Potential Energy Recovery using MHP in Irrigation Networks: Case studies in Southern Spain

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REDAWN (Reducing Energy Dependency in Atlantic Area Water Networks)

- **Atlantic Area**
- **Main Partners**

[Map of the Atlantic area showing regions like Madeira, Açores, and Islas Canarias.]

[Logos of partners including Trinity College Dublin, TÉCNICO LÍSBOA, wat:t, hidr@power, SMPGA, FAEN, and Interreg.]
Potential energy recovery assessment in Irrigation Networks using MHP

• **Summary**
  1. Research background & motivation
  2. Methodology
     1. Hydraulic simulation ➔ Identification of excess pressure areas ➔ $H_d$
     2. Statistical Analysis
        1. Forecasting irrigation requirements ➔ Monthly irrigation time
        2. Clément formula ➔ Open hydrant probability
        3. On-demand simulations ➔ Monthly average flows
     3. Power calculation
  3. Energy recovery assessment
     1. Monthly energy calculation
        1. Monthly averages ➔ Different efficiency
  4. Geographical analysis
     1. Geodatabase generation
     2. Energy gradient mapping ➔ Interpolation
Reducing Energy Dependency in Atlantic area Water Networks

**Background & motivations**

- **Causes:**
  - Water Industry is the 4th most energy intensive sector and contributes heavily to CO₂ emissions.
  - Globally, 2-3% of energy usage is reported to be associated with the production, distribution and treatment of water.
  - Up to 80% of the cost of water for producers and consumers is associated with the energy required to extract, treat, and distribute water.
  - Agriculture activity is the most intensive water consumer, reaching up to 95% of the water use in some countries.
  - Improvement in water efficiency → Increasing of energy consumption in irrigation networks.
  - MOM Costs in irrigation networks have increased in around 500%.

- **Solutions:**
  - Micro Hydropower technology for energy recovery in water distribution networks.
  - Potential available in irrigation networks
    - Pérez Sánchez: 188 MWh in 290 ha
    - García Morillo: 310 MWh in 400 ha
2.1. Hydraulic Simulation

- Previous work
  - Base demand calculation
  - Elevation extraction (GIS)
  - Hydraulic model definition

- Excess Pressure Areas location

Boundary condition:
- Design head: 100% Simultaneity

Example:
- \( \Delta H_1 = 19.2 \) m
- \( \Delta H_2 = 13.9 \) m
- \( \Delta H_3 = 19.7 \) m
- \( \Delta H_4 = 18.0 \) m
- \( \Delta H_5 = 14.3 \) m
2.2 Statistical Analysis

I. **Water requirements forecasting**

- Crop distribution
- Calculations → FAO Paper 56

![Chart showing crop distribution with Citrus 56%, Maize 32%, Cotton 9%, and Sunflower 3%]

**Example case**

![Chart showing rainfall and ETo over a year]

**Irrigation requirements**

![Chart showing irrigation requirements over a year]
### 2.2. Statistical Analysis

#### II. Clément methodology

- Monthly irrigation requirements
  \[ \mathbf{IN}_{ij} \text{ (l ha}^{-1}\text{ month}^{-1}) \]
  
  Every hydrant will have its own value depending on the percentage of crops assigned.

- Open hydrant probability

1) Dotation assigned, \( q_{i_{\text{max}}} \)
2) Monthly irrigation time required
   \[ t'_{ij} = \frac{1}{3600} \frac{\mathbf{IN}_{ij}}{q_{i_{\text{max}}}} \]
3) Monthly water availability
   \[ T'_{ij} = \text{hours \( n_j \)} \]
4) Monthly open hydrant probability
   \[ p_{ij} = \frac{t'_{ij}}{T'_{ij}} \]

