# Optimizing Turn Assignments in Tree-Structured Irrigation Networks Using Computational Techniques

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## ABSTRACT

The increasing scarcity of available water resources for agriculture has intensified the need for more advanced and effective methodologies for irrigation scheduling. While most of the simpler structural solutions have already been implemented, there is a growing demand for decision support systems that can manage the complexities of water resource allocation. This paper presents the development of WISCHE (Water Irrigation Scheduling), a comprehensive decision support system specifically designed to optimize irrigation scheduling in an arborescent network. The system has been successfully implemented in the "La Comunidad de Regantes, Riegos de Levante, Canal 2nd" irrigation area located in eastern Spain. This region covers 2188 hectares and consists of 2831 hydrants distributed across 20 sectors. Irrigation scheduling is required on a daily basis with five distinct time periods. The input data includes network topology, periodic demands, and historical consumption records, while the output is an optimized schedule of hydrant usage. The turn assignments generated by WISCHE must satisfy two types of constraints: the physical limitations of the irrigation network (including water flow and pressure) and the priority of demand based on previous consumption and requests. To address the physical constraints, the system employs a mixed 0–1 separable quadratic program. Furthermore, the system prioritizes hydrants based on their historical usage, with those previously underserved being given higher priority in future schedules. WISCHE has demonstrated success in balancing the needs of the network with equitable water distribution among users.

**Keywords:** water resource scheduling, agriculture irrigation, decision support system, mixed 0–1 quadratic programming, network optimization.

## I. INTRODUCTION

Southern Spain is currently enduring a prolonged period of severe drought, which has placed increasing pressure on the region's water resources. In response to these circumstances and the broader impact of climate change, the demand for the effective management of water resources has grown significantly. According to research by Gomez-Limon and Martinez [1], the rational scheduling and planning of water resources are essential for mitigating the consequences of water scarcity. It is important to differentiate between long-term water resource planning and short-term water distribution scheduling. While water resource planning is generally a long-term endeavor, daily water distribution scheduling requires a more immediate and flexible approach. In terms of planning, the literature identifies two different environments: deterministic, as discussed by Andreu et al. [2], and stochastic, which accounts for uncertainty in key factors such as water inflow and demand, as presented by Escudero [3]. This paper focuses on the latter—using stochastic models to optimize daily water distribution.

"La Comunidad General de Regantes, Riegos de Levante, Canal 2nd," located in Elche, Spain, is actively implementing a modernization project to improve its irrigation infrastructure, driven by the need to optimize water usage. This project includes the development of a telemetry and monitoring system to improve irrigation management across the network. Given the structure of the irrigation network and the necessity for daily irrigation, a system is needed to efficiently assign irrigation turns for hydrants, taking into account both network limitations and the demands of farmers based on previous water usage.

This paper is structured as follows: Section two presents a detailed problem definition along with the primary objectives of this research. Section three introduces the functionality and modules of the WISCHE decision support system, including the mathematical models and algorithms utilized for turn assignment. Section four illustrates the computational results of the system's application in the test environment, following a step-by-step example of the scheduling process. Section five offers conclusions drawn from the research and outlines future research directions.

## II. PROBLEM DEFINITION AND OBJECTIVES

The irrigation network under study consists of 2405 hydrants covering a total surface area of 2188 hectares. The irrigation schedule operates daily and provides five four-hour turns per day. Each hydrant is allowed to request one to four turns depending on the size of its irrigable surface. Due to physical constraints of the network, such as flow capacity and available water, not all demands can be met simultaneously. This requires an efficient turn assignment system to be in place. The goal of the WISCHE system is to optimize the assignment of irrigation turns by balancing two types of constraints: (1) the physical limitations of the network, such as water flow and pressure, and (2) demand-based constraints, which prioritize hydrants based on historical usage and unmet demand. The system aims to ensure equitable water distribution while respecting the physical limitations of the irrigation network.

## III. APPLICATION FUNCTIONALITY

Development Tools

To ensure efficiency and performance, the WISCHE system was coded in C++ using Borland Builder® C++ v6.0 as the development environment. This platform was chosen for its strong support of Graphic User Interface (GUI) development and its capability for handling complex mathematical computations. The mathematical model used for turn assignment was implemented using CPLEX, a robust tool for solving optimization problems. The entire application runs on a Microsoft Windows® operating system.

**Input Data Files**

-Network_Topology: This file represents the real-world irrigation network. It contains a comprehensive list of hydrants, each identified by its unique code, geographic coordinates, and antecedent nodes. This file is automatically loaded into the system at startup.

-Weekly_Telemetry: This file contains historical water consumption data for each hydrant, recorded daily over a weekly period. The data is collected through the SCADA system and loaded by the user into the application via the Telemetría module. Once loaded, the file is added to the system's Log_Telemetry database.

-Daily_Applications: This file contains daily irrigation requests from farmers, specifying the start times for each hydrant. The data is generated based on a template filled out by users and is loaded into the system via the Solicitudes module. Once processed, the file is stored in the Log_Applications database.

**Scheduling Constraints**

The scheduling process is guided by two main types of constraints:

1. Physical Constraints: These include limitations on water flow and pressure within the irrigation network. A mixed 0–1 separable quadratic program is employed to ensure that these constraints are respected during turn assignments.
2. Demand-Based Constraints: These are derived from the historical water consumption of each hydrant. Hydrants that have previously been underserved or have adhered closely to their requested turns are given higher priority in future schedules.

Output

The output of the WISCHE system is an optimized irrigation schedule that assigns turns to hydrants based on both the physical limitations of the network and the priority of demand. The system ensures that as many farmer requests are met as possible while maintaining network stability.

## IV. MODULE FUNCTIONALITY

The WISCHE application is structured to provide users with a streamlined and effective interface for irrigation scheduling. Upon startup, the application loads the Network Topology file, and then the Control Panel presents the user with three main modules: Telemetrías (Telemetries), Asignación de Prioridades (Priority Assignment), and Asignación de Turnos (Turn Assignment).

Within the Telemetrías module, the user can upload the Weekly_Telemetry file, which can automatically be appended to the Log_Telemetry file (this log file is loaded into the system when the form starts). Additionally, this module offers

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optional functionalities for displaying loaded files, pre-processing data, and generating customizable graphs based on the telemetric data, with further details provided in section 3.3.3.

The Asignación de Prioridades (Priority Allocation) module allows users to fill in or modify an application form template, load the weekly irrigation requests, and initiate the priority generation process, which is fully explained in section 3.3.1. Users can also display the generated priorities and create additional customizable graphs based on past usage data.

In the Asignación de Turnos (Turn Allocation) module, the user sets essential network parameters, including maximum water flow speed, minimum pressure, and head-node pressure. There are also optional features that enable users to minimize maximum speed and/or pressure. The module also includes a heuristic option for generating high-quality but non-optimal solutions in a shorter time frame, as detailed in section 3.3.2.

**Priority Generation Procedure**
The priority assigned to a hydrant during a specific irrigation turn is calculated using two factors: the first factor is the hydrant's previous usage of the requested turns, measured as the ratio of real water consumption to maximum possible consumption for that period. The second factor is the proportion of turns previously requested but not attended. The user can adjust the weight of each factor according to their impact values. The priorities are displayed in a two-dimensional matrix (hydrant, turn), as shown in Figure 1, which illustrates the application window used for customizing and calculating these priorities.

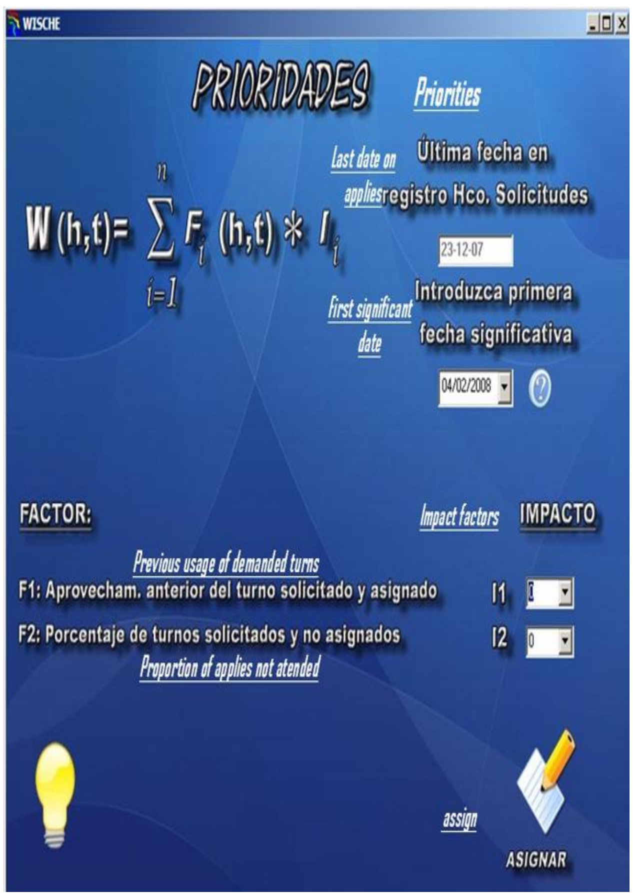


**Figure 1: Priorities Form.**

## V. MATHEMATICAL MODEL FOR TURN ASSIGNMENT

The core objective of the WISCHE system is to activate the maximum number of hydrants during each time period while

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prioritizing those with higher priority values. To ensure the proper functioning of the irrigation network, the pressure head at each hydrant must not drop below a specified threshold. This constraint is modeled using the Darcy-Weisbach equation. Additionally, the water discharge at each node during each time period is regulated, with water flow velocity limitations applied to the upstream pipe segments, as illustrated in Figure 2.

