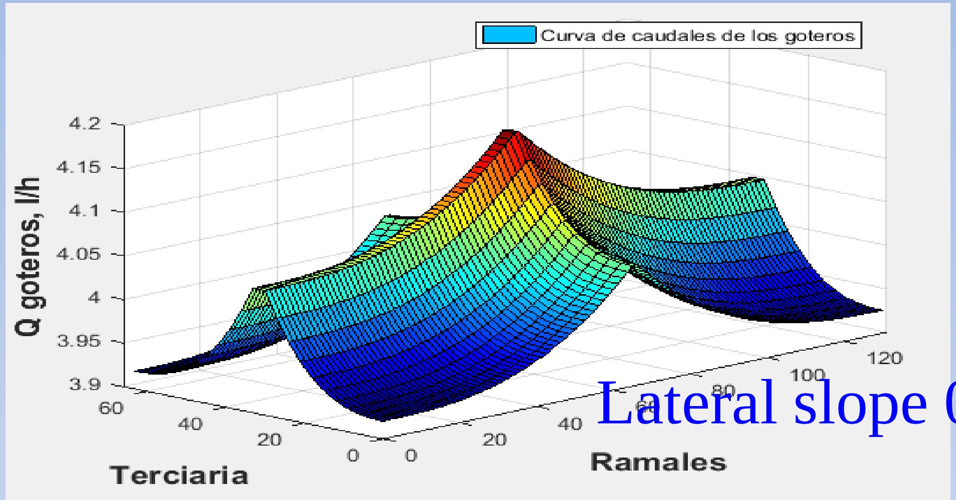
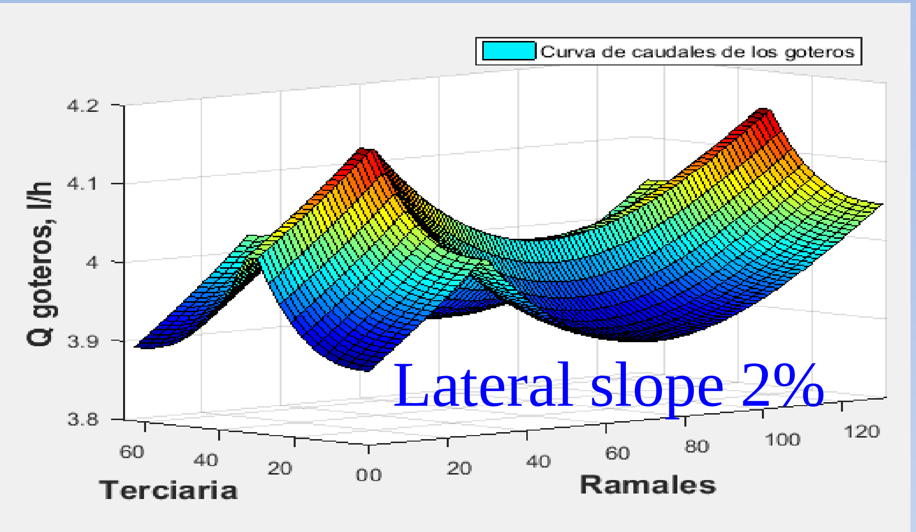
Example of 0.76 ha subunit (120 m x 63m) of vineyard at 3m x 1,5m (22 lines of 120 m vine plant) using emitters of q_a = 2 L h^{-1} , working to a pressure of 10 m, and with different slope in lateral and 0% in manifold