\[
\begin{align*}
\begin{pmatrix}
q_{1_{\text{max}}} \\
q_{i_{\text{max}}} \\
q_{n_{\text{max}}}
\end{pmatrix}
&\rightarrow
\begin{pmatrix}
t'_{1_{1},1} & t'_{1_{1},j} & t'_{1_{1},12} \\
t'_{1_{2},1} & \cdots & t'_{1_{2},12} \\
t'_{n_{1},1} & t'_{n_{1},j} & t'_{n_{1},12} \\
\cdots & \cdots & \cdots \\
T'_{1_{1},1} & T'_{1_{1},j} & T'_{1_{1},12} \\
T'_{1_{2},1} & \cdots & T'_{1_{2},12} \\
T'_{n_{1},1} & T'_{n_{1},j} & T'_{n_{1},12} \\
\cdots & \cdots & \cdots \\
p_{1_{1},1} & p_{1_{1},j} & p_{1_{1},12} \\
p_{1_{2},1} & \cdots & p_{1_{2},12} \\
p_{n_{1},1} & p_{n_{1},j} & p_{n_{1},12} \\
\cdots & \cdots & \cdots
\end{pmatrix}
\end{align*}
\]
2.3. On-demand simulations

3. On-demand simulations: Bernoulli experiment
   - Repeated independent trials → Bernoulli Trials
     - Generation of 15,000 monthly vectors with random values between 0 and 1, comparing them with the open hydrant probability matrix

   • Simulations results:
     1) 12 Binomial Distributions
     2) Average flow calculation
        Knowing that:
        • Higher probability of open hydrant in summer
        • First and last months of irrigation season lower requirements
        • BEP flow = 0.7 Qd (Novara el al., 2018)

        \[ Q_{mean,j} = \frac{1}{n} \sum_{x=1}^{n} x_i \]

Result

\[ S: \text{Success} \]
\[ F: \text{Failure} \]

\[ \text{If } R_{ij} > p_{ij} \rightarrow X = 0 (F) \]
\[ \text{If } R_{ij} \leq p_{ij} \rightarrow X = 1 (S) \]

2.4. Power calculation

Example EPP 1: Mean flows
- May: 75 l/s
- June: 171 l/s
- July: 190 l/s
- August: 129 l/s
- September: 39 l/s

• May: 41%  
• June: 93%  
• July: 103%  
• August: 70%  
• September: 21%

\[ P_t = \frac{Q_{Aug}}{0.7} H \gamma \eta_{max} = Q_d H \gamma \eta_{max} = 17.3 \text{ kW} \]
3. Energy recovery assessment

1. Monthly energy recovered for mean flows

1.1. BEP Flow: \( \eta_{max} = 0.5 \)
\[ Q = 0.7 Q_d \]

\[ E_{BEP} = P t'_{BEPj} \]

1.2. Lower efficiencies: \( \eta_j < \eta_{max} < 0.5 \)
\[ \forall Q \neq Q_d \]

\[ E_{var j} = P \sum_{j=1}^{n} \eta_{REL_j} t'_{j} \]

2. Results

- Networks analysed: 12
- Potential points: 43
- Potential: > 1 MW
- Energy: > 1 GWh
4. Geographical Analysis

1. Geodatabase generation

\[
\begin{align*}
P_{1,1} & \quad P_{1,2} & \quad \cdots & \quad P_{1,j} & \quad \cdots & \quad P_{1,11} & \quad P_{1,12} \\
P_{2,1} & \quad P_{2,2} & \quad \cdots & \quad P_{2,j} & \quad \cdots & \quad P_{2,11} & \quad P_{2,12} \\
\vdots & \quad \vdots & \quad \ddots & \quad \vdots & \quad \ddots & \quad \vdots & \quad \vdots \\
P_{n,1} & \quad P_{n,2} & \quad \cdots & \quad P_{n,j} & \quad \cdots & \quad P_{n,11} & \quad P_{n,12} \\
\end{align*}
\]

2. Gradient Map

- Power

- Energy

![Map showing geographical analysis](image-url)
5. Conclusions and future works

• This first assessment has been used to identify the potential of energy recovery in Irrigation Networks.

• Deeper analysis of the energy recovery.

• Development of different types of strategies for MHP installation in these infrastructures.
  • Statistical analysis of the behaviour of the network based on combinatorial analysis.
    • Optimise the pressure management.
    • Maximise energy recovery
    • Minimise risk investment

• Construction of a demo site where a diesel generator will be replaced by a PAT.

• Gather information of irrigation networks all around the AA for geodatabase generation

• Cartography of potential available in Irrigation Networks in the AA.
6. Demonstration pilot plant
Thank you very much for your attention!

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