Moreover, once a hydrant is activated, its irrigation process must continue uninterrupted, meaning it can only be turned on once and will remain open for consecutive time periods. In some cases, hydrant schedules must be fixed to accommodate logistical constraints imposed by the system operators. The entire problem is formulated as a mixed 0–1 program, as proposed by Almiñana et al. [4]. The calculation of friction factors in the irrigation pipes is handled using the Colebrook-White equation [5], and explicit friction factor calculations for special types of pipes are provided by Yoo et al. [6]. The final irrigation schedule is obtained by iterating through the mixed 0–1 linear problem, with turn assignment results visualized in Figure 3.

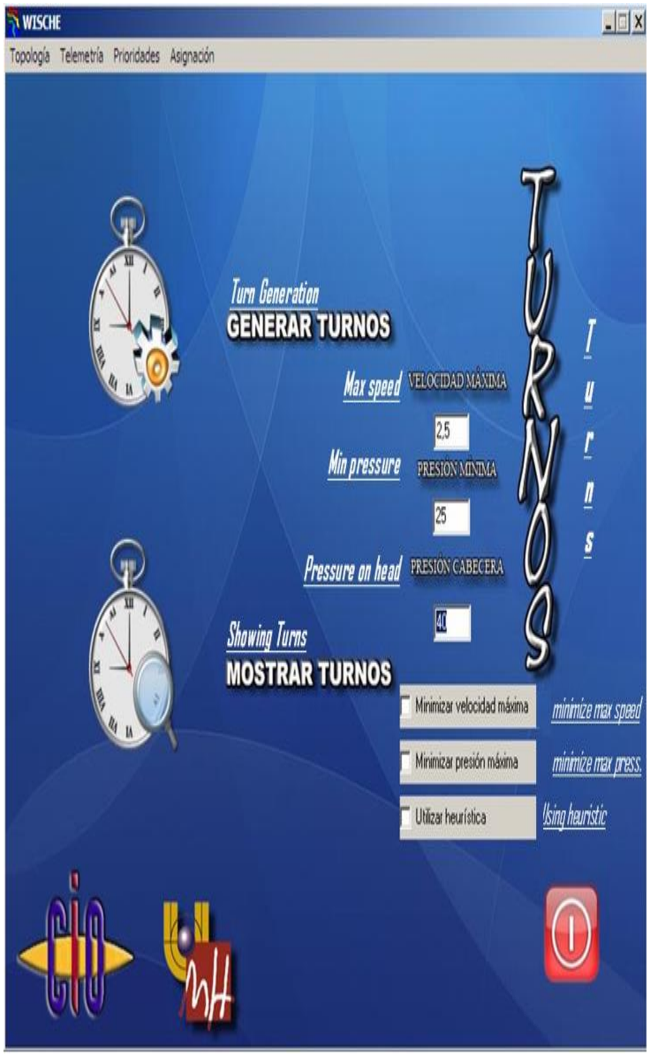


**Figure 2: Turn Assignment Form.**

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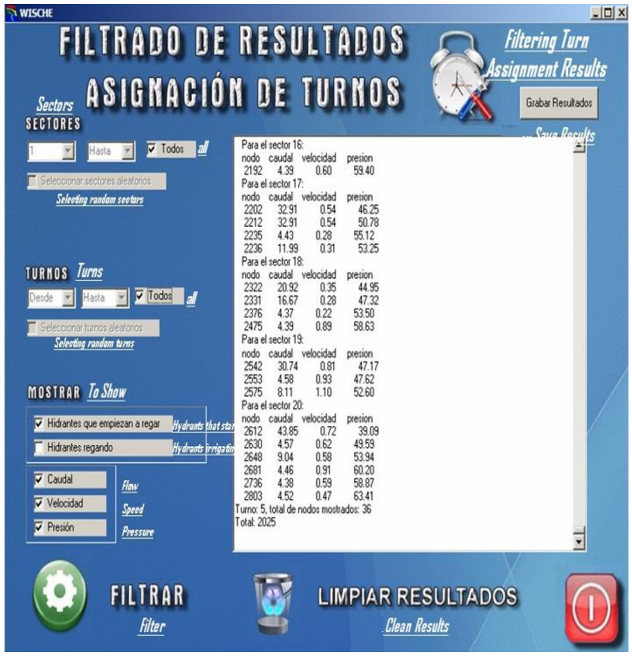


**Figure 3: Turn Assignment Visualization Form.**

## VI. CUSTOMIZABLE GRAPH GENERATION

The WISCHE application allows users to create customizable graphs using two data sets: telemetric data and historical irrigation applications. Users can select a specific time period and choose from different graph types, as well as select the parameters they wish to display. The system offers 3D visualization and clustering capabilities. Figure 4 provides an example of graph generation based on telemetric data, comparing the maximum water flow across multiple time periods.

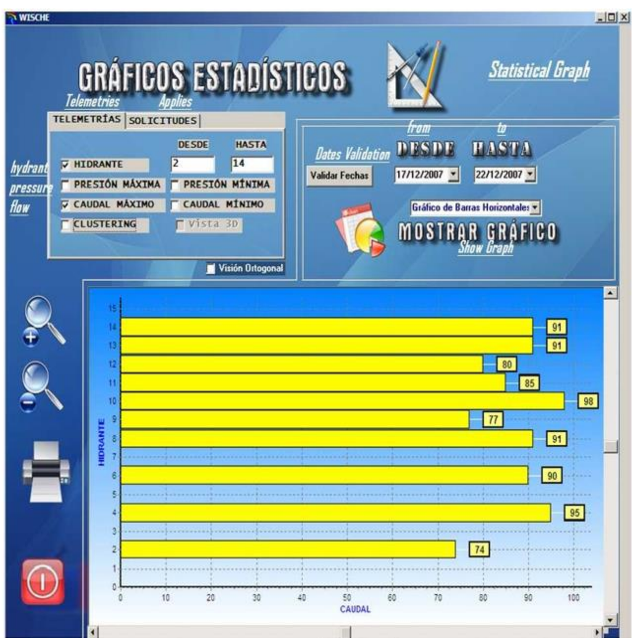


**Figure 4: Graph Generation Form.**

**Output Data File**

- Assignments: This file contains a comprehensive list of hydrants in the network, along with the irrigation turns assigned to them for a given week. It is generated by the Asignación de Turnos (Turn Allocation) form when the user selects the corresponding option.

## VII. COMPUTATIONAL EXPERIENCE

In this section, we outline the complete process of running the WISCHE system. The computational experience was conducted on an Intel Core Duo 1.66 GHz processor with 2 GB of RAM, running the Microsoft Windows® XP Operating System. While the topology file was based on real-world data, the other files used in the simulation were artificially generated since the network infrastructure and SCADA system were still in the process of being installed. Table 1 provides an example of a complete application trace, with optional actions indicated in brackets.

**Table 1: Example of a Complete Application Trace.**

| Action | Form | Option | Time / Size |
|---|---|---|---|
| Loading topology | Starting | (auto) | 1 sec. / 321 Kb |
| Loading telemetric log file | Telemetries | (auto) | 1 sec. / 360 Kb |
| Loading weekly telemetries file | Telemetries | Read Weekly Telem. or Record | 9 sec. / 7360 Kb |
| [Data pre-processing] | Telemetries | Data Preprocessing | — |
| [Showing telemetric] | Telemetries | Show Telemetry | — |
| [Graph generation] | Telemetries | Graphs | — |
| Filling in application form | Pr. Assig. | Application Forms | — |
| Loading weekly applications | Pr. Assig. | Read weekly Application Forms | 1.5 sec. / 369 Kb |
| Priorities generation | Pr. Assig. | Generate Priorities | 4 sec. |
| [Showing priorities] | Pr. Assig. | Show Priorities | — |
| [Graphs generation] | Pr. Assig. | Graphs | — |
| Turns generation | Asig. Tur. | Generate Turns | 2.5 – 12 min. |
| [Showing turns] | Asig. Tur. | Show Turns | — |

## VIII. CONCLUSIONS

WISCHE was developed in collaboration with Riegos de Levante, an irrigation community that urgently requires efficient irrigation scheduling due to frequent water shortages. The system enables community managers to schedule hydrant irrigation turns one week in advance, with flexibility built into the scheduling process. Its priority system ensures that farmers submitting early and reasonable requests are given precedence. WISCHE addresses all operational constraints, generating optimal solutions within a short 12-minute timeframe. When using heuristic options, this time is reduced to 2–3 minutes, producing high-quality scheduling results that meet the needs of network managers. Even under high water demand, WISCHE guarantees safe and efficient network operation. Moreover, its customizable graphing features offer valuable insights into farmers' water usage patterns, allowing managers to analyze telemetric data and assess flow and pressure conditions during peak demand periods.

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