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

REDAWN
Reducing Energy Dependency in Atlantic area Water Networks

3rd EWaS International Conference: "Insights on the Water-Energy-Food Nexus"

Miguel Crespo Chacón, *Juan Antonio Rodríguez Díaz, Jorge García Morillo, John Gallagher, Paul Coughlan, Aonghus McNabola*

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International Conference 3rd EWaS

REDAWN (Reducing Energy Dependency in Atlantic Area Water Networks)

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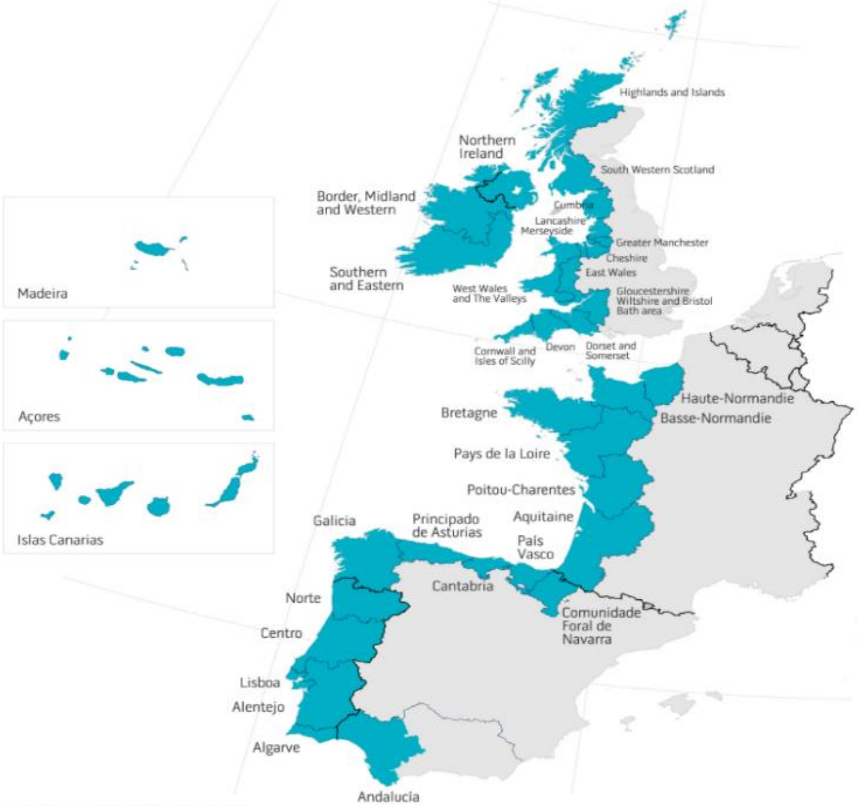
- ***Atlantic Area***



ATLANTIC AREA PROGRAMME 2014-2020

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WatEf — At the University of Bath — Supported By: Department for Environment Food & Rural Affairs
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FAEN | hidropower | SMPGA | Renova | Trinity College Dublin | WatEf — Water Efficiency Network

Interreg Atlantic Area — European Regional Development Fund — European Union

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

Potential energy recovery assessment in Irrigation Networks using MHP

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- ***Background & motivations***

  - *Causes:*
    - Water Industry is the **4th most energy intensive sector** and contributes heavily to CO_2 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

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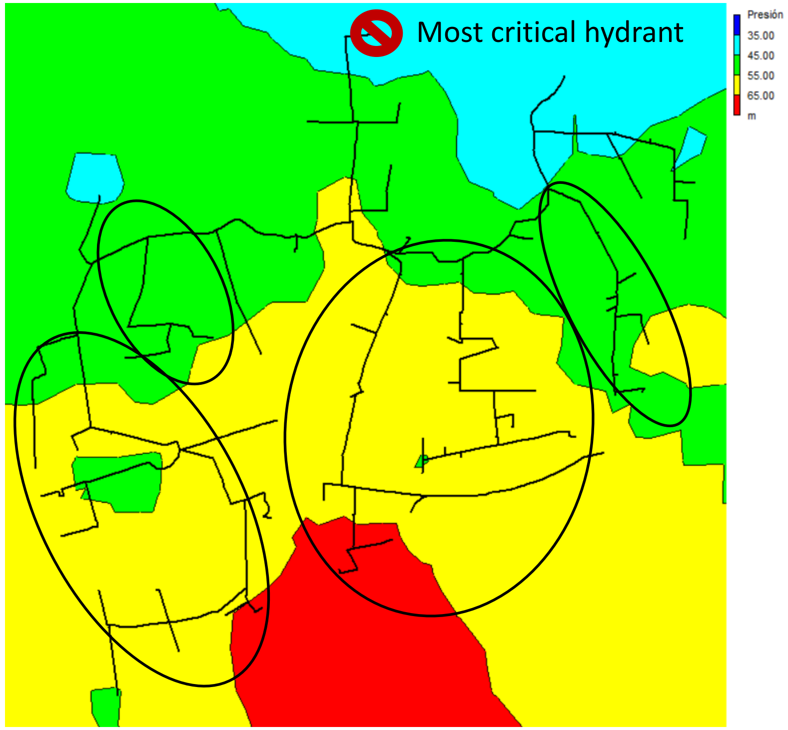
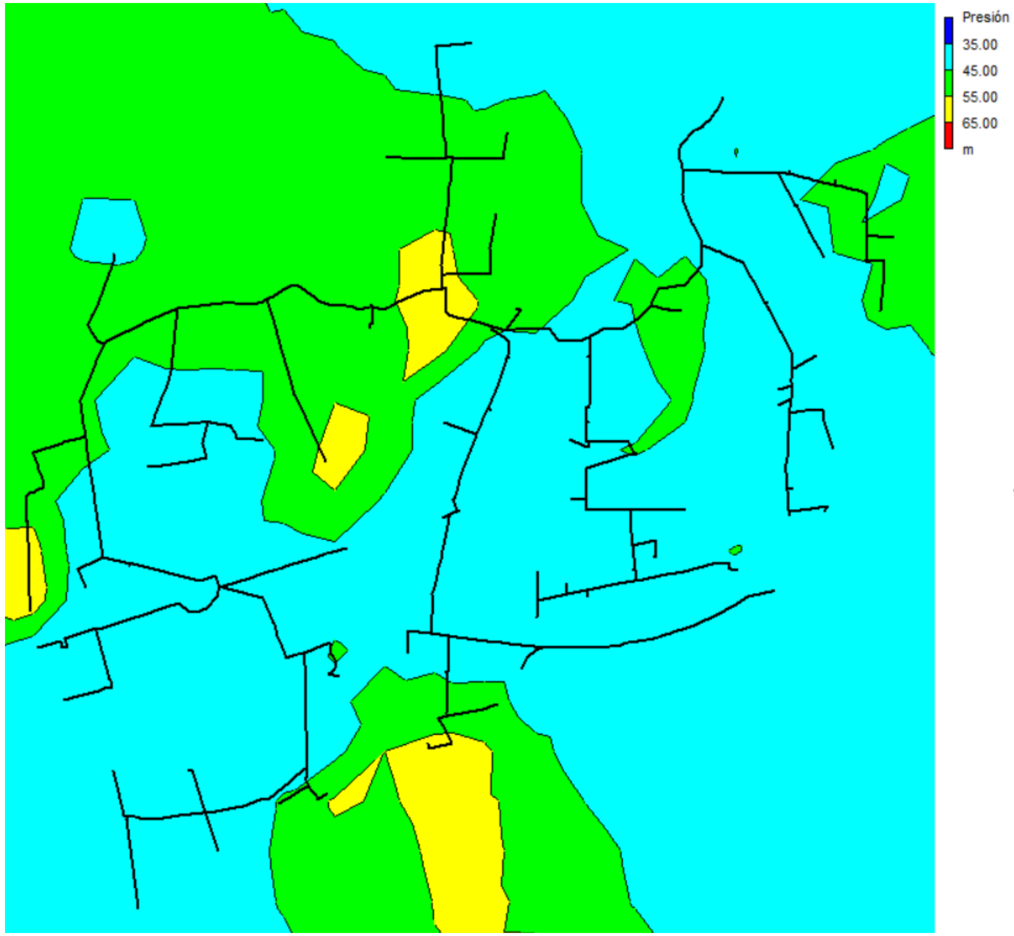
2.1. Hydraulic Simulation

