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Mathematical models applied to irrigation networks

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Research topics:

FLUIDS, WATER AND ENVIRONMENTAL FIELDS
SIMULATION MODELS
OPTIMIZATION MODELS
HEURISTIC AND META-HEURISTIC TECHNIQUES

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RUC-APS

WATER IN
AGRICULTURE PRODUCTION SYSTEMS

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The Mediterranean area of Spain and southern Italy have a similar problem…

- DRY WEATHER
- LACK OF WATER

It has a lot of interest…

- Optimization of irrigation networks (to save water).
- Optimization of pumping in irrigation networks (to save water and energy).

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IRRIFRAME

ALSIA participates in the project **IRRIFRAME**:

IT Irrigation Advisory Services for Farm Water Management

- Water balance model aimed at crop irrigation management at a field scale and therefore the processes and calculation simulated by the model reflect such aim.
- The model has a structure that is concerned with the soil-plant-atmosphere continuum.
- It includes the soil, with its water balance; the plant, with its development, growth; and the atmosphere, with its thermal regime, rainfall and evaporative demand.

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Previous works

- Different metaheuristic techniques…
  - Genetic Algorithms (GA)
  - Particle Swarm Optimization (PSO)
  - Harmony Search (HS)
- Applied to different networks…
  - Water distribution networks
  - Sewer systems

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Metaheuristic techniques

- **Genetic Algorithms (GA)**

- A genetic algorithm is a search heuristic that is inspired by Charles Darwin's theory of natural evolution. This algorithm reflects the process of natural selection where the fittest individuals are selected for reproduction in order to produce offspring of the next generation.

- Genetic Algorithms are systematic methods for the resolution of searching and optimization problems that apply the same methods of the biological evolution. A chromosome represents a solution to the problem. This solution is constituted by a serial of genes that defines a unique solution of the optimization process. The method tries the evolution of a random population through a parallelism similar to the laws of the natural selection. This is obtained through three basic processes: reproduction, crossover and mutation.

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Metaheuristic techniques

- **Particle Swarm Optimization (PSO)**

- Particle Swarm Optimization is an evolutionary computation technique that was first developed by Kennedy and Eberhart in 1995.

- The idea is to simulate the social behaviour of a flock of birds in their endeavour to reach, when flying through the field (search space), their unknown destination (fitness function), e.g. the location of food resources. In PSO, each problem solution is a bird of the flock and is referred to as a particle. In this algorithm, birds evolve in terms of their individual and social behaviour and mutually coordinate their movement towards their destination.

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Metaheuristic techniques

- **Harmony Search (HS)**

- Harmony Search is a phenomenon-mimicking metaheuristic introduced in 2001 by Zong Woo Geem, Joong Hoon Kim, and G. V. Loganathan.

- Harmony search is inspired by the improvisation process of music players. HS was conceptualized using musical process of searching for a perfect state of harmony. This harmony in music is analogous to find the optimality in an optimization process. In music improvisation process musician plays different notes of different musical instrument and find the best combination of frequency for best tune. Similarly in HS method also best combination of available solutions is selected and objective function is optimized.

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Some research papers

- **"Design of water distribution networks using a pseudo-genetic algorithm and sensitivity of genetic operators"**

  Vicente S. Fuertes-Miquel *et al*.

  Water Resources Management (ISSN 0920-4741)

  Volume 27, Issue 12, 2013, pp 4149-4162

  - Design of water distribution networks.
  - A modified pseudo-genetic algorithm (PGA) is used.
  - The coding of chromosomes is performed using integer coding (in a traditional GA, binary coding is utilized).
  - Through statistical analysis of the obtained solutions, more suitable values of mutation and crossover probabilities were discovered.
  - A proper combination of population and crossover and mutation probabilities leads to a high probability that good solutions will be obtained.

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Some research papers

- **"Application of the harmony search algorithm to water distribution networks design"**

  Vicente S. Fuertes-Miquel *et al*.