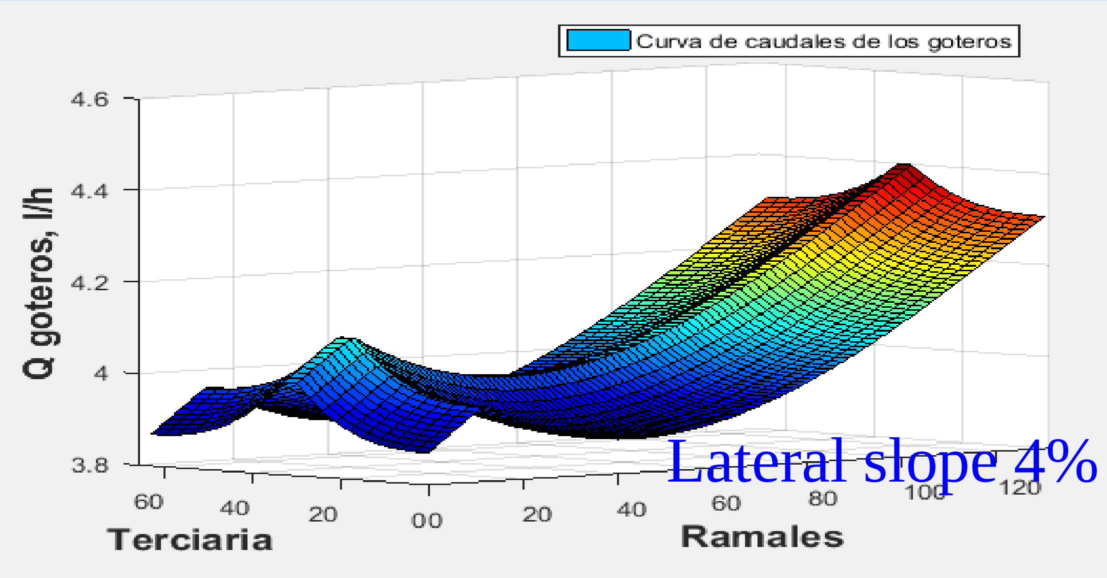
Discharge distribution



CU %	99.3
UE %	94.4
CV_q %	2.3
C_T (€ ha^{-1} $year^{-1}$)	219.3



CU %	98.9
UE %	93.8
CV_q %	2.3
C_T (€ ha^{-1} $year^{-1}$)	220.3



CU %	96.54
UE %	91.1
CV_q %	3.0
C_T (€ ha^{-1} $year^{-1}$)	224.8

RESULTS OF **PRESUD**

Drip irrigation (Carrión et al. 2013)

Subunit area (ha)	Lateral length (m)	Manifold length (m)				C_i (€ $ha^{-1}Y^{-1}$)	H_0 (m)	EU (%)	Δq (%)	Δh (%)
	Lateral diam. (mm)	Manifold diameter (mm)								
	16	50	63	75	90					
0.32	80	40				214,1	10.4	92.6	2.9	5.9
0.50	91		55			212,9	10.4	92.4	5.3	10.7
0.75	94		80			218,9	10.8	91.9	5.3	10.8
1.00	110			90		220,1	10.8	91.7	5.62	11.3
1.25	139			90		218,3	11.2	91.2	8.39	17.0
1.50	136				110	225,8	11.0	90.9	7.3	14.8
1.75	146				120	225,0	11.3	90.7	9.0	18.4

Subunit area (ha)	Lateral length (m)	Manifold length (m)					C_i (€ $ha^{-1}Y^{-1}$)	H_0 (m)	EU (%)	Δq (%)	Δh (%)
	Lateral diam. (mm)	Manifold diameter (mm)									
	16	40	50	63	75	90					
0.5	111	45					60,2	10.7	92.7	4.3	8.7
1.25	104		120				63,8	11.2	92.0	7.7	15.6
1.75	130			135			66,6	11.2	91.8	8.0	16.1
2.25	150			150			64,9	11.9	91.3	11.9	24.4
2.75	158				174		68,7	11.7	91.2	10.9	22.2
3.25	175				186		67,5	12.3	90.6	14.6	30.0
3.75	187					201	72,5	12.2	90.4	13.8	28.3

Conclusions

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CONCLUSIONS

- The most interesting design of subunits for vegetable crops is to use low q_a
- The criterion of limiting Δq< 10%, considering EU= 90% , widely used when designing a drip irrigation subunit, is not always the most convenient value from an economic point of view, and the PRESUD tool developed obtains better solutions.

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