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26th ERC & 66th IEC

ALGORITHMS AND TOOLS FOR OPTIMUM SCHEDULING OF ON-DEMAND IRRIGATION FOR EFFECTIVE ENERGY COST REDUCTION

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Gobierno Aragón

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MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

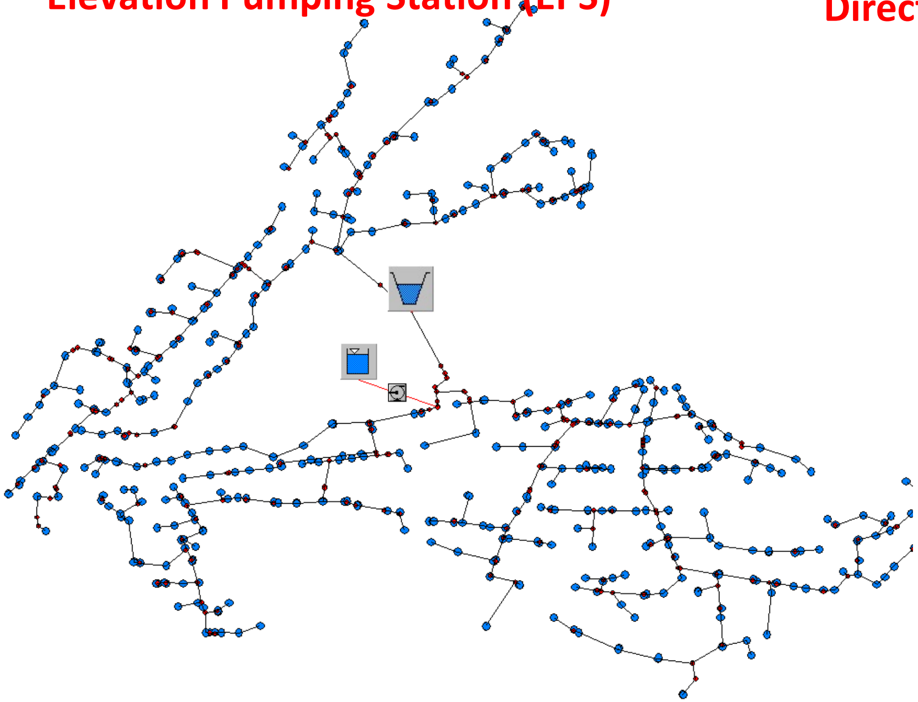
THE STRATEGY…

ENERGY IN IRRIGATION PIPE NETWORKS

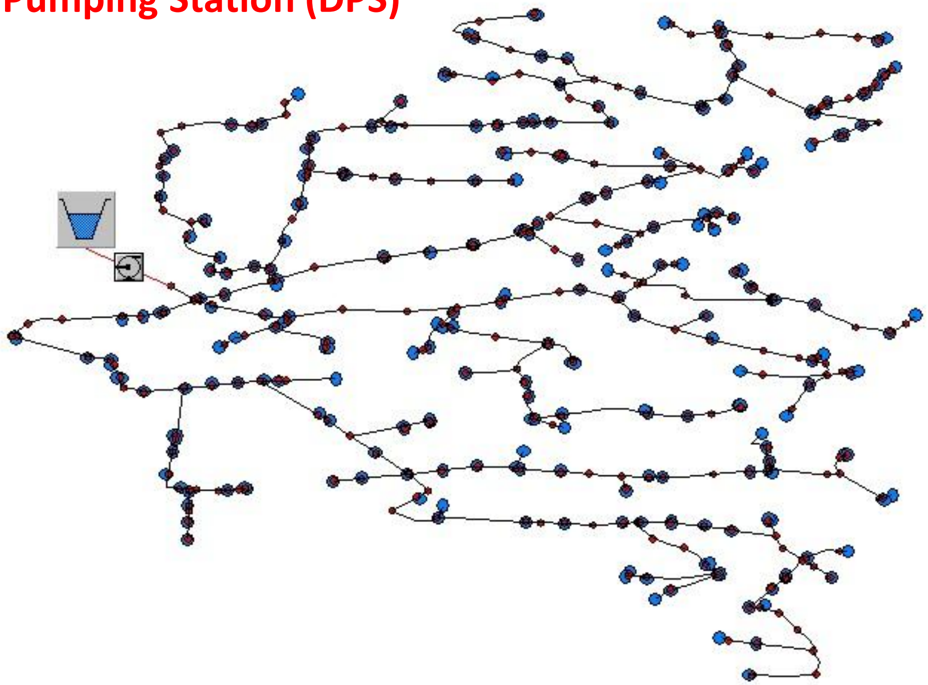
- Pressurized irrigation can be efficiently introduced by means of collective water distribution pipe networks.

- When pressurization requires pumping systems, two extreme schemes are found: pumping to a intermediate reservoir or direct pumping to the network (Mixed solutions may be recommended. Ask me why during coffee break)-

Elevation Pumping Station (EPS)

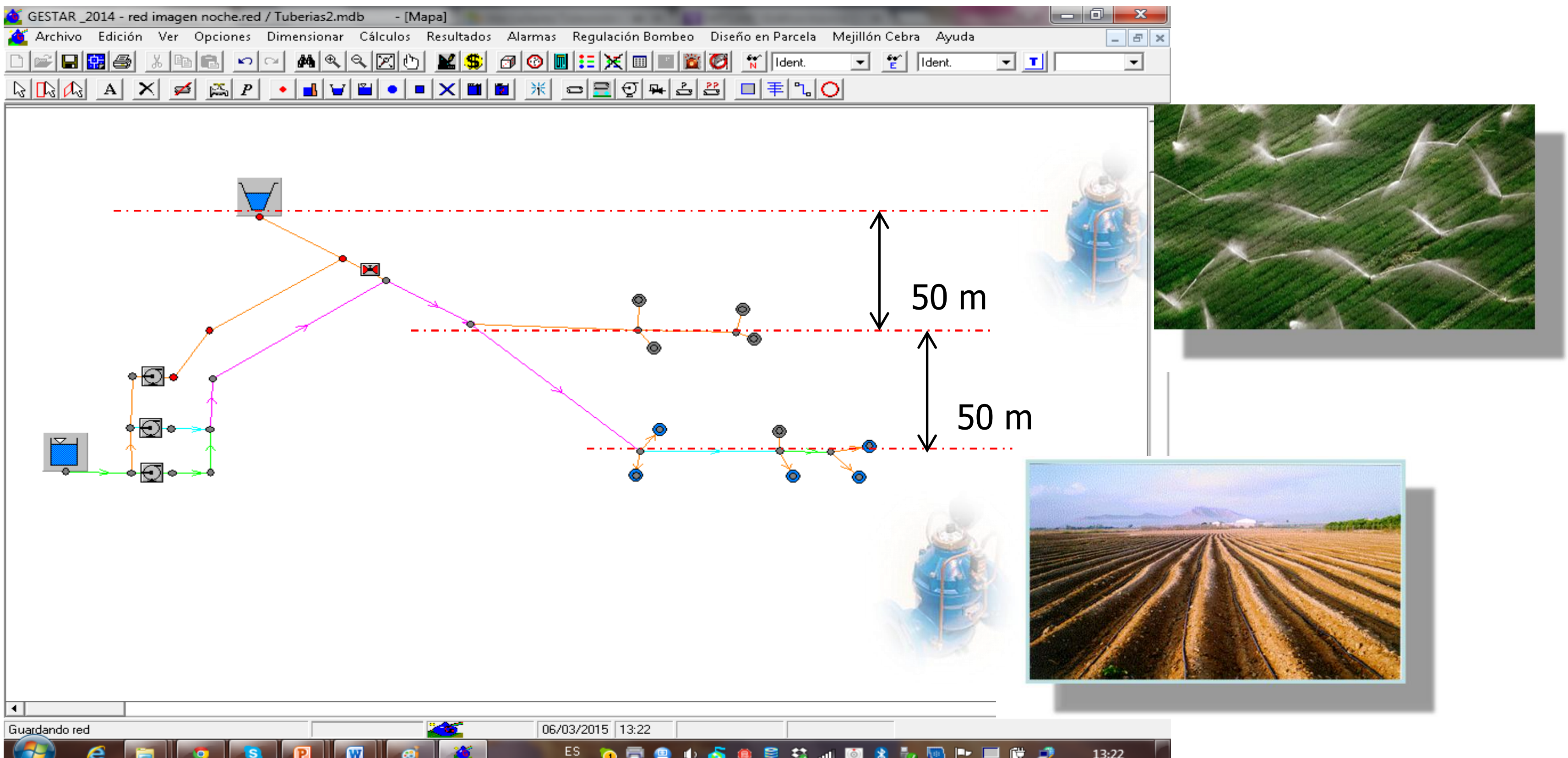


Direct Pumping Station (DPS)



THE FACTS …

- Quite different Hydraulic Head requirements at hydrants can be found



THE FACTS...