  IWEH09. International Workshop on Environmental Hydraulics: Theoretical, Experimental &Computational Solutions (ISBN 978-84-89487-28-4)

  October 2009

  - Design of water distribution networks.
  - The Harmony Search (HS), a heuristic technique of optimization, is used.
  - HS is applied to a network studied in the literature (network of Hanoi).
  - A statistical analysis of the obtained solutions is made.
  - The values of the harmony parameters more suitable are obtained.
  - Analysis of the influence of harmony parameters in the velocity of the algorithm.

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Some research papers

- **"Comparison of evolutionary algorithms for design of sewer systems"**
  Vicente S. Fuertes-Miquel *et al*.
  IWEH09. International Workshop on Environmental Hydraulics: Theoretical, Experimental &Computational Solutions (ISBN 978-84-89487-28-4)
  October 2009

  - Design of sewer systems.
  - Evolutionary algorithms are used.
  - Comparison between Genetic Algorithms (GA) and Particle Swarm Optimization (PSO).
  - Advantages and disadvantages of applying each of these methods.

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Some research papers

- **“Design optimization of wastewater collection networks by PSO”**
  Vicente S. Fuertes-Miquel *et al*.
  Computers & Mathematics with Applications (ISSN 0898-1221)
  Volume 56, Issue 3, 2008, pp 777-784

  – Design of wastewater collection networks.
  – Particle Swarm Optimization (PSO) is used.
  – This evolutionary technique is adapted for dealing both with continuous and discrete variables as required by this problem.
  – Comparison between Particle Swarm Optimization (PSO) and dynamic programming.

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Some research papers

- **"Study of sensitivity of the parameters of a genetic algorithm for design of water distribution networks"**

  Vicente S. Fuertes-Miquel *et al*.

  Journal of Urban and Environmental Engineering (ISSN 1982-3932)

  Volume 1, Issue 2, 2007, pp 61-69

  - Design of water distribution networks.
  - A modified pseudo-genetic algorithm (PGA) is used.
  - The codification of the chromosomes is made of numerical form instead of the binary codification.
  - PGA is applied to a network studied in the literature (network of Hanoi).
  - A statistical analysis of the obtained solutions is made.
  - This analysis allows verifying the values of mutation and crossing probability more suitable for the proposed method.
  - The influence of the population size is analyzed in the final solutions on the network of Hanoi.

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We have experience in mathematical models for design and optimization of **water supply networks and sewer systems**…

…and this experience could be applied to **irrigation networks**.

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Bibliographic review (irrigation networks)

- **“Plant-Based Methods for Irrigation Scheduling of Woody Crops”**
  José Enrique Fernández
  Horticulturae (MDPI)
  Volume 3, Issue 2, June 2017

  – The increasing world population and expected climate scenarios impel the agricultural sector towards a more efficient use of water.
  – The relevance of precision irrigation for a rational use of water in agriculture, and methods related to the use of plant-based measurements for both the assessment of plant water stress and irrigation scheduling, are considered.
  – These include non-automated, conventional methods based on manual records of plant water status and gas exchange, and automated methods where the related variable is recorded continuously and automatically.

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Bibliographic review (irrigation networks)

- **“Developing an Optimal Design Model of Furrow Irrigation Based on the Minimum Cost and Maximum Irrigation Efficiency”**

  Kaveh Ostad-Ali-Askari, Mohammad Shayannezhad

  International Bulletin of Water Resources & Development

  Volume 3, Issue 2, Autumn 2015, Pages 18-23

  - The main objective of the furrow irrigation is appropriate selection of planning and managerial variables.
  - These variables are: the furrow length, flow rate to the furrow and cut-off time. These variables are computed through optimization based on minimizing the total irrigation cost and maximizing the application efficiency of irrigation.
  - The objective function has been formed based on costs of the water, worker and head ditch and furrow digging.

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Bibliographic review (irrigation networks)

- **“Mathematical model for robust control of an irrigation main canal pool”**

  R. Rivas-Perez, V. Feliu-Batlle, F.J. Castillo-Garcia, A. Linares-Saez

  Environmental Modelling & Software (Elsevier)

  Volume 51, January 2014, Pages 207-220

  - The formulation and development of a mathematical model for high-performance robust controller design techniques, based on a complete identification for control procedure, of an irrigation main canal pool, which is characterized by the exhibition of large variations in its dynamic parameters when the discharge regime changes in the operating range [Q_{min}, Q_{max}].
  - This kind of models facilitates the design of robust controllers, which allow improving the operability of irrigation main canal pools and also substantially reduce water losses.

