

“The use of mathematical models for the management of operations in water distribution networks”

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Tesi di Laurea Specialistica in “Ingegneria Idraulica, dei Trasporti e del Territorio”

“L’ USO DEI MODELLI MATEMATICI PER LA GESTIONE DELLE
OPERAZIONI NELLE RETI DI DISTRIBUZIONE”

SOMMARIO

L'acqua è sempre stata un elemento essenziale del territorio e del sistema ambientale ed è una risorsa insostituibile per lo sviluppo di varie attività umane e il miglioramento della qualità della vita. Tra i vari usi delle acque, quello destinato al consumo umano, è sicuramente di vitale importanza, come testimoniano i notevoli sforzi compiuti dagli uomini delle più antiche culture nella realizzazione di opere (acquedotti) finalizzate al trasporto e alla distribuzione di acqua potabile.

Gli acquedotti costituiscono quindi una delle più importanti questioni di ingegneria idraulica, che ha attirato sempre più l'attenzione di ricercatori e ingegneri, a causa della quantità di acqua via via più richiesta dall'uomo per soddisfare le sue esigenze e delle conseguenti difficoltà a reperire nuove risorse idriche, per garantire l'acqua di caratteristiche adeguate. Il problema è stato aggravato dal fatto che la mancanza d'acqua per uso potabile, soprattutto negli ultimi decenni, è aumentata a causa del deterioramento della qualità delle risorse, dovuta proprio a quei fattori che hanno dato origine alla richiesta di acqua sempre più elevata (miglioramento dello standard di vita, crescita della popolazione, e sviluppo delle attività umane). E' quindi chiaro che l'acqua di buona qualità è un bene limitato, per questo motivo dobbiamo farne un uso razionale, cercando di contenere le perdite, e adottando misure e azioni necessarie per la tutela delle risorse idriche dall'inquinamento con lo scopo di salvaguardare un bene così prezioso. L'acqua potabile, dunque, è stata inserita in numerosi progetti di sensibilizzazione e protezione, che hanno evidenziato la necessità di una tutela sempre più omogenea e globale espressasi prima a livello nazionale e in seguito anche a livello comunitario: una serie di disposizioni legislative hanno imposto una conduzione oculata ed igienicamente controllata della distribuzione acquedottistica.

La tradizionale politica di gestione pubblica che si è concentrata sulla necessità di garantire una qualità di servizio minimo, indipendentemente dai costi connessi con i processi di captazione, trattamento e distribuzione di acqua, in molti casi, anche sconosciuti, si è evoluta verso modelli più efficienti con costi sensibili. Questi nuovi modelli interamente o parzialmente finanziati dai sistemi di gestione pubblica non solo migliorano la qualità del servizio offerto agli utenti, ma soprattutto ottimizzano le risorse, riducendo i costi e causando il minimo impatto ambientale. In aggiunta la nuova sfida sollevata dalla Direttiva Europea quadro sulle acque (2000/60/CE), che impone il recupero dei costi per migliorare l'efficienza idrica e la sostenibilità ambientale, ha portato a un significativo cambiamento a tutti i livelli della gestione idrica. Di conseguenza, nuove priorità sono state stabilite in termini di gestione delle infrastrutture che richiedono la riduzione delle perdite idriche e il miglioramento dell'efficienza dell'acqua nelle reti urbane per il consumo umano.

Il presente progetto, valido come prova finale del Corso di Laurea Specialistica in Idraulica, dei Trasporti e del Territorio, è stato sviluppato a seguito di un periodo di stage all'estero nel Dipartimento di Reti Idrauliche in Pressione presso l'Università Politecnica di Valencia.

Il progetto viene articolato in 6 capitoli distinti:

1. Introduzione generale sul progetto: scopo, motivazioni e descrizione strutturale;
2. Uso dei modelli idraulici nelle reti di distribuzione d'acqua in pressione: vengono introdotti i modelli matematici, esponendo la loro utilità e i vantaggi che se ne traggono dal suo utilizzo. In seguito sono analizzati gli strumenti e le informazioni necessarie al confezionamento del modello e l'applicazione per la simulazione: GIS ed EPANET;
3. Strumenti e informazioni necessarie a integrare il modello: l'applicazione SCADA come sistema di supervisione, monitoraggio, allarme e comando degli organi di regolazione e immagazzinamento dati;
4. Applicazione del sistema SCADA alla rete di distribuzione: SCA-Red, il software per la gestione della simulazione. Successivamente viene utilizzata l'applicazione che permette di analizzare i dati storici della base dati di SCADA relativi all'anno 2012, per ricercare lo stato di carica del modello;
5. Applicazione del modello alla rete di Valencia e simulazione di una situazione d'emergenza: descrizione della rete di Valencia e rappresentazione del modello strategico; simulazione di uno scenario passato e disamina della rete attraverso le principali variabili idrauliche; simulazione di una probabile situazione d'emergenza. A conclusione del capitolo vengono elencati tutti i tipici scenari in cui il modello viene utilizzato dall'impresa direttrice **Aguas de Valencia S.A.**, fungendo da strumento di supporto per prendere le decisioni per la gestione delle operazioni.
6. Conclusioni e sviluppi futuri: utilità del progetto e campi d'investigazione futura.