- Quite different Hydraulic Head requirements at hydrants can be found
- Energy cost uses to vary along the day, with **valley**, medium and **peaks hours**

CALENDARIO DH6 2008 PENÍNSULA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Enero	P6	P6	P6	P6	P6	P6	P6	P6	P2	P2	P1	P1	P1	P2	P2	P2	P2	P2	P1	P1	P1	P2	P2	P2
Febrero	P6	P6	P6	P6	P6	P6	P6	P6	P2	P2	P1	P1	P1	P2	P2	P2	P2	P2	P1	P1	P1	P2	P2	P2
Marzo	P6	P6	P6	P6	P6	P6	P6	P6	P4	P4	P4	P4	P4	P4	P4	P4	P3	P3	P3	P3	P3	P3	P4	P4
Abril	P6	P6	P6	P6	P6	P6	P6	P6	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5
Mayo	P6	P6	P6	P6	P6	P6	P6	P6	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5
1ª Junio																								
2ª Junio																								
Julio																								
Agosto																								
Septiembre	P6	P6	P6	P6	P6	P6	P6	P6	P4	P3	P3	P3	P3	P3	P3	P4	P4	P4	P4	P4	P4	P4	P4	P4
Octubre	P6	P6	P6	P6	P6	P6	P6	P6	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5	P5
Noviembre	P6	P6	P6	P6	P6	P6	P6	P6	P4	P4	P4	P4	P4	P4	P4	P4	P3	P3	P3	P3	P3	P3	P4	P4
Diciembre	P6	P6	P6	P6	P6	P6	P6	P6	P2	P2	P1	P1	P1	P2	P2	P2	P2	P2	P1	P1	P1	P2	P2	P2

EVEN FLAT RATE OR NO ENERGY

THE FACTS…

- Quite different pressure requirements at hydrants can be found.
- Energy cost use to vary along the day, with valley, medium and peaks hours
- The water demands can be easily anticipated and admit rescheduling

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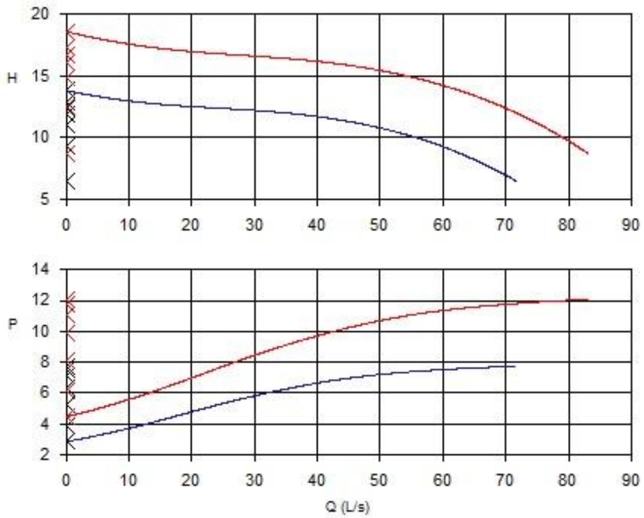
- Energy cost use to vary along the day, with valley, medium and peaks hours
- The water demands can be easily anticipated and admit rescheduling
- The pressure supplied by pumping stations can be modulated (Inverters)



GESTAR 2014 Pump Selector and Analyzer Tooll

MIX AND SHAKE THE FACTS, THE IDEA…

IFFERENT REQUERIMENTS

PRESSURE MODULATION

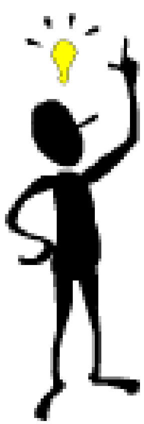
ENERGY COST

RESCHEDULING

ON DEMAND

MINUMUM COST

LOW UNCERTAINITY



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DEMAND MANAGEMENT: SAVING ENERGY COST

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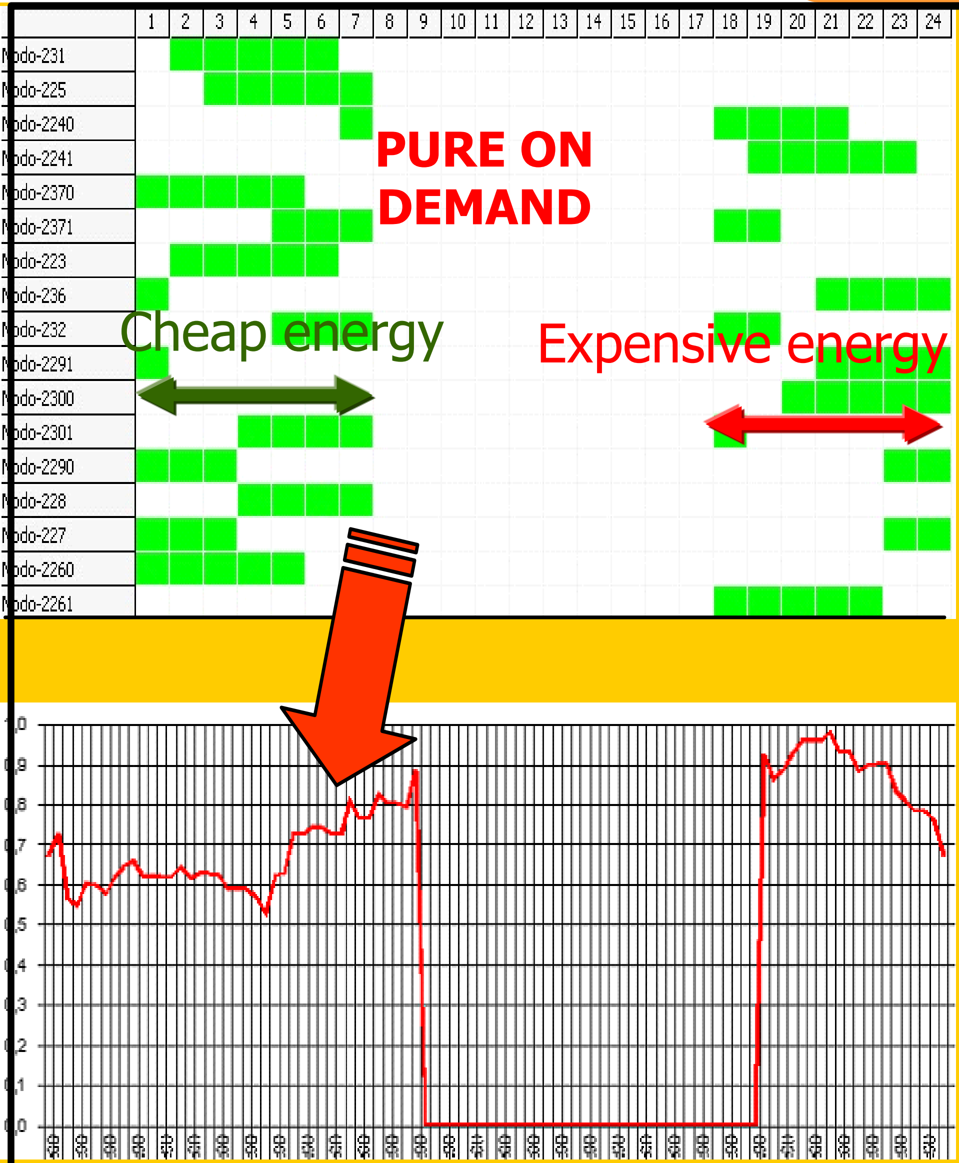
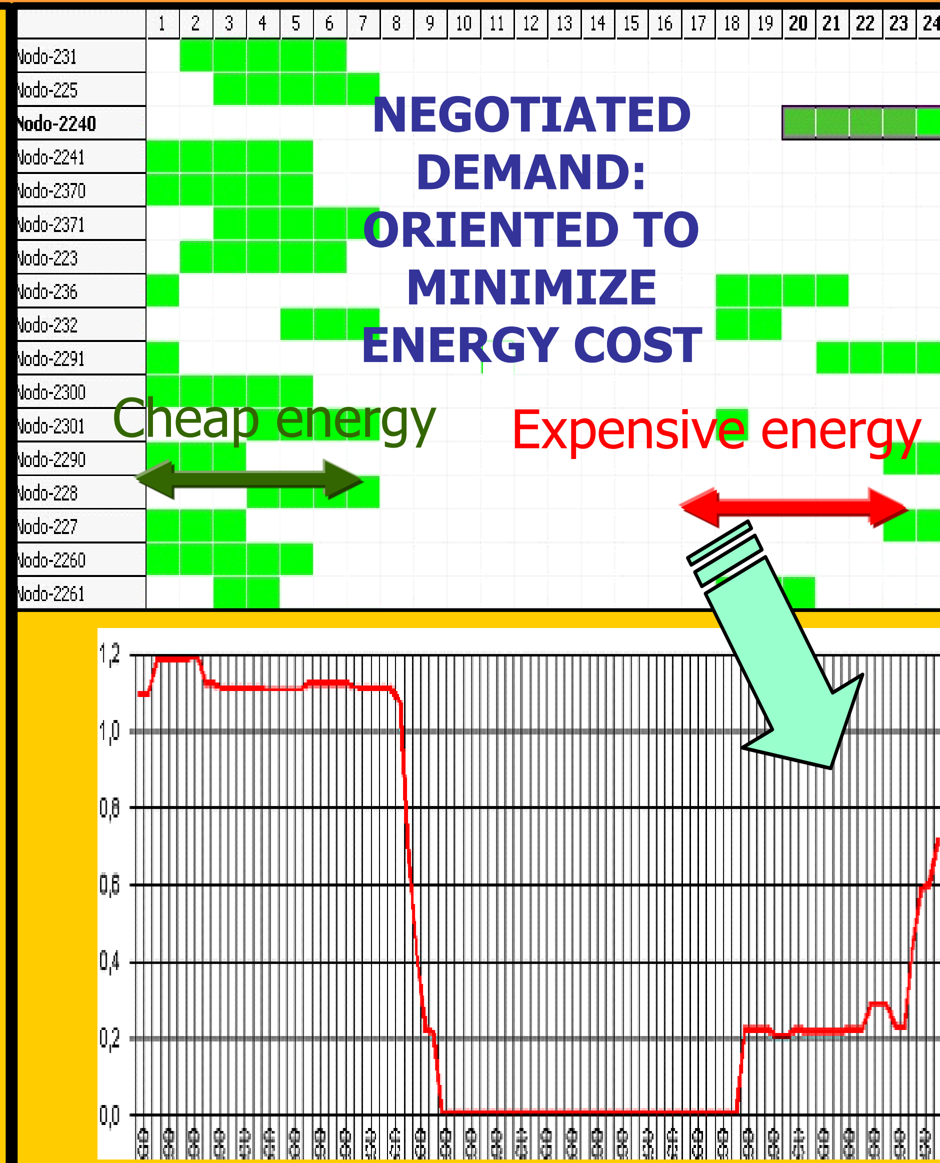




Demand / pressure management

- **Goal is to fulfill all the hydrants demands** (meting many different REQUERIMENTS: flow rate, irrigation duration, time window, minimum pressure, max velocity, and others,…) **at minimum energy cost** (kWh and billing) by **appropriate scheduling** (and pumping station pressure control if possible). **=> Optimization problem with multiple decision variables and restrictions.**

- **The most cost/benefit effective strategy** (minimum or no investment required, maximum savings, i.e. 12-35% or more), **and complementary with others**

- **It allows renewable and conventional/combined energy sources exploitation.**

- **Over sizing associated to on demand designs, helps to introduce the strategy in existing networks** (but specific methodology must be introduced in design of new systems to be operate under this advanced scheme, in order to obtain the most of the its advantages).

- **Adaptable to** (continuous) **changing conditions.**

DEMAND MANAGEMENT: SAVING ENERGY COST

Idea formulation is easy , but requires specific tools:

- Because of the network hydraulic constrains (head loses, max velocities,..) not any demand combination followingg the idea can be satisfied
- Hundreds of billions of demand combinations will not meet these requirements (pressure, velocity, …).
- A small set (thousands /tens of thousand) of demand combinations will achieve the requirements (pressure, velocity, …) ¿how we found those?
- Among these, we should find the combination with minimum (or nearly minimum) cost

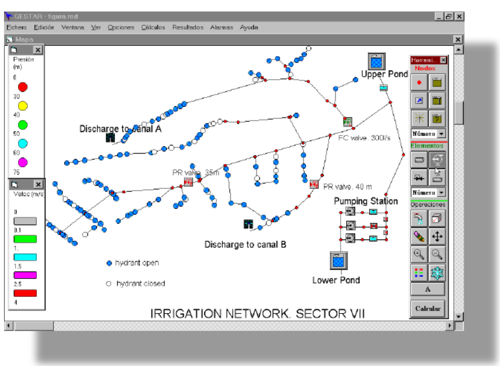
This **calls for appropriate ICT providing Decision Support System** in management (and design). Specially **success** and effectiveness in **irrigation networks** as they have **low uncertainty, limited extensions** and feasible **demand control/conditioning**

THE TOOL …

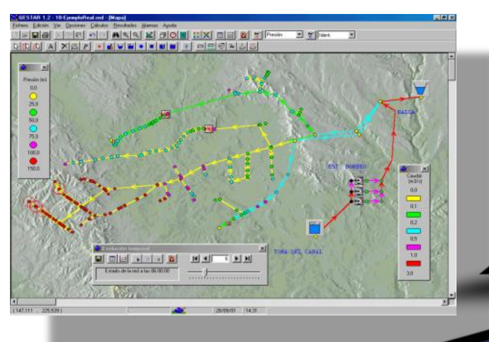
… GESTAR, a SOFTWARE PACKADGE for DESIGN and MANAGEMENT of IRRIGATION NETWORKS, INCLUDES the NECESARY DSS to ACHIVE the GOALS

From Scientific Production to Technology Transfer, user friendly environment

1997

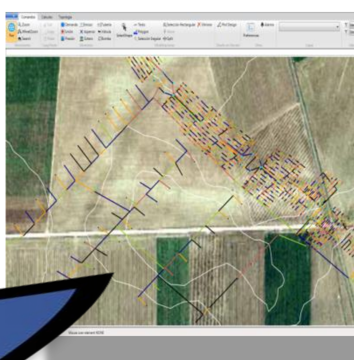


2014

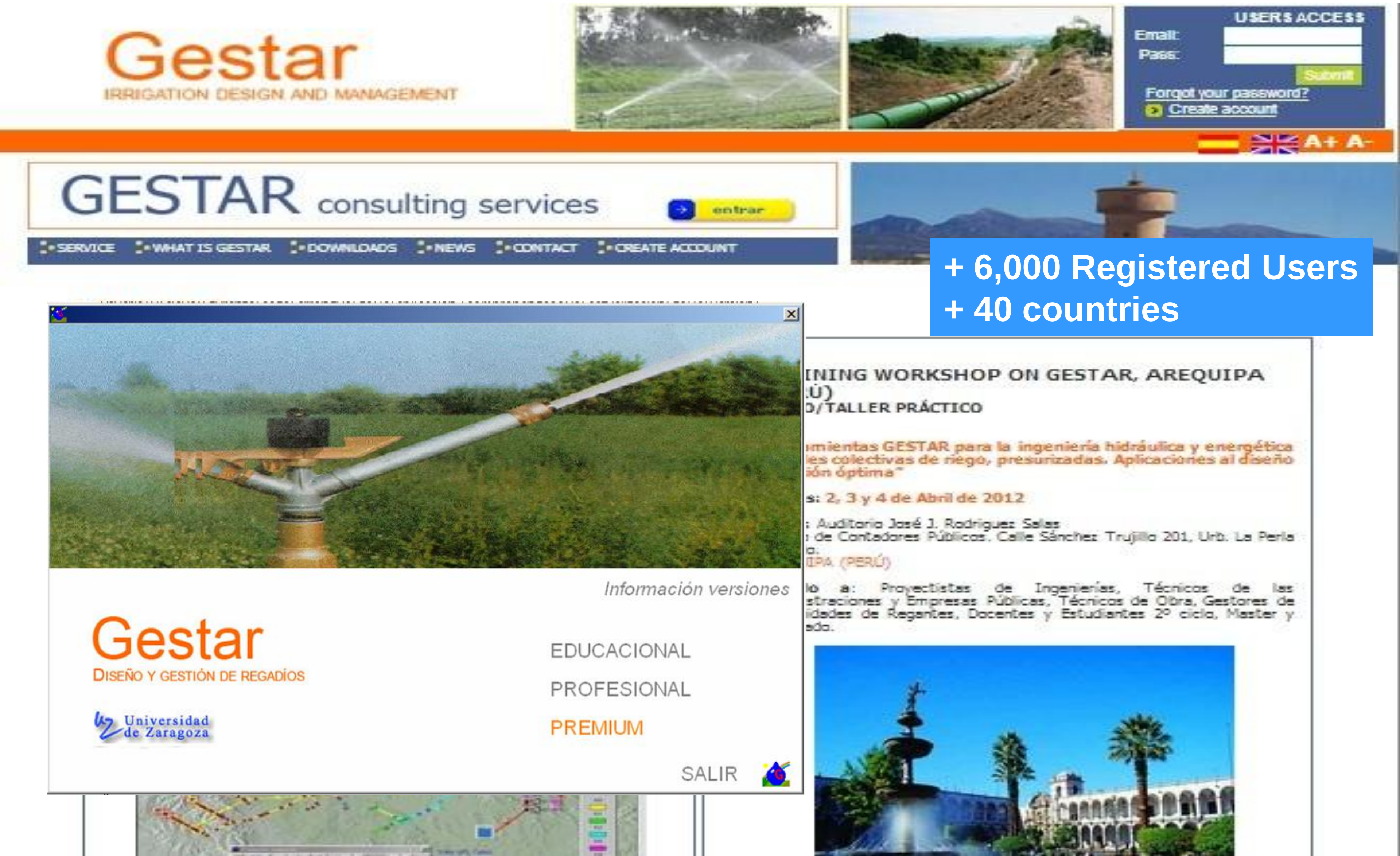


Languages.
Spanish
English
French
Portuguese

2016



GESTAR HOME PAGE:



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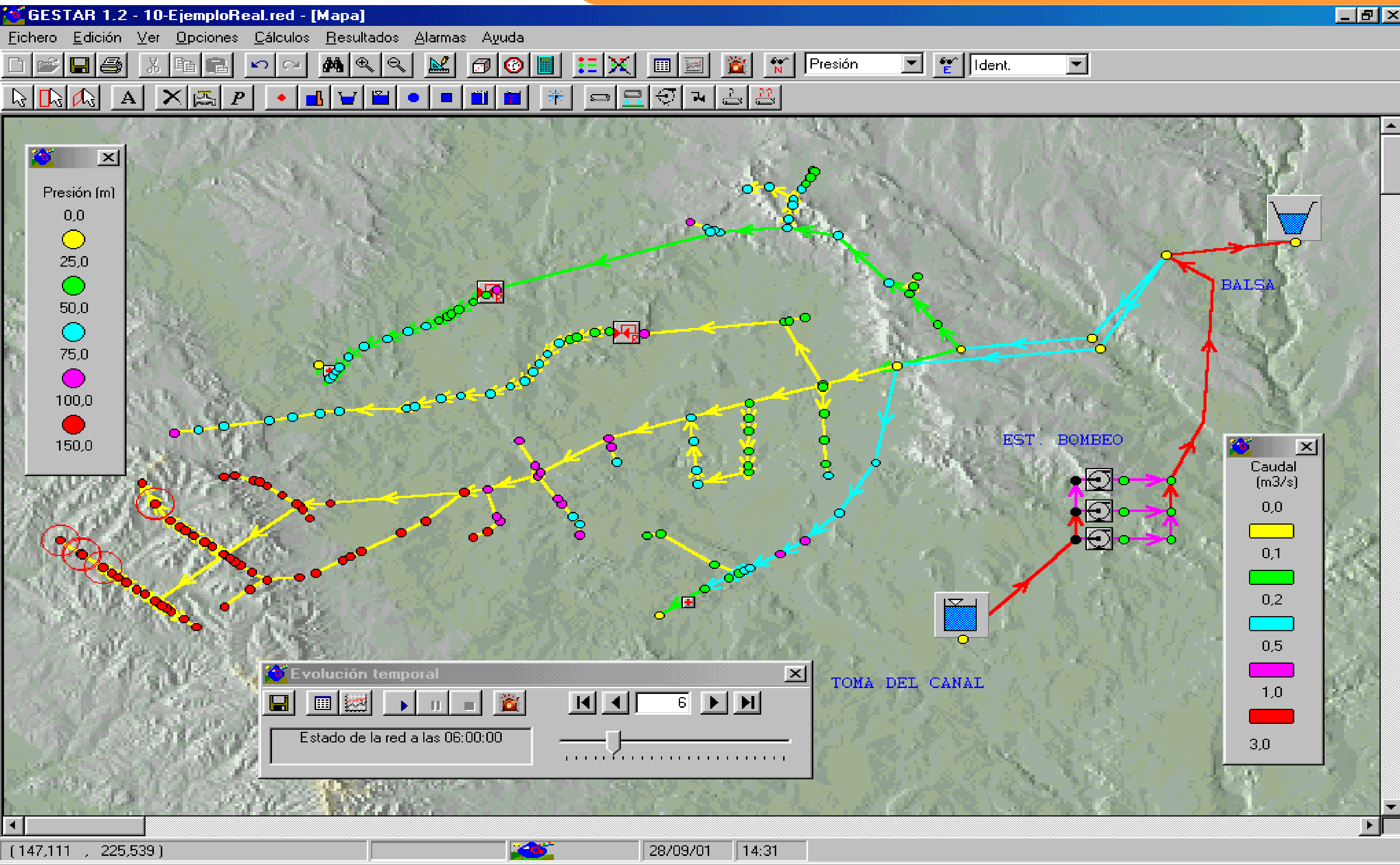


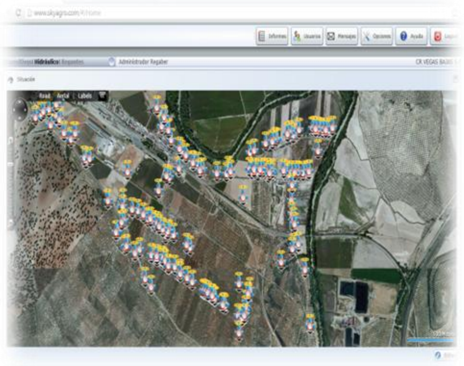
COMPLETE AND POWERFULL SOFTWARE

DESIGN

EXECUTION

REHABILIATION

AUDIT,…



MANAGEMENT

Deal with..

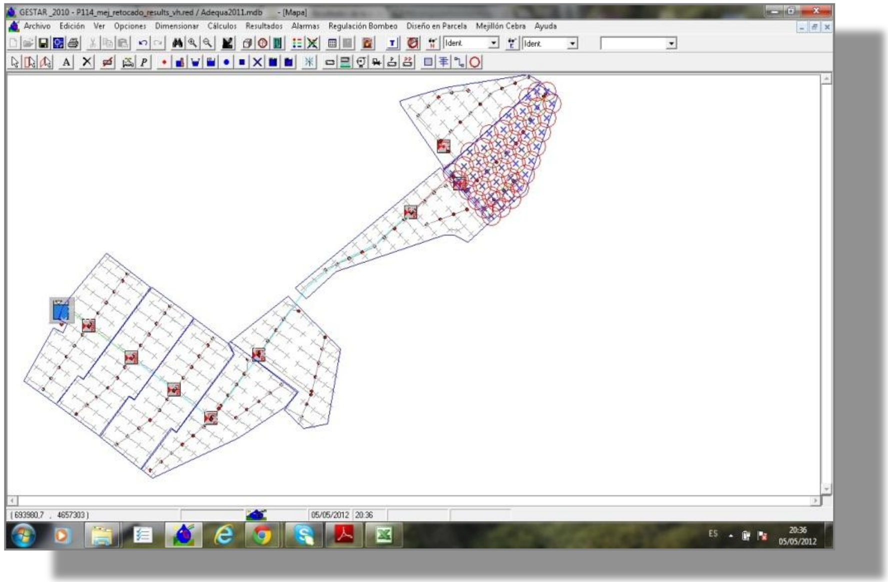
hydraulics

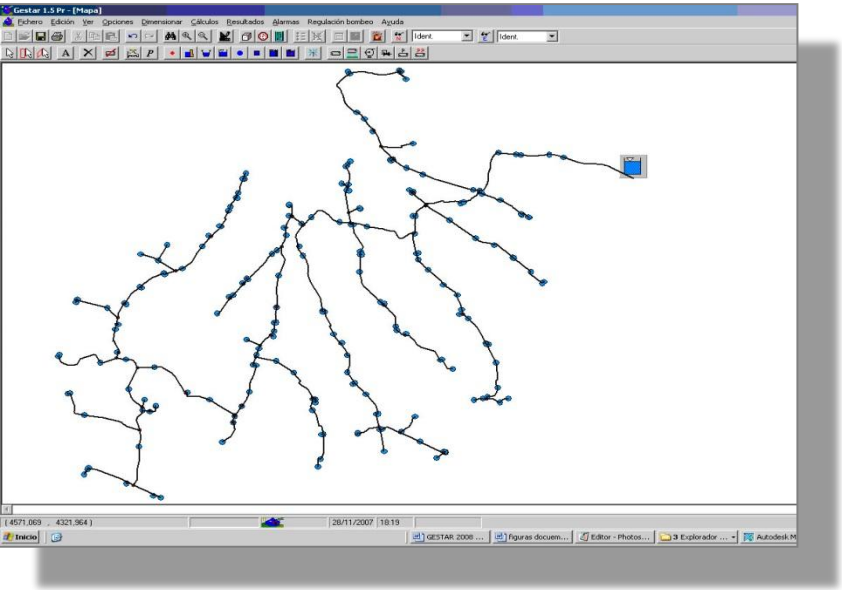
hydraulics

energy

energy

Multiple tools for collective distribution network (plus on plot network: sprinkle and drip irrigation).





COMPLETE AND POWERFULL SOFTWARE

Savings …

20% infraestructure cost

20% water use

Up to 35% energy cost

GESTAR 2014 MAIN MODULES STRUCTURE

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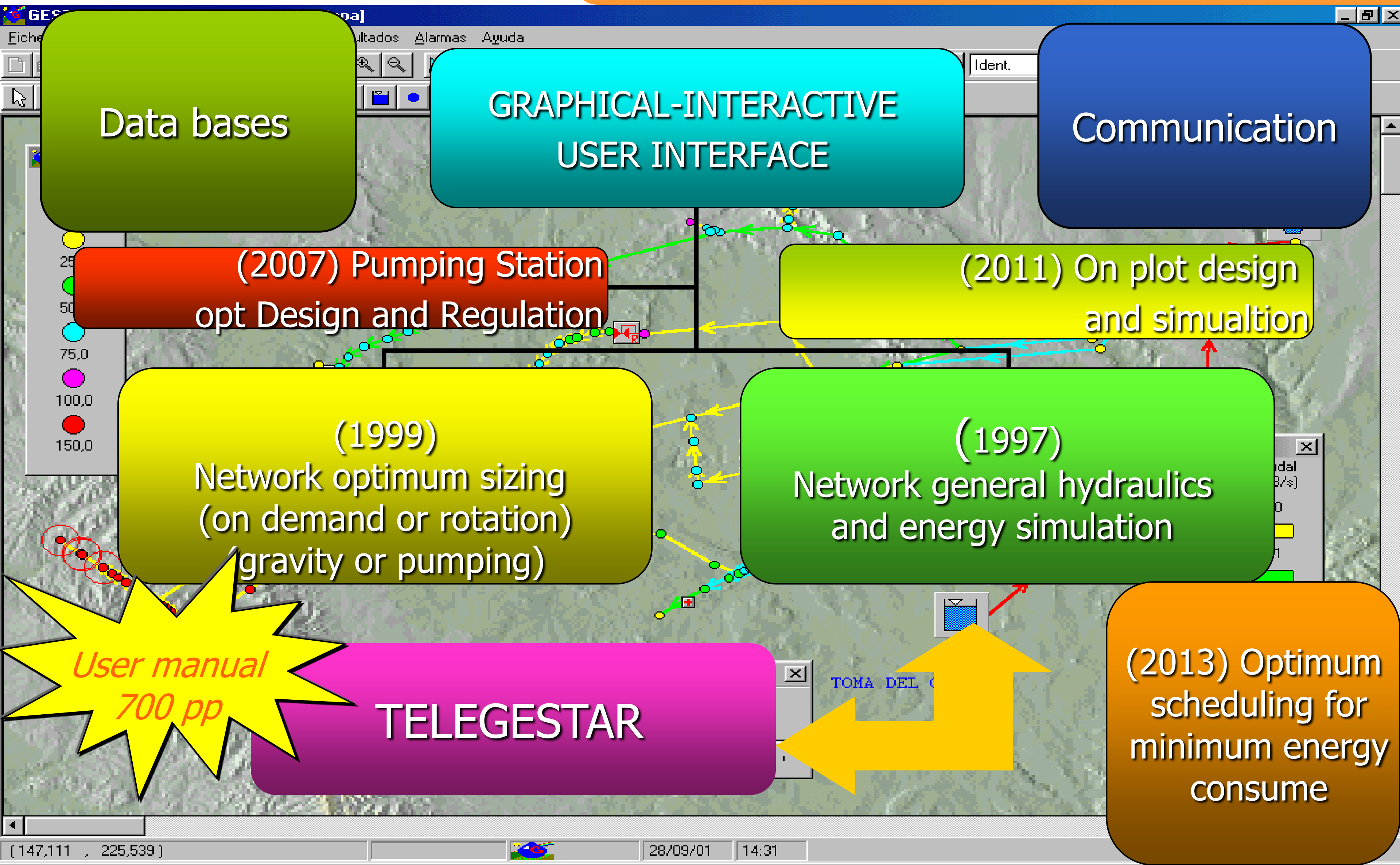

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SOME GESTAR ENERGY RELATED TOOLS

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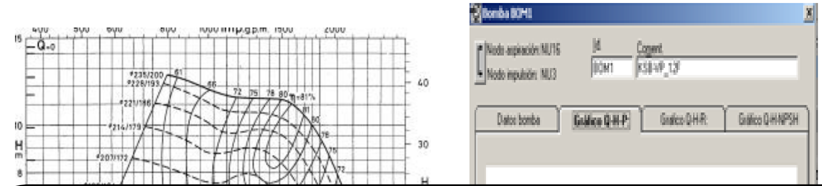
- Accurate modelling of pumps and pumping stations curves using splines and uncoupled nodal equations.

- Synthetic modelling of Direct Pumping Stations and their regulation with virtual characteristic curves..

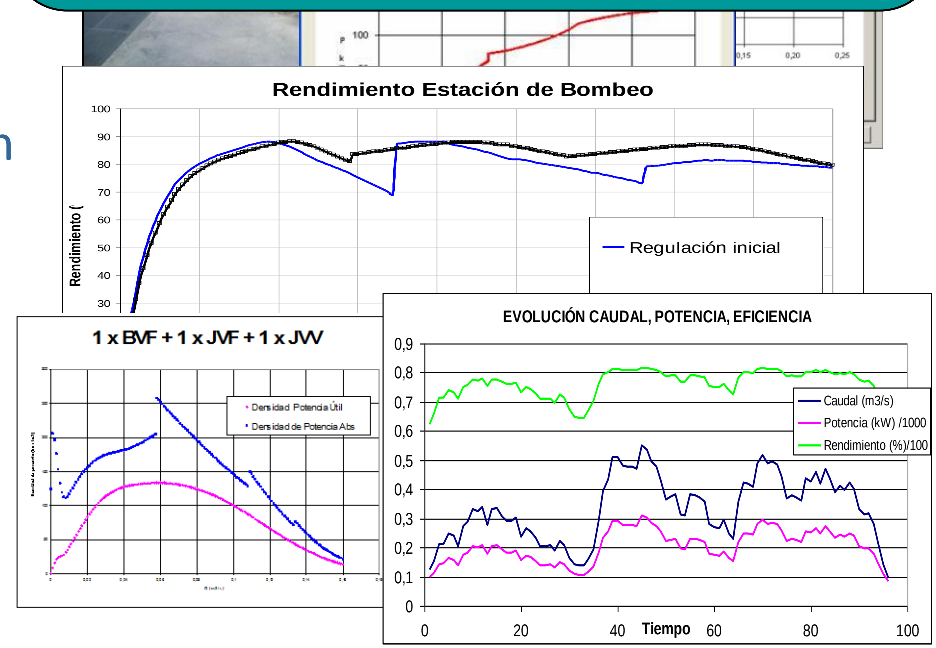
- Automatic configuration of Direct Pumping Stations with any composition and regulation

- Direct Pumping Station efficiency optimizer

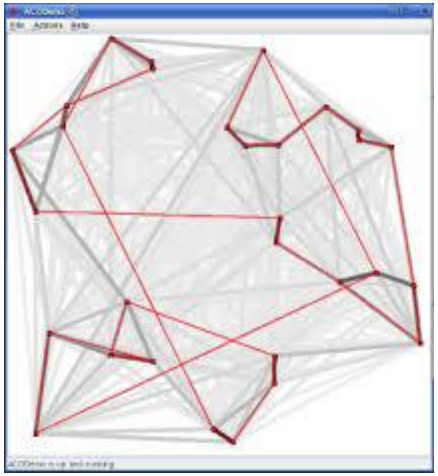
-Statistical and deterministic (simulation) prediction of energy consume and costs.



PRO_RIEGO
(PROGRAM IRRIGATION):
Scheduling for
minimum energy cost in TeleGESTAR
(evolutionary optimization algorithm)



THE EVOLUTIONARY ALGORITHM,



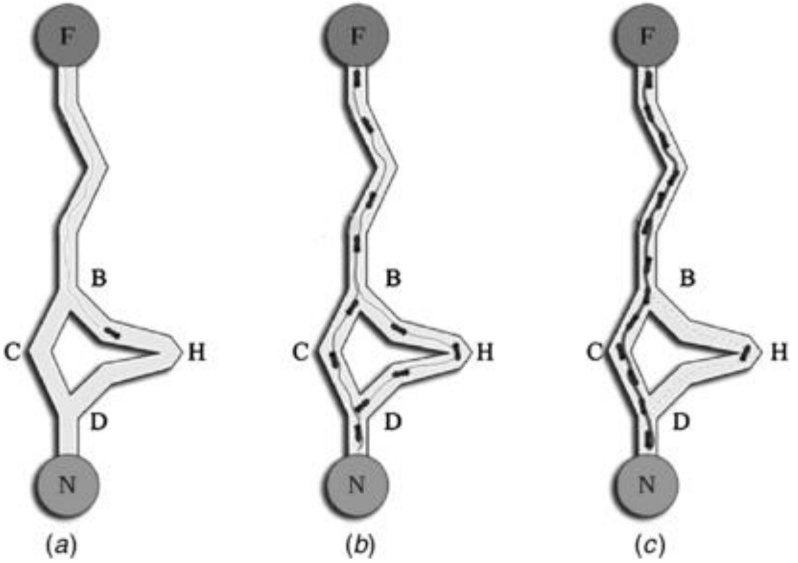
ANT COLONY OPTIMIZATION ALGORITHM

- Meta heuristic algorithm inspired in the ants strategies for search food

- Initially ants search for food and return to anthill by random walks, but they deposit pheromone along the way, More intense pheromone in return way if they have been success.

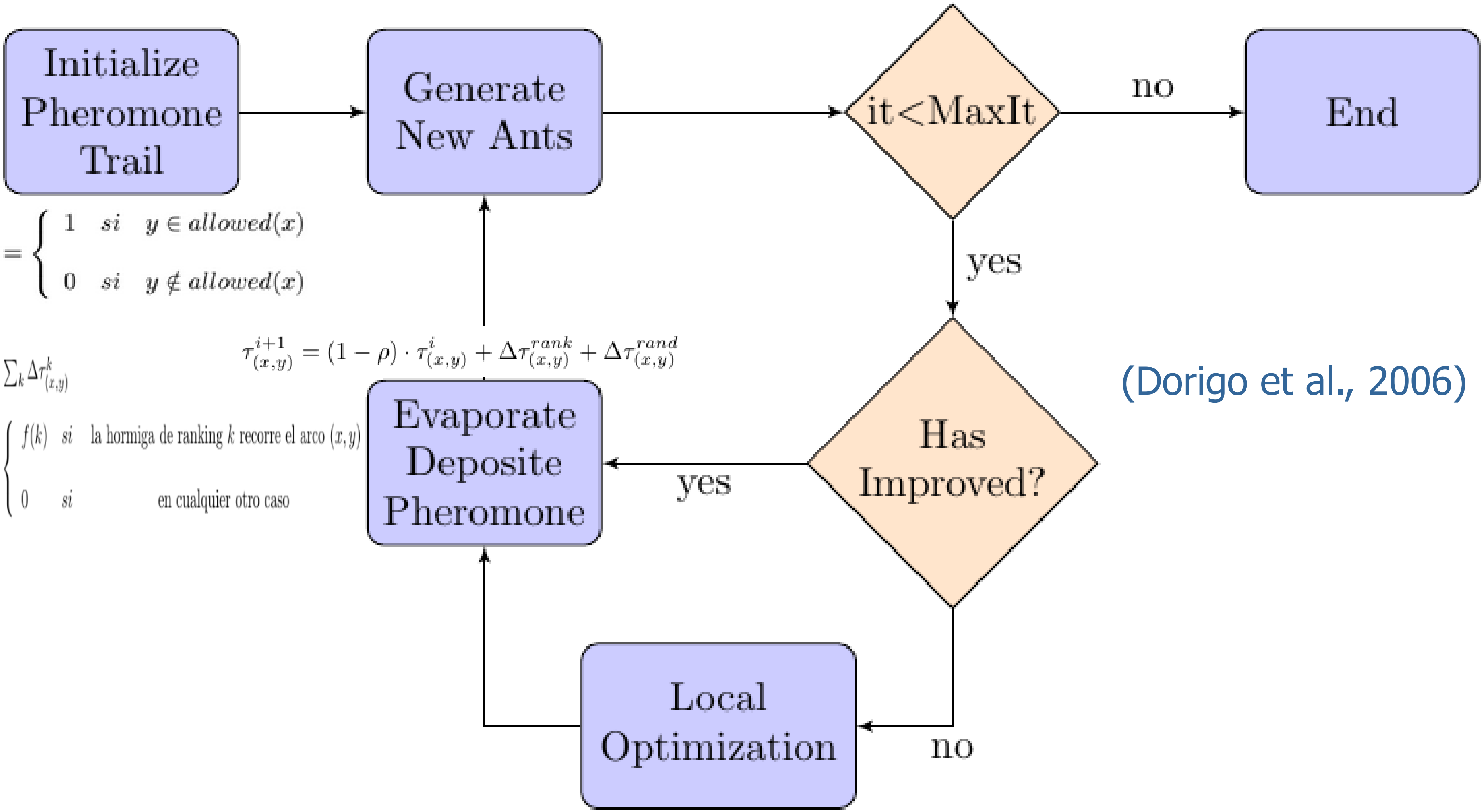
- The pheromones are volatile substances that attracts to other ants, reinforcing the best paths and making disappear the unfruitful.

- After some cycles, the preferred route is optimum, (It goes straight and safely from the anthill to the feeding source)



ANT COLONY OPTIMIZATION ALGORITHM

$$p^k_{(x,y)} = \begin{cases} \frac{\tau_{(x,y)}}{\sum_{k \in allowed(x)} \tau_{(x,k)}} & si \quad j \in allowed(x) \\ 0 & si \quad j \notin allowed(x) \end{cases}$$



$$\tau^0_{(x,y)} = \begin{cases} 1 & si \quad y \in allowed(x) \\ 0 & si \quad y \notin allowed(x) \end{cases}$$

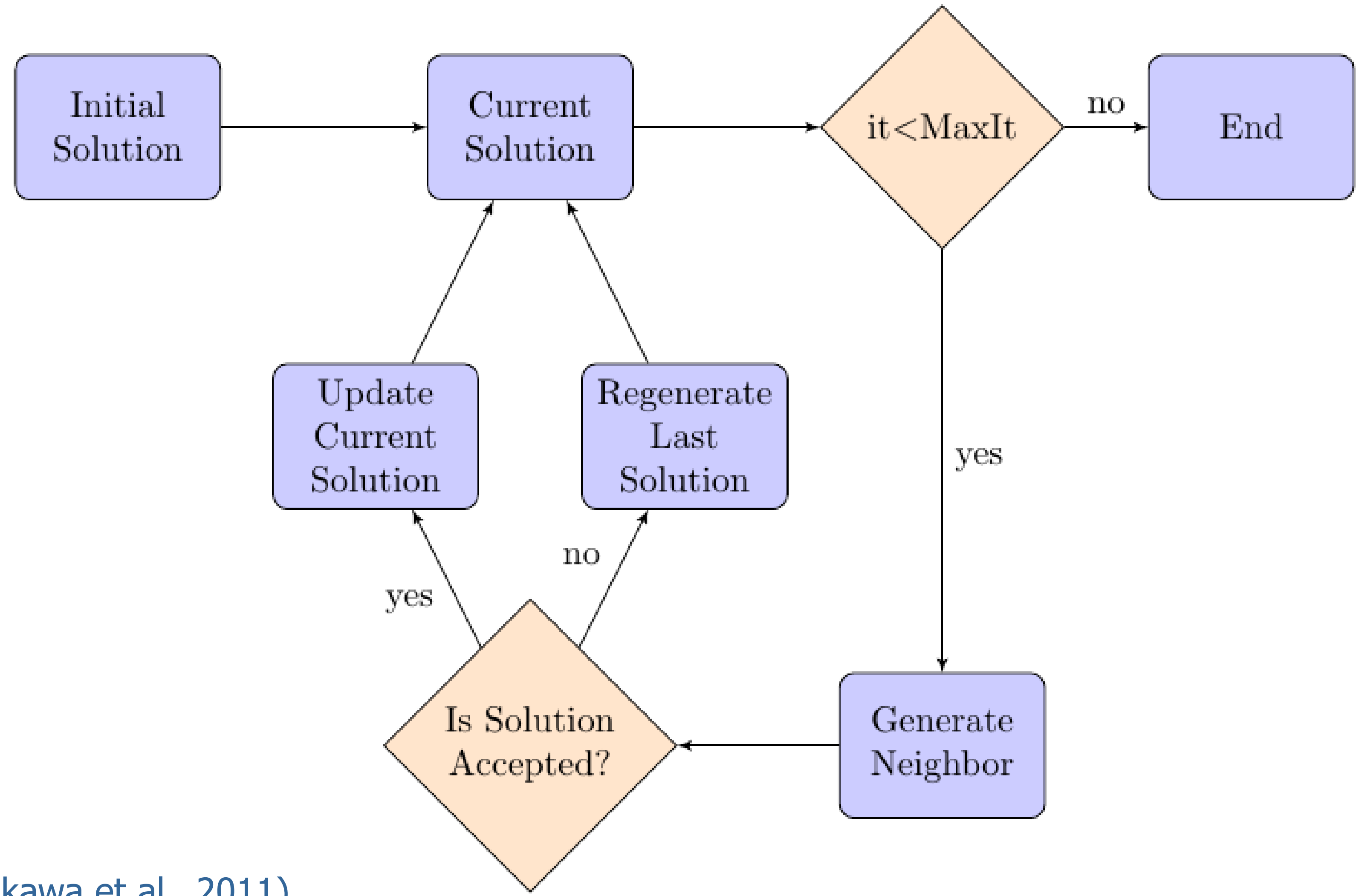
$$\tau^{i+1}_{(x,y)} = (1-\rho) \cdot \tau^i_{(x,y)} + \Delta\tau^{rank}_{(x,y)} + \Delta\tau^{rand}_{(x,y)}$$

$$\Delta\tau^{rank}_{(x,y)} = \sum_k \Delta\tau^k_{(x,y)}$$

$$\Delta\tau^k_{(x,y)} = \begin{cases} f(k) & si \quad \text{la hormiga de ranking } k \text{ recorre el arco } (x,y) \\ 0 & si \quad \text{en cualquier otro caso} \end{cases}$$

(Dorigo et al., 2006)

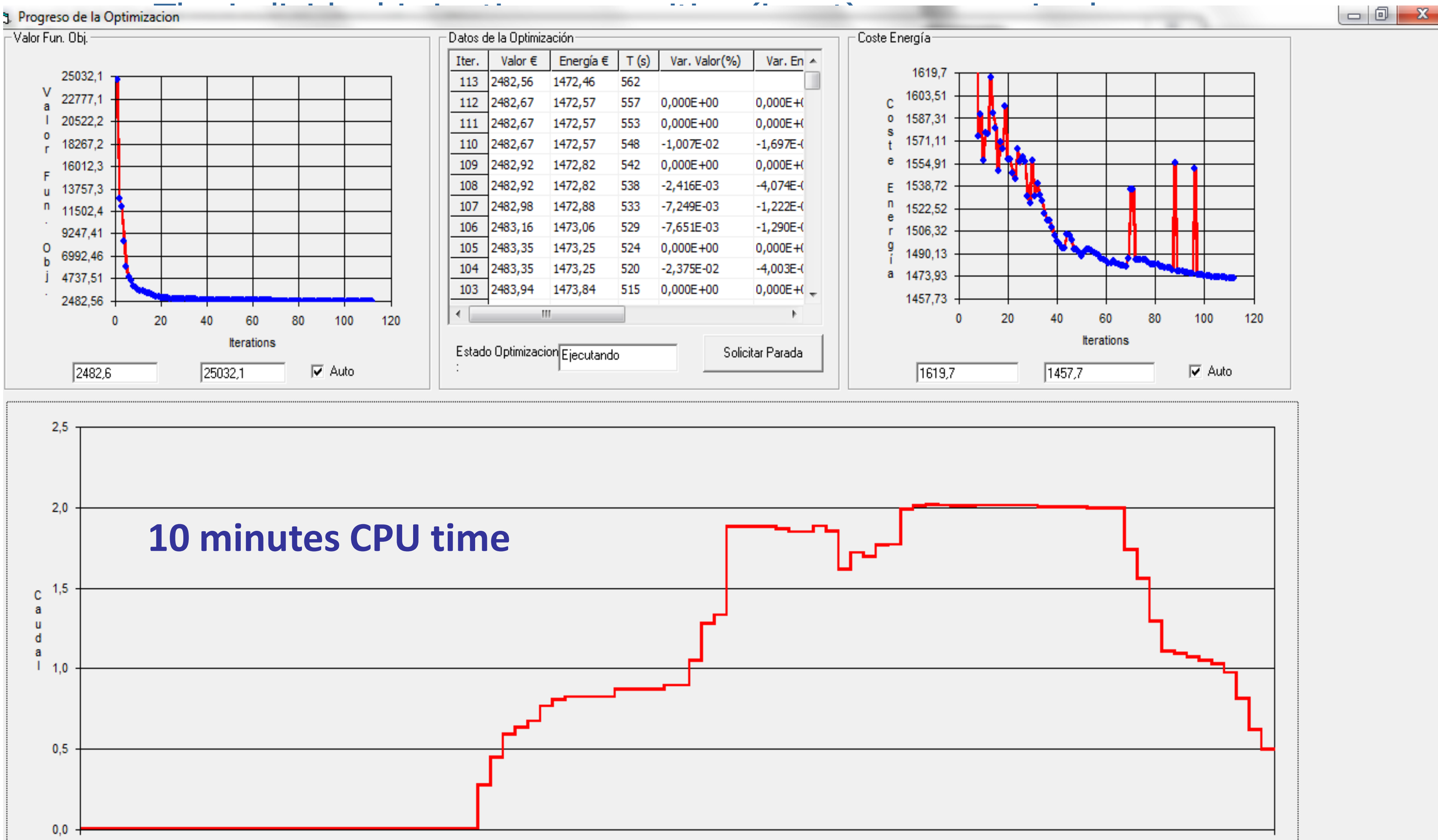
LOCAL OPTIMIZATION: HILL CLIMBING



(Hayakawa et al., 2011)

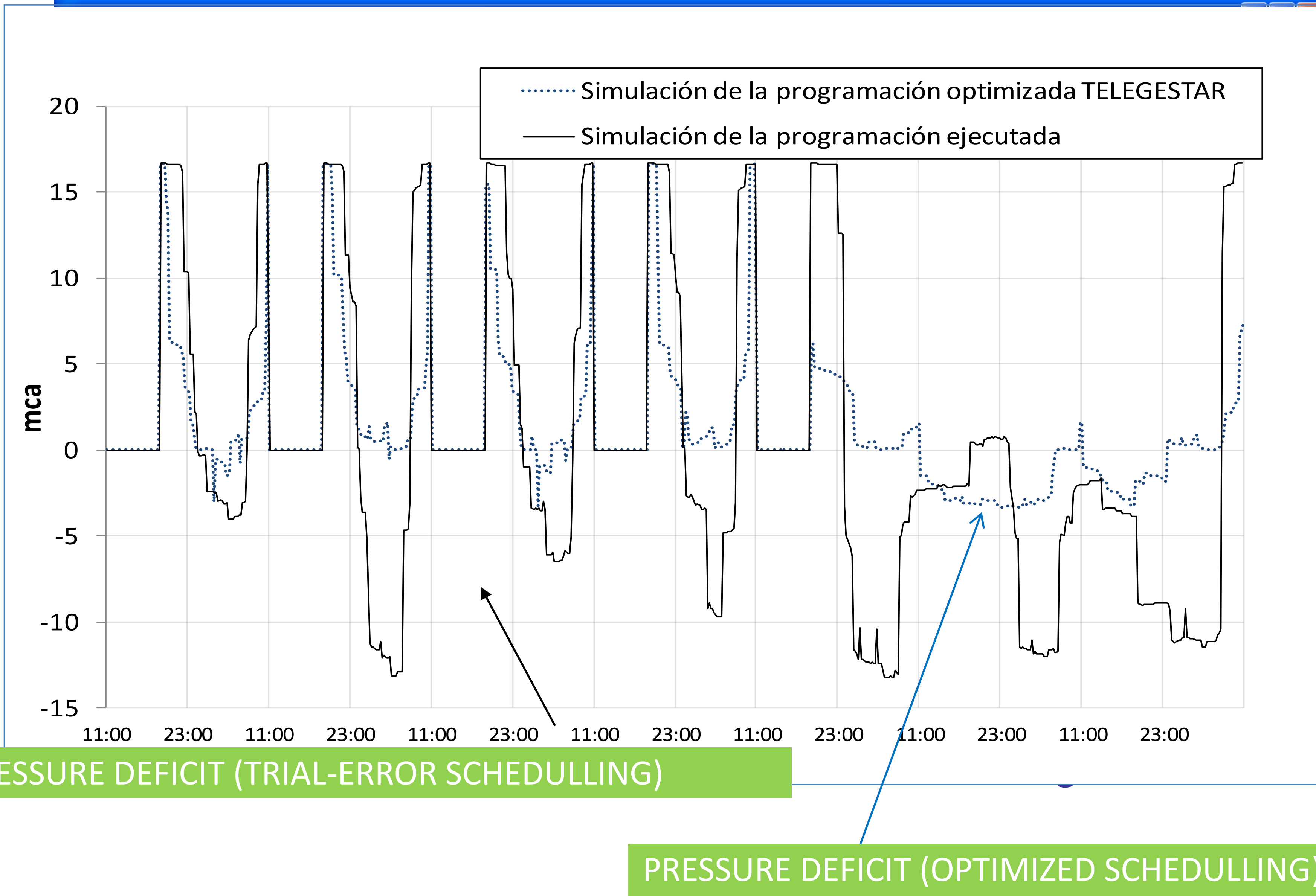
THE RESULTS…

TeleGESTAR SCHEDULLING OPTIMIZATION



Pumping Station flow rate after optimized scheduling for 24 h

TeleGESTAR SCHEDULLING OPTIMIZATION



CASE STUDY A) LAVIOLADA NETWORK

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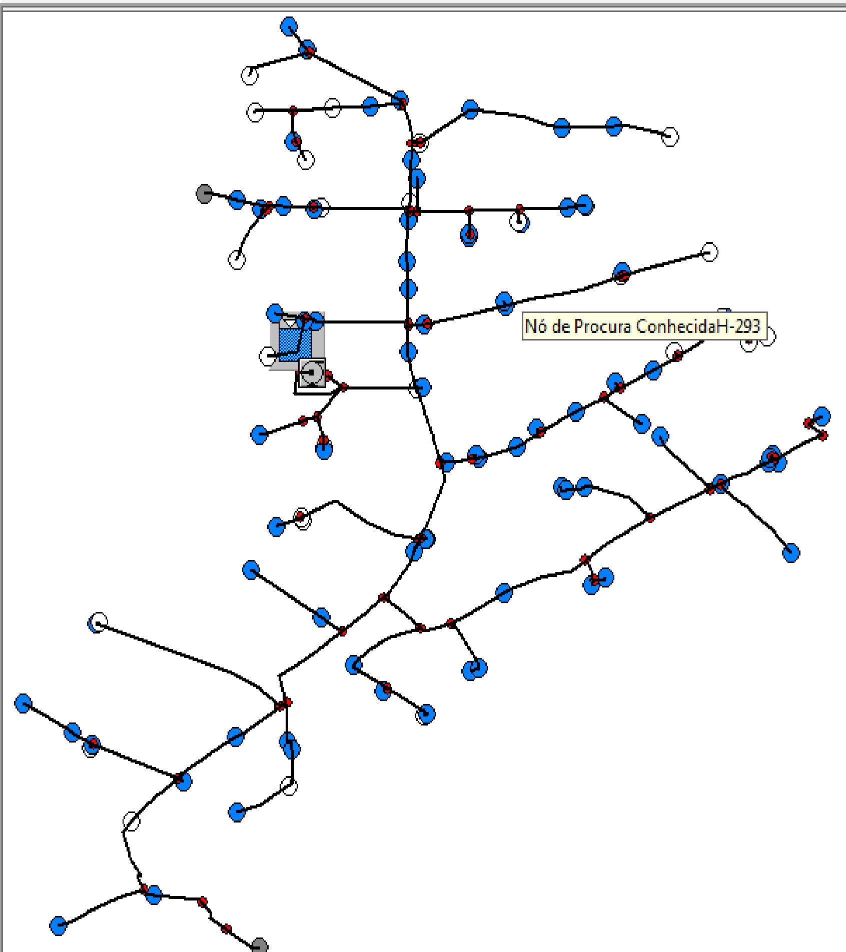
GESTAR _2014 - secuencia Ejemplo aperturas.red / Tuberias2.mdb - [Mapa]

Ficheiro Edição Ver Opções Dimensionar Cálculos Resultados Alarmes Regulação Bombagem Desenho de Parcela Mexilhão-zebra Ajuda

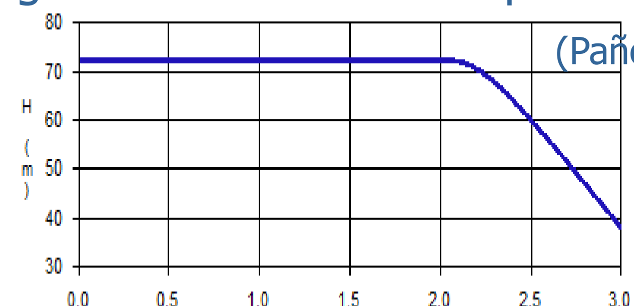


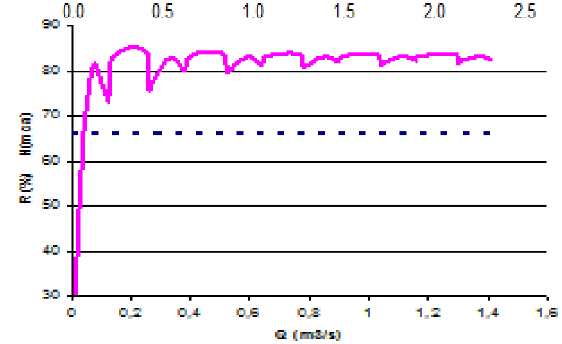
Violada (Almudévar) WUA (Spain)

- Irrigated Surface : 1,335 ha
- Design max flow rate 2.1 m^3/s

Pumping station: GESTAR compact modeling

(Paño et al., 2012)





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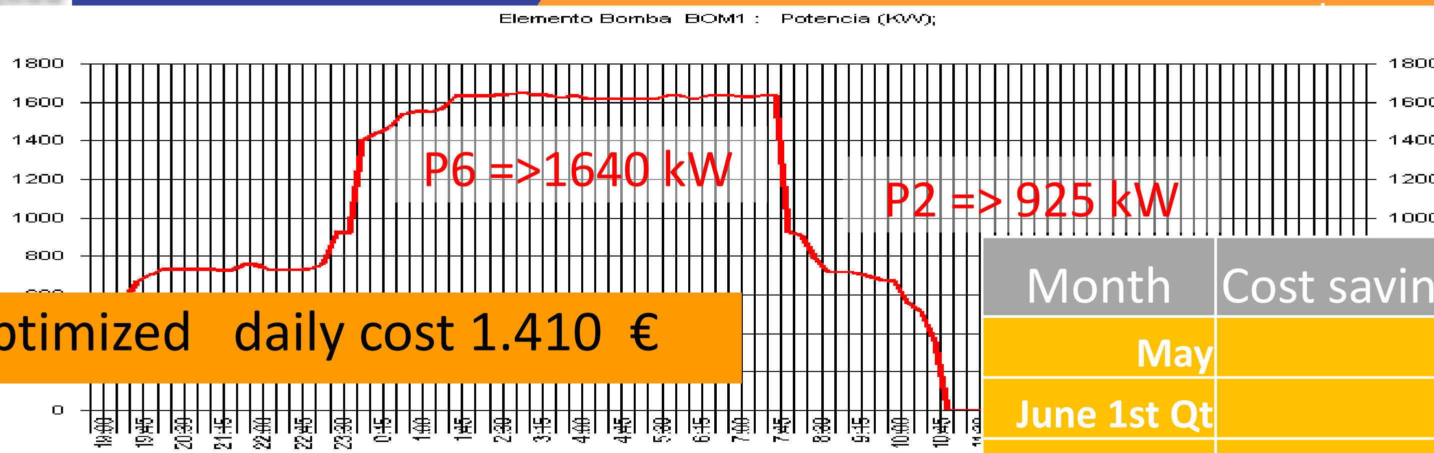
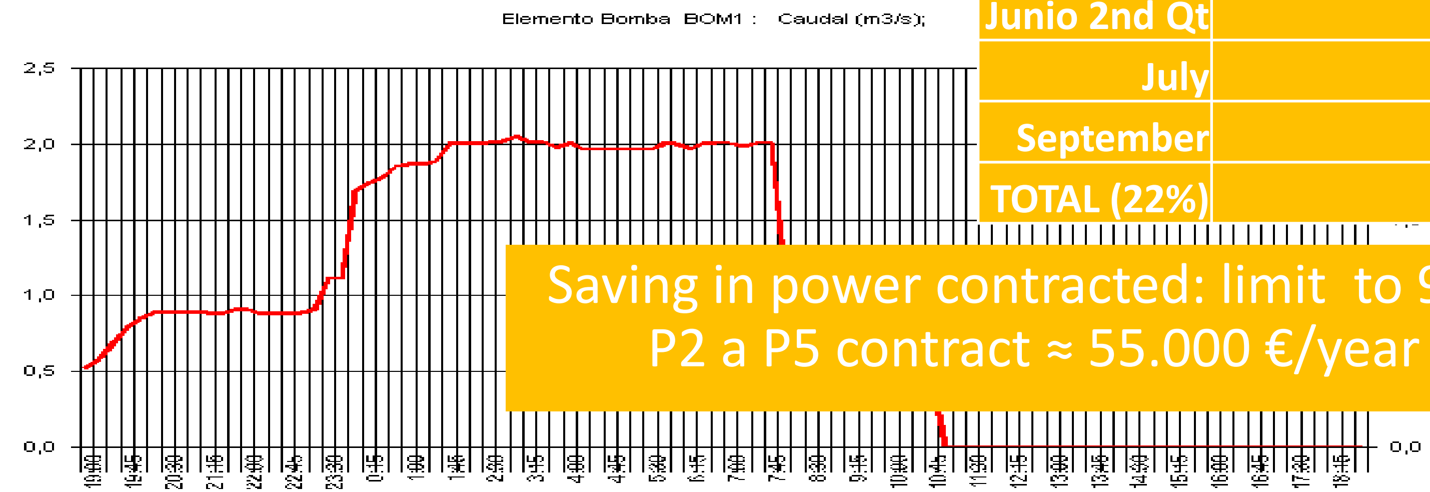
CASE STUDY A) LAVIOLADA NETWORK