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Bibliographic review (irrigation networks)

- **“Efficiency of water application of irrigation systems based on microsprinkling in banana plantations”**

  A.J.P. Silva, E.F. Coelho, J.H. Miranda

  Scientia Agricola

  Volume 70, Issue 3, May-June 2013, Pages 139-146

  - Further food production may be limited by the reduced availability of water resources.
  - Since irrigated agriculture is the productive sector that presents a higher demand of water, this sector has been under intense pressure in order to ensure food production with improved efficiency of water use.
  - This study aimed to determine water application efficiency of banana trees using microsprinkler irrigation systems.

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Bibliographic review (irrigation networks)

- **“Optimal Operation Scheduling of Irrigation Canals Using Genetic Algorithm”**

  Y.P. Mathur, Gunwant Sharma, A.W. Pawde

  International Journal of Recent Trends in Engineering

  Volume 1, Issue 6, May 2009

  - Canal scheduling is an important activity that significantly influences production of crops compared to other aspects of agriculture.
  - Irrigation canal scheduling is the activity of preparing an optimal schedule of outlets on supply canal as per need of user, subject to canal system constraints.
  - In this paper, the problem of optimal operational scheduling of irrigation canal with provision to open some outlet at specific time slot as per request of user using Genetic Algorithm is presented.

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Bibliographic review (irrigation networks)

- **“Optimal reservoir operation for irrigation of multiple crops using elitist-mutated particle swarm optimization”**

  M. Janga Reddy, D. Nagesh Kumar

  Hydrological Sciences Journal des Sciences Hydrologiques

  Volume 52, Issue 4, August 2007, Pages 686-701

  – To achieve social and economic sustainability in arid and semi-arid areas under water scarce situations, it is vital to promote efficient use of water through improved management of water resources.
  – This paper presents a particle swarm optimization based solution to a detailed operational model for short-term reservoir operation for irrigation of multiple crops.
  – The model integrates the dynamics associated with the water released from a reservoir to the actual water utilized by crops at farm level.

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Bibliographic review (irrigation networks)

- **“Reservoir operation in assigning optimal multi-crop irrigation áreas”**
  Mahdi Moradi-Jalal, Omid Bozorg Haddad, Bryan W. Karney, M.A. Mariño
  Agricultural Water Management (Elsevier)
  Volume 90, Issues 1–2, May 2007, Pages 149-159

  – A mathematical model is developed for the optimal multi-crop irrigation areas associated with reservoir operation policies in a reservoir-irrigation system.
  – The objective is to maximize the annual benefit of the system by supplying irrigation water for a proposed multi-crop pattern over the planning period.
  – Herein, three sets of constraints are applied to the system: achieving monthly balance in the reservoir, covering water demand for crop production, considering evaporation loss from the reservoir, and governing equations for reservoir release and operations.

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Bibliographic review (pumping in irrigation networks)

- **“Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies”**

  S.S. Chandel, M. Nagaraju Naik, Rahul Chandel

  Renewable and Sustainable Energy Reviews (Elsevier)

  Volume 49, September 2015, Pages 1084-1099

  - The deficit in electricity and high diesel costs affects the pumping requirements of community water supplies and irrigation; so using solar energy for water pumping is a promising alternative to conventional electricity and diesel based pumping systems.
  - The main objective of the study is to present a comprehensive literature review of solar pumping technology, evaluate the economic viability, identify research gaps and impediments in the widespread propagation of solar water pumping systems and technology.

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Bibliographic review (pumping in irrigation networks)

- **“Optimal design and operation of irrigation pumping stations using mathematical programming and Genetic Algorithm (GA)”**

  Mahdi Moradi-Jalal, Bryan W. Karney

  Journal of Hydraulic Research (Taylor & Francis)

  Volume 46, Issue 2, April 2008, Pages 237-246

  – For many water authorities worldwide, one of the greatest potential areas for energy savings is in pump selection and in the related effective scheduling of daily pump operations.

