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

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THE STRATEGY...
• 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)
• Quite different Hydraulic Head requirements at hydrants can be found
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• Energy cost uses to vary along the day, with valley, medium and peaks hours
• Quite different pressure requirements at hydrants can be found.

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• The water demands can be easily anticipated and admit rescheduling
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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
• The pressure supplied by pumping stations can be modulated (Inverters)
MIX AND SHAKE THE FACTS, THE IDEA...
DEMAND MANAGEMENT: SAVING ENERGY COST

Cheap energy

Expensive energy

NEGOTIATED DEMAND: ORIENTED TO MINIMIZE ENERGY COST

PURE ON DEMAND
Demand / pressure management

- Goal is to fulfill all the hydrants demands (meting many different REQUIREMENTS: 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.
Idea formulation is easy, but requires specific tools:

- Because of the network hydraulic constrains (head loses, max velocities, ..) not any demand combination following 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 PACKAGE for DESIGN and MANAGEMENT of IRRIGATION NETWORKS, INCLUDES the NECESSARY DSS to ACHIEVE the GOALS

From Scientific Production to Technology Transfer, user friendly environment 2016

1997 - 2014

Languages:
- Spanish
- English
- French
- Portuguese
GESTAR HOME PAGE:

+ 6,000 Registered Users
+ 40 countries
DESIGN
EXECUTION
REHABILITATION
AUDIT,...
MANAGEMENT
Deal with..
Multiple tools for collective distribution network (plus on plot network: sprinkle and drip irrigation).
Savings ...

20% infrastructure cost

20% water use

Up to 35% energy cost
GESTAR 2014 MAIN MODULES STRUCTURE

- Data bases
- GRAPHICAL-INTERACTIVE USER INTERFACE
- Communication
- (2007) Pumping Station opt Design and Regulation
- (2011) On plot design and simulation
- (1999) Network optimum sizing (on demand or rotation) (gravity or pumping)
- (1997) Network general hydraulics and energy simulation
- (2013) Optimum scheduling for minimum energy consume
- User manual 700 pp

www.gestarcad.com
- 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,
• 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)
\[ p^k_{(x,y)} = \begin{cases} \frac{\tau_{(x,y)}}{\sum_{k \in \text{allowed}(x)} \tau_{(x,k)}} & \text{si } j \in \text{allowed}(x) \\ 0 & \text{si } j \notin \text{allowed}(x) \end{cases} \]

\[ \tau_{(x,y)}^0 = \begin{cases} 1 & \text{si } y \in \text{allowed}(x) \\ 0 & \text{si } y \notin \text{allowed}(x) \end{cases} \]

\[ \tau_{(x,y)}^{i+1} = (1 - \rho) \cdot \tau_{(x,y)}^i + \Delta \tau_{(x,y)}^{\text{rank}} + \Delta \tau_{(x,y)}^{\text{rand}} \]

\[ \Delta \tau_{(x,y)}^{\text{rank}} = \sum_k \Delta \tau_{(x,y)}^k \]

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

(Dorigo et al., 2006)
LOCAL OPTIMIZATION: HILL CLIMBING

(Hayakawa et al., 2011)
THE RESULTS...
The individual irrigation necessities (input) are organized to get the minimum cost (satisfying pressure and others requirements).

TeleGESTAR SCHEDULLING OPTIMIZATION

Pumping Station flow rate after optimized scheduling for 24 h

10 minutes CPU time
TeleGESTAR SCHEDULLING OPTIMIZATION

Pumping Station Flow rate after optimized scheduling for 1 week

120 minutes CPU time

PRESSURE DEFICIT (TRIAL-ERROR SCHEDULLING)

PRESSURE DEFICIT (OPTIMIZED SCHEDULLING)

Simulación de la programación optimizada TELEGESTAR
Simulación de la programación ejecutada
Violada (Almudévar) WUA (Spain)

- Irrigated Surface: 1,335 ha
- Design max flow rate: 2.1 m³/s

Pumping station: GESTAR compact modeling

(Paño et al., 2012)
Case Study A) Laviolada Network

Optimized daily cost: 1.410 €

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 €

<table>
<thead>
<tr>
<th>Month</th>
<th>Cost savings (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>2,464</td>
</tr>
<tr>
<td>June 1st Qt</td>
<td>792</td>
</tr>
<tr>
<td>June 2nd Qt</td>
<td>4,510</td>
</tr>
<tr>
<td>July</td>
<td>9,020</td>
</tr>
<tr>
<td>September</td>
<td>2,574</td>
</tr>
<tr>
<td>TOTAL (22%)</td>
<td>19,360</td>
</tr>
</tbody>
</table>

TOTAL SAVING: 74,000 € year (32%)
Callén WUA (Spain)

- Irrigated Surface 698 ha
- Design max flow rate 0.820 m³/s

Pumping station: GESTAR compact modeling

(Paño et al., 2012)
• 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)
<table>
<thead>
<tr>
<th>Name of the network with DPS</th>
<th>WUA</th>
<th>Area (ha) (n.° of hydrants)</th>
<th>Nominal pressure on demand (m)</th>
<th>Total energy costs on demand (€/year)</th>
<th>% Saving achieved using PRORIEGO</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAVIOLADA (Almudevar)</td>
<td>1,335 (106)</td>
<td>66</td>
<td></td>
<td>231,000</td>
<td>32%</td>
</tr>
<tr>
<td>NETWORK 3 (Mequinenza)</td>
<td>1,000 (101)</td>
<td>65</td>
<td></td>
<td>88,000*</td>
<td>16%</td>
</tr>
<tr>
<td>NETWORK A and B (Callén)</td>
<td>1,135 (89)</td>
<td>70 -44.5 50 -25</td>
<td></td>
<td>216,000</td>
<td>18%</td>
</tr>
<tr>
<td>PHASE II (Molinar)</td>
<td>3,644 (273)</td>
<td>68 -48</td>
<td></td>
<td>963,000</td>
<td>16%-20% (Estimated)</td>
</tr>
</tbody>
</table>
• 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.
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
- **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**).