Optimized daily cost 1.410 €

Month	Cost savings (€)
May	2.464
June 1st Qt	792
Junio 2nd Qt	4.510
July	9.020
September	2574
TOTAL (22%)	19.360



Saving in power contracted: limit to 925 kW P2 a P5 contract ≈ 55.000 €/year (40%)

Energy saving July month: ≈ (1.820-1.410) €/year* 22 days = 9.020 €

TOTAL SAVING : 74.000 € year (32%)

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CASE B) CALLEN WUA NETWORK

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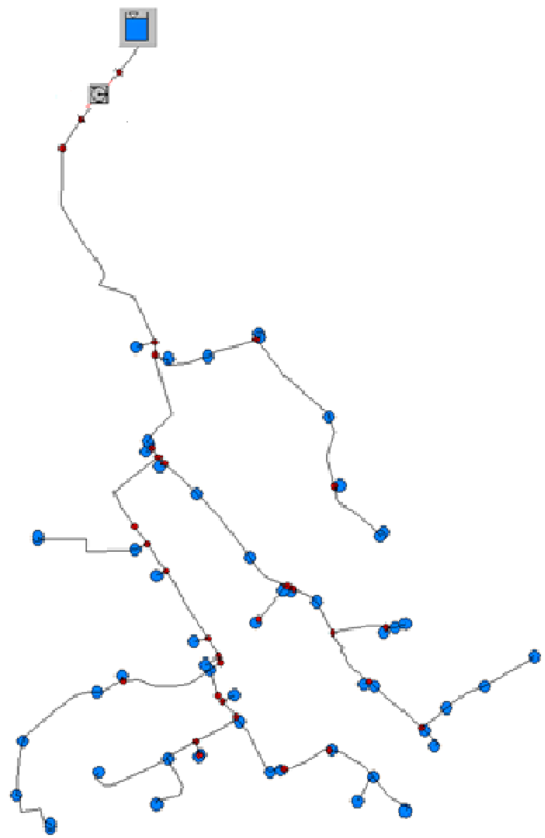
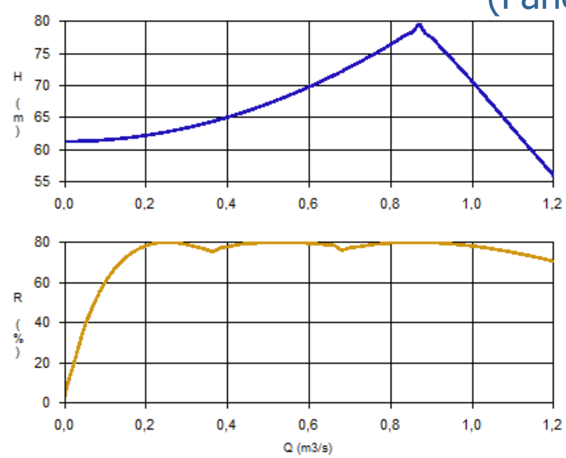


Callén WUA (Spain)

- Irrigated Surface 698 ha
- Design max flow rate 0.820 m^3/s

Pumping station: GESTAR compact modeling

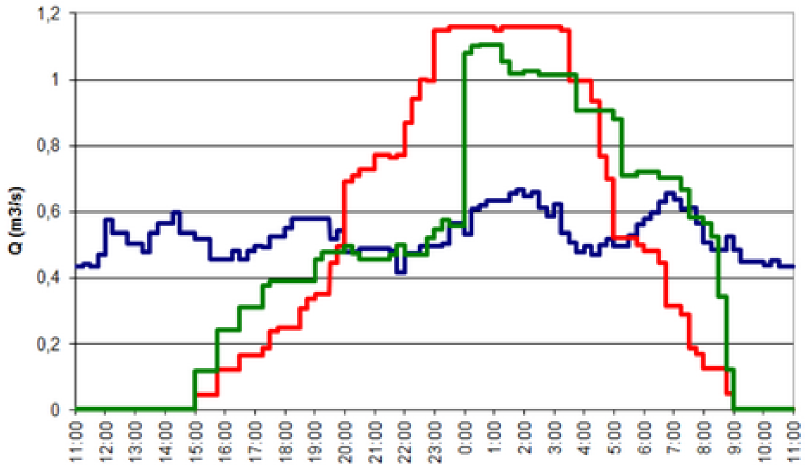
(Paño et al., 2012)

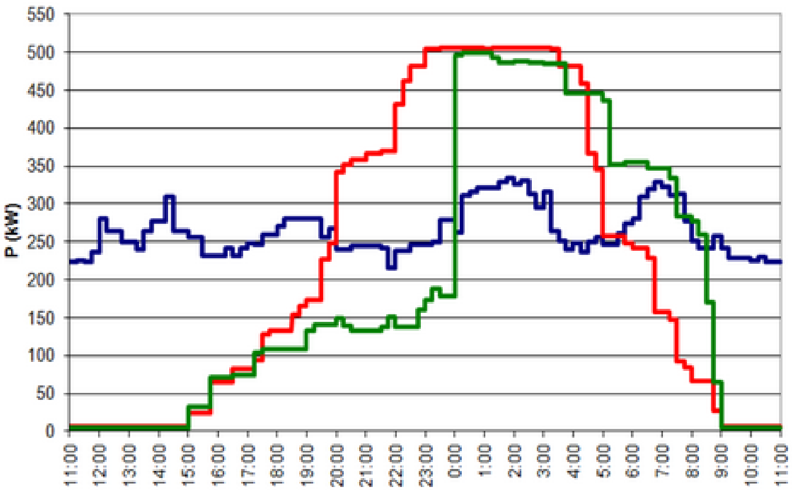


CASE B) CALLEN WUA NETWORK

- Pure on demand: Energy cost 298 €/day, July
- Demand optimized 1 pressure level: Cost 278,56 €/day., July
- Demand optimized 2 pressure levels: Cost 245,5 €/day., July

Yearly energy bill savings: 20% (20.550 € /year)





STUDY CASES. IMPACT IN ENERGY COST

Name of the network with DPS	WUA	Area (ha) (n.º of hydrants)	Nominal pressure on demand (m)	Total energy costs on demand (€/year)	% Saving achieved using PRORIEGO
LAVIOLADA	(Almudevar)	1,335 (106)	66	**231,000**	**32%**
NETWORK 3	(Mequinenza)	1,000 (101)	65	**88,000***	**16 %**
NETWORK A and B	(Callén)	1,135 (89)	70 -44.5 50 -25	**216,000**	**18%**
PHASE II	(Molinar)	3,644 (273)	68 -48	**963,000**	**16%-20% (Estimated)**

CONCLUSIONS

- Water distribution by **pressurized networks** is increasing in **irrigation** applications with **remarkable consume of water an energy,** not to be neglected
- Demand characteristics and infrastructure constrains in irrigation networks make them **vulnerable**, but at the same time irrigation networks allow to implement **efficient demand management** thanks to **ICT** and **DSS** technologies, specifically developed for such a systems.
- The Decision Support tool presented for optimum demands scheduling, based on Ant Colony evolutionary algorithms, achieves significant **savings in energy cost** (15-35%) and improve of **service** and **water efficient** use (pressure satisfaction).
- The tools can be applied in any context, with any level of technology implementation
- The negotiated demand oriented to minimize energy cost calls for specific design metrologies
- It constitutes and **excellent showcase** about ICT and DSS technologies benefits applied to water and energy management in distribution networks, and a example of positive technology cross transfers

ACKNOWLEDGMENTS

PLAN NACIONAL DE INVESTIGACIÓN CIENTÍFICA, DESARROLLO E INNOVACIÓN TECNOLÓGICA SUBPROGRAMA INNPACTO. PROJECT I PT-060000-2010-27 *"TECNOLOGÍAS AVANZADAS PARA LA EFICACIA ENERGÉTICA EN LA INGENIERÍA Y LA GESTIÓN DE SISTEMAS DE RIEGO"*.

GOBIERNO DE ARAGÓN. "*CONVENIO GESTAR 2013-2015 INGENIERIA, ANÁLISIS Y GESTIÓN DE REDES DE RIEGO PARA LA MODERNIZACIÓN DE REGADÍOS"*. CONVENIO CONVENIO CON UNIVERSIDAD DE ZARAGOZA

PRESSURIZED IRRIGATION NETWORKS

- **Branched networks**, (more vulnerable to over demands and breakouts) sized with criteria of **minimum cost**.
- **Disperse** networks and **limited number of users**.
- **Intermittent** (not continuous) use of the **demand** nodes (hydrants)
- **High flow rates** at hydrants (decisions of individual users affect the network)
- **High variability** in flow demands (along the day along the season)-
- Quite **different pressure requirements** at hydrants can be found
- **Preferred use is "on demand"** scheme, freedom to use the hydrant at any time (but **network is not designed to supply water to all hydrants simultaneously**) .