  – The optimal control and operation of an irrigation pumping station is achieved here by first solving the nonlinear governing model using Lagrange Multipliers (LM) and then through Genetic Algorithm (GA) approach. Computation in both methods is driven by an objective function that includes operating and capital costs subject to various performance and hydraulic constraints.

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Bibliographic review (pumping in irrigation networks)

- **“Optimal design and operation of irrigation pumping systems using particle swarm optimization algorithm”**

  M.H. Afshar, R. Rajabpour

  International Journal of Civil Engineerng

  Volume 5, Issue 4, December 2007

  – This paper presents a relatively new management model for the optimal design and operation of irrigation water pumping systems. The model makes use of the newly introduced particle swarm optimization algorithm.
  – The proposed model is applied to the design and operation of a real-world irrigation pumping system and the results are presented and compared with those of a genetic algorithm.

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Bibliographic review (pumping in irrigation networks)

- **“A model for optimal sizing of photovoltaic irrigation water pumping systems”**

  Zvonimir Glasnovic, Jure Margeta

  Solar Energy (Elsevier)

  Volume 81, Issue 7, July 2007, Pages 904-916

  – This work approaches the subject problem systematically, meaning that all relevant system elements and their characteristics have been analyzed: PV water pumping system, local climate, boreholes, soil, crops and method of irrigation.

  – The result of such approach is the new mathematical hybrid simulation optimization model for optimal sizing of PV irrigation water pumping systems, that uses dynamic programming for optimizing.

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Bibliographic review (pumping in irrigation networks)

- **“Optimal Design and Operation of Irrigation Pumping Stations”**
  Mahdi Moradi-Jalal, Miguel A. Mariño, Abbas Afshar
  Journal of Irrigation and Drainage Engineering (ASCE)
  Volume 129, Issue 3, June 2003

  – A methodology based on solving a large-scale nonlinear programming problem is presented for the optimal design and operation of pumping stations.
  – Optimum design and operation refers to the selection of pump type, capacity, and number of units as well as scheduling the operation of irrigation pumps that results in minimum design and operating cost for a given set of demand curves.

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Bibliographic review
(energy recovering in irrigation networks)

- **"Modeling Irrigation Networks for the Quantification of Potential Energy Recovering: A Case Study"**

  M. Pérez-Sánchez, F.J. Sánchez-Romero, H.M. Ramos, P.A. López

  Water (MDPI)

  Volume 8, Issue 6, June 2016

  – Water irrigation systems are required to provide adequate pressure levels in any sort of network. Quite frequently, this requirement is achieved by using pressure reducing valves (PRVs). Nevertheless, the possibility of using hydraulic machines to recover energy instead of PRVs could reduce the energy footprint of the whole system.

  – In this research, a new methodology is proposed to help water managers quantify the potential energy recovering of an irrigation water network with adequate conditions of topographies distribution.

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Bibliographic review
(energy recovering in irrigation networks)

- **“Energy Recovery in Existing Water Networks: Towards Greater Sustainability”**

  M. Pérez-Sánchez, F.J. Sánchez-Romero, H.M. Ramos, P.A. López

  Water (MDPI)

  Volume 9, Issue 2, February 2017

  – Analyses of possible synergies between energy recovery and water management are essential for achieving sustainable improvements in the performance of irrigation water networks.
  – Improving the energy efficiency of water systems by hydraulic energy recovery is becoming an inevitable trend for energy conservation, emissions reduction, and the increase of profit margins as well as for environmental requirements.

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Bibliographic review (energy recovering in irrigation networks)

- **"Optimization Strategy for Improving the Energy Efficiency of Irrigation Systems by Micro Hydropower: Practical Application"**

  M. Pérez-Sánchez, F.J. Sánchez-Romero, H.M. Ramos, P.A. López

  Water (MDPI)

  Volume 9, Issue 10, October 2017

  - Nowadays, the use of micro hydropower in water systems is being analysed to improve the overall energy efficiency. In this line, the present research is focused on the proposal and development of a novel optimization strategy for increasing the energy efficiency in pressurized irrigation networks by energy recovering.
  - The recovered energy is maximized considering different objective functions. The proposal of this strategy shows the real possibility of installing micro hydropower machines to improve the water–energy nexus management in pressurized systems.

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