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



- ***Excess Pressure Areas location***



Boundary condition:

- Design head: 100% Simultaneity

<u>Example:</u>

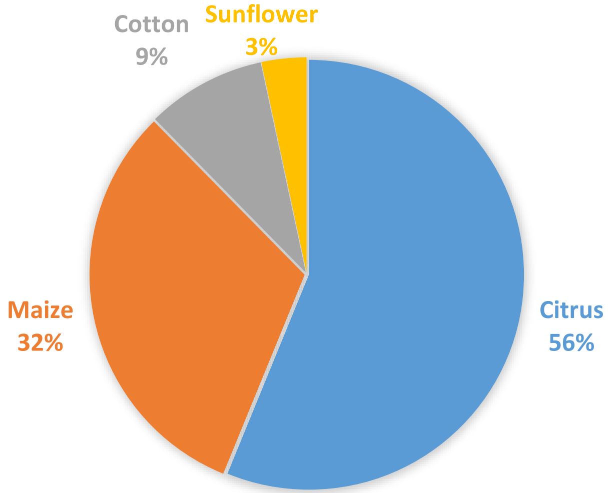
- $\Delta H_1 = 19.2$ m
- $\Delta H_2 = 13.9$ m
- $\Delta H_3 = 19.7$ m
- $\Delta H_4 = 18.0$ m
- $\Delta H_5 = 14.3$ m

2.2 Statistical Analysis

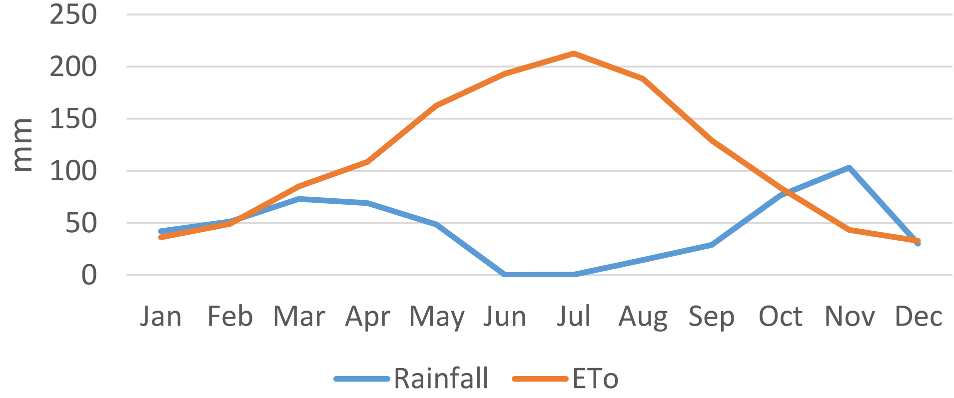
I. *Water requirements forecasting*

- Crop distribution
- Calculations → FAO Paper 56

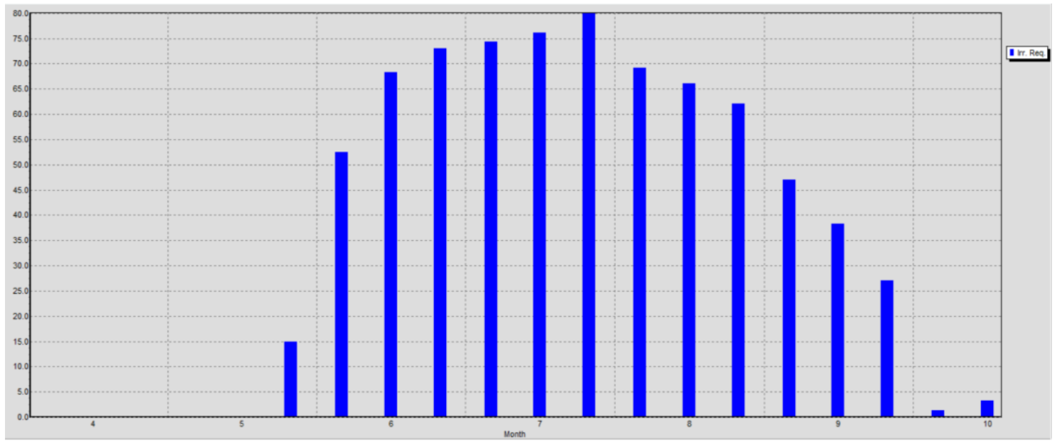
Example case



Agro-climatic parameters



Irrigation requirements



2.2. Statistical Analysis

II. Clément methodology

- Monthly irrigation requirements

$IN_{ij}\ (l\ ha^{-1} month^{-1})$

i: number of hydrant

j: month

Every hydrant will have its own value depending on the percentage of crops assigned

$$\begin{pmatrix} IN_{1,1} & \cdot & IN_{1,j} & \cdot & IN_{1,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ IN_{i,1} & \cdot & IN_{i,j} & \cdot & IN_{i,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ IN_{n,1} & \cdot & IN_{n,j} & \cdot & IN_{n,12} \end{pmatrix}$$

- Open hydrant probability

1) Dotation assigned, q_{imax}

$$\begin{pmatrix} q_{1\,max} \\ \cdot \\ q_{imax} \\ \cdot \\ q_{nmax} \end{pmatrix}$$

2) Monthly irrigation time required

$$t'_{ij} = \frac{1}{3600} \frac{IN_{ij}}{q_{imax}}$$

$$\begin{pmatrix} t'_{1,1} & \cdot & t'_{1,j} & \cdot & t'_{1,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ t'_{i,1} & \cdot & t'_{i,j} & \cdot & t'_{i,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ t'_{n,1} & \cdot & t'_{n,j} & \cdot & t'_{n,12} \end{pmatrix}$$

3) Monthly water availability

$$T'_{ij} = hours\ n_j$$

$$\begin{pmatrix} T'_{1,1} & \cdot & T'_{1,j} & \cdot & T'_{1,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ T'_{i,1} & \cdot & T'_{i,j} & \cdot & T'_{i,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ T'_{n,1} & \cdot & T'_{n,j} & \cdot & T'_{n,12} \end{pmatrix}$$

4) Monthly open hydrant probability

$$p_{ij} = \frac{t'_{ij}}{T'_{ij}}$$

$$\begin{pmatrix} p_{1,1} & \cdot & p_{1,j} & \cdot & p_{1,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ p_{i,1} & \cdot & p_{i,j} & \cdot & p_{i,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ p_{n,1} & \cdot & p_{n,j} & \cdot & p_{n,12} \end{pmatrix}$$

2.3. On-demand simulations

3. ***On-demand simulations: Bernoulli experiment***

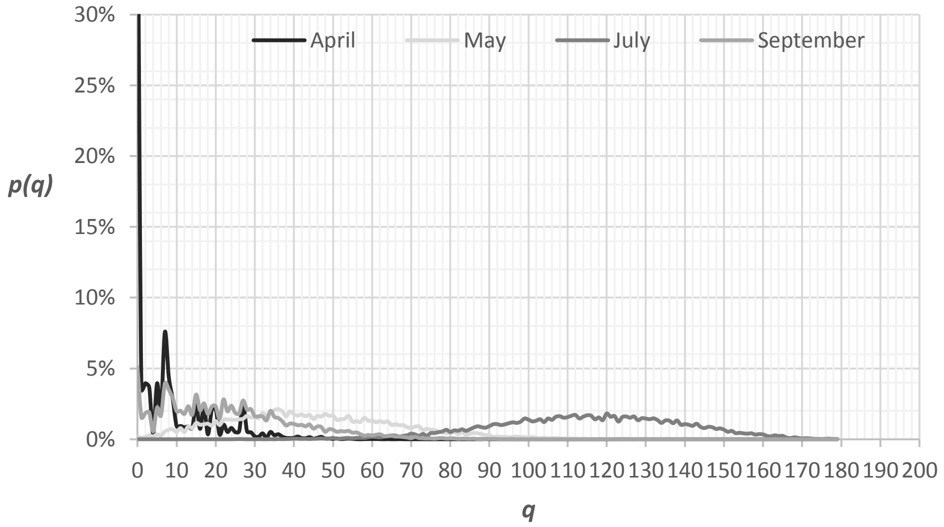
- Repeated independent trials →Bernoulli Trials → **Result**: $S: Success$, $F: Failure$

Generation of 15,000 monthly vectors with random values between 0 and 1, comparing them with the open hydrant probability matrix

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

- 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 Q_d (Novara el al., 2018)

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

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

BEP ⇒

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

$$P_1 = \frac{Q_{Aug}}{0.7} H\ \gamma\ \eta_{max} = Q_d\ H\ \gamma\ \eta_{max} = 17.3\ kW$$

3. Energy recovery assessment

1. Monthly energy recovered for mean flows

1.1. BEP Flow: $\eta_{max} = 0.5$

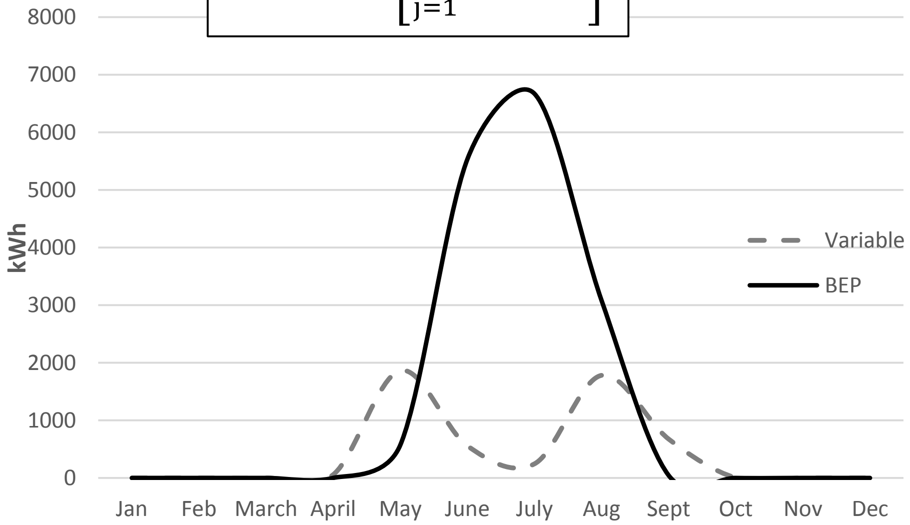
$$Q = 0.7\, Q_d$$

$$E_{BEP} = P\, t'_{BEP\,j}$$

1.2. Lower efficiencies: $\eta_j < \eta_{max} < 0.5$

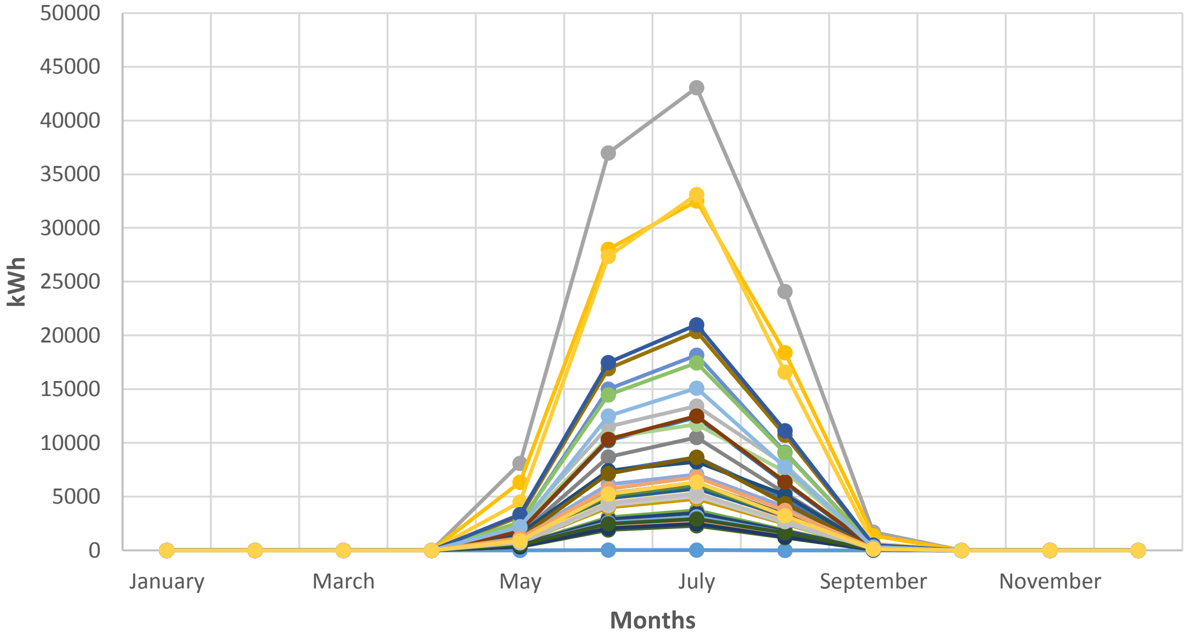
$$\forall\, Q \neq Q_d$$

$$E_{var\,j} = P\left[\sum_{j=1}^{n} \eta_{REL\,j}\, t'_j\right]$$



2. Results

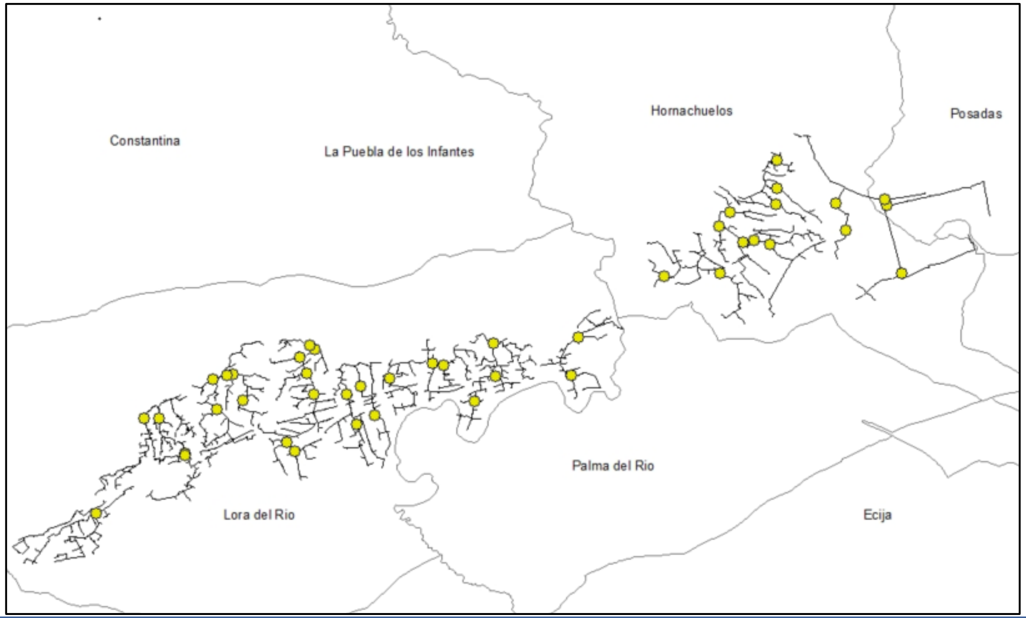
- Networks analysed: 12
- Potential points: 43
- Potential: > 1 MW
- Energy: > 1 GWh



4. Geographical Analysis

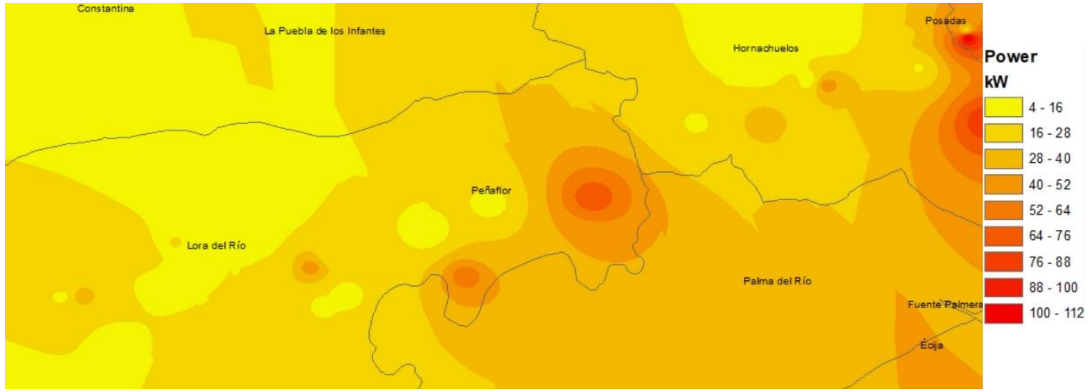
1. Geodatabase generation

$$\begin{pmatrix} P_{1,1} & P_{1,2} & \cdot & \cdot & P_{1,j} & \cdot & \cdot & P_{1,11} & P_{1,12} \\ P_{2,1} & P_{2,2} & \cdot & \cdot & P_{2,j} & \cdot & \cdot & P_{2,11} & P_{2,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ P_{i,1} & P_{i,2} & \cdot & \cdot & P_{i,j} & \cdot & \cdot & P_{i,11} & P_{i,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ P_{n,1} & P_{n,2} & \cdot & \cdot & P_{n,j} & \cdot & \cdot & P_{n,11} & P_{n,12} \end{pmatrix} \begin{pmatrix} E_{T1,1} & E_{T1,2} & \cdot & \cdot & E_{T1,j} & \cdot & \cdot & E_{T1,11} & E_{T1,12} \\ E_{T2,1} & E_{T2,2} & \cdot & \cdot & E_{T2,j} & \cdot & \cdot & E_{T2,11} & E_{T2,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ E_{Ti,1} & E_{Ti,2} & \cdot & \cdot & E_{Ti,j} & \cdot & \cdot & E_{Ti,11} & E_{Ti,12} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ E_{Tn,1} & E_{Tn,2} & \cdot & \cdot & E_{Tn,j} & \cdot & \cdot & E_{Tn,11} & E_{Tn,12} \end{pmatrix}$$

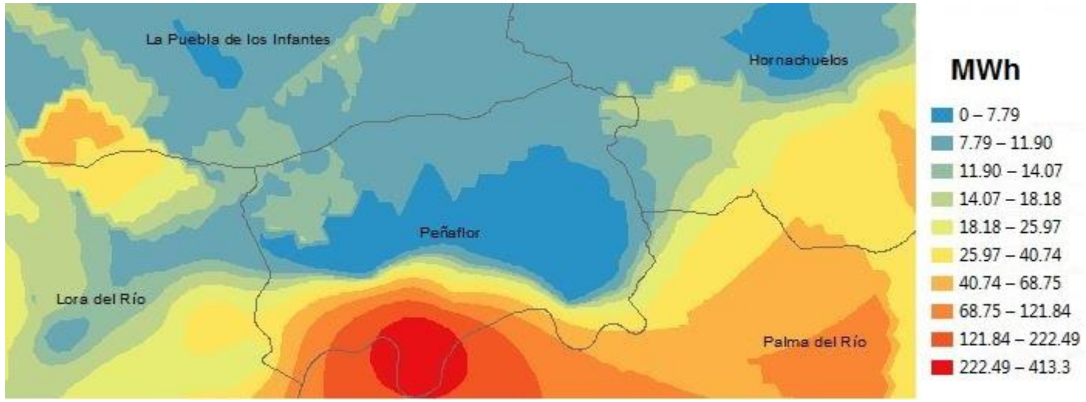


2. Gradient Map

- Power



- Energy



5. Conclusions and future works

- This first assessment has been used to identified 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

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Thank you very much for your attention!

Miguel Crespo Chacón

crespocm@tcd.ie

PhD Candidate – Trinity College Dublin

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CONTACT US:

REDAWN Lead Partner:

Terry WAUGH

Phone: +442890727763

Email: comms@redawn.eu

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