Le principali motivazioni che ci hanno spinto a tutelare un bene di primaria necessità come l'acqua, le possiamo sintetizzare in alcuni punti chiave:

- Problematica della gestione: aumento dei costi di captazione, trattamento e distribuzione; aumento della domanda e diminuzione delle risorse;
- Obiettivi delle imprese: ottimizzare le risorse e ridurre i costi di gestione;
- Direttiva Europea (2000/60/CE): migliorare l'efficienza idrica e la sostenibilità ambientale.

Per salvaguardare un bene così prezioso, nell'ultimo decennio, le imprese direttrici si sono preoccupate di cambiare strategia di gestione passando da un'amministrazione tradizionale che si poneva l'obiettivo di soddisfare la domanda, a una nuova strategia di conduzione che si pone i seguenti obiettivi:

- Migliorare la qualità del servizio agli utenti;
- Minimizzare le perdite;
- Ridurre i costi energetici di gestione.

Con lo scopo di raggiungere tali obiettivi, si propone di affrontare gli attuali problemi di gestione delle reti idriche urbane, utilizzando nuove tecnologie di elaborazione delle informazioni con tecniche di modellazione di rete innovative che permettono l'ottenimento di strumenti di supporto per facilitare la diagnosi del sistema, e per poter successivamente gestire al meglio tutte quelle operazioni necessarie al mantenimento della rete idrica urbana.

Uso dei modelli idraulici nelle reti di distribuzione d'acqua in pressione

Nell'ultimo decennio, grazie alle nuove tecniche di modellazione delle reti si è riuscito a capire le potenzialità che può offrire un modello matematico, la miriade di campi in cui riesce a trovare applicazione e i vantaggi che si possono trarre da uno strumento del genere. In maniera sintetica proviamo a rispondere a 3 domande fondamentali per comprendere il concetto di modello matematico esaminando il nostro campo di applicazione, ovvero la rete di distribuzione d'acqua in pressione:

1. Che cos'è un modello matematico?
 2. A cosa serve un modello matematico?
 3. I vantaggi di un modello idraulico in una rete di distribuzione?
- ✓ Un modello matematico è un modello costruito usando il linguaggio e gli strumenti della matematica. Un modello di un sistema esprime la conoscenza di un fenomeno e come tale consente di rispondere a domande sul sistema senza la necessità di compiere un esperimento. Esso costituisce quindi un potente mezzo di previsione e descrizione del comportamento di un sistema. Tutti i settori della scienza, ma non solo, fanno largo uso di modelli matematici per modellizzare determinati aspetti del mondo.
 - ✓ Come tutti gli altri modelli usati nella scienza, il suo scopo è quello di rappresentare il più incisivamente possibile un determinato oggetto, un fenomeno reale o un insieme di fenomeni (sistema fisico). Un modello matematico è spesso costruito con lo scopo di fornire previsioni sullo 'stato' futuro di un fenomeno o di un sistema. Generalmente, il modello descrive la probabile evoluzione di un fenomeno o di un sistema sulla base di dati iniziali (condizioni iniziali) forniti dall'utente (l'input) restituendo dei dati finali (output). L'efficacia del modello può essere quindi misurata comparando i dati finali con il risultato effettivo osservato dell'evoluzione del fenomeno o del sistema.
 - ✓ I modelli idraulici sono utilizzati nelle reti di distribuzione per pianificare, progettare e gestire i servizi idrici necessari per servire gli utenti aggiuntivi e mantenere i servizi esistenti negli anni futuri. Durante il funzionamento di una rete di distribuzione si presenteranno delle situazioni problematiche che si potranno risolvere nella maniera più adeguata possibile attraverso l'utilizzo di un modello idraulico: in caso di eventuali guasti o rotture in punti strategici della rete, sarà possibile valutare l'entità del danno e adottare le necessarie precauzioni.

Strumenti e informazioni necessari al confezionamento del modello

Descritta l'utilità di un modello idraulico, come passo successivo si esamina il problema di confezionamento di un modello che rappresenti la rete acquedottistica di Valencia. Vista la complessità di una rete idraulica che fornisce una popolazione di circa 1,5 milioni di abitanti, appare evidente il fatto di avere a che fare con un grande volume di informazioni cartografiche che sono gestite dal sistema di informazione territoriale GIS che permette l'acquisizione, la registrazione, la visualizzazione e la restituzione di informazioni derivanti da dati georeferenziati.

Tale applicazione permette, infatti, di gestire al meglio e nel modo più funzionale possibile:

- Utenti;
- Letture dei contatori;
- Dati di telemetria;
- Domanda della portata per ciascun nodo della rete.

Inoltre grazie alla personalizzazione di GIS si è riuscito a sviluppare uno strumento specifico chiamato GISRED per facilitare la confezione dei modelli, la calibrazione e il mantenimento degli stessi, e adottare il modello dei dati al simulatore EPANET.

Per la simulazione di reti di condotte in pressione si è utilizzato il software più conosciuto a livello mondiale: EPANET. Grazie ad esso, siamo riusciti a simulare in un periodo esteso il comportamento idraulico della rete tracciando il flusso dell'acqua in ogni tubazione, la pressione a ogni nodo e il livello in ogni serbatoio. I risultati ottenuti sono mostrati attraverso grafici, e rappresentazioni con mappe delle isolinee per riprodurre con una sola immagine il comportamento dell'intera rete.

L'integrazione del modello con i dati reali, invece, avviene con il software SCADA. Questa applicazione permette il monitoraggio in tempo reale dei sistemi di distribuzione d'acqua, con lo scopo di utilizzare il modello idraulico al fine di aiutare gli operatori della rete nella gestione delle operazioni di manovra. Si tratta di uno strumento indispensabile per gli operatori della rete in quanto permette loro di:

- Valutare le azioni riguardanti la situazione attuale in modo tale da anticipare il comportamento della rete nelle prossime ore;
- Ottimizzare la rete in tempo reale, ridurre le perdite, minimizzare il consumo energetico e controllare la qualità dell'acqua;
- Pianificare le operazioni di mantenimento e gestire le manovre in situazioni d'emergenza;
- Esportare il modello idraulico adattato alle condizioni reali al software di simulazione Epanet.

A seguito di una descrizione delle applicazioni e informazioni necessarie alla costruzione di un modello si è passati a esaminare il caso di studio della rete di Valencia: simulando un periodo passato per la riproduzione di risultati simulati per esaminare il comportamento della rete nelle condizioni più sfavorevoli possibili con lo scopo di migliorare la qualità del servizio all'utente, migliorare la capacità di risposta sotto condizioni anomale di funzionamento (simulazione di una situazione d'emergenza), ridurre i costi di operazione con un'ottimizzazione del consumo energetico.

Caso di studio: Applicazione del modello alla rete di distribuzione di Valencia

La città di Valencia si trova sulla costa orientale della Spagna, zona densamente popolata da circa 1,5 milioni di persone, distribuite in circa 44 Comuni. La rete che alimenta la città di Valencia è stata costruita nei primi anni del 1900. La prima fonte di acqua potabile è stata l'impianto di trattamento di " La Presa ", che attinge l'acqua dal fiume "Turia".

Attualmente, la rete include un sistema di distribuzione più grande che comprende tutte le reti dei 44 comuni menzionati. L'intera rete è chiamata Sistema Basico Metropolitano (SBM), e uno dei suoi scopi principali è stato quello di rendere possibile la fornitura di tutte le popolazioni con l'acqua di superficie. In questo modo, durante gli anni '80, l'aumento del consumo di acqua, l'aumento di nitrati delle acque sotterranee, e la necessità di garantire l'approvvigionamento per la città e la sua area metropolitana, ha costretto l'autorità a progettare un'altra pianta "Picassent", che riceve l'acqua dal fiume "Jucar" per mezzo di un canale di trasferimento, contribuendo così ad

aumentare le fonti alternative per il sistema globale. Come conseguenza, l'intera area metropolitana è attualmente alimentata con acqua di superficie.

Analisi dati storici anno 2012 e Carica del modello

Per ricercare il periodo di carica del modello, cioè quel periodo che rappresentasse la situazione di massimo consumo, ci siamo serviti dei dati immagazzinati da SCADA nella base dati attraverso un'applicazione elaborata dall'impresa che gestisce la rete di distribuzione. Analizzando il consumo giornaliero dell'intero anno 2012, risulta che Giugno è il mese con il consumo più alto. Successivamente è stato esaminato tale mese dal punto di vista qualitativo, poichè non tutti i segnali trasmessi sono accettabili, in quanto, per mancanza di tensione o per errori di comunicazione, non si hanno a disposizione tutti i dati. Inoltre, alcuni di essi assumono valori anomali a causa di “rumori magnetici” ambientali. A seguito di queste analisi è stato scelto come giorno rappresentativo dell'anno il 27: giorno in cui i valori sono prossimi alla realtà nel periodo dell'anno in cui si verifica il consumo più elevato.

Simulazione di un periodo passato per la riproduzione di scenari

Scelto lo stato di carica, abbiamo caricato il modello con i dati importati da SCADA ed esportato al simulatore EPANET. Dalle simulazioni abbiamo tirato fuori alcune mappe che rappresentavano la rete, riportando:

- * quote del terreno di tutti i punti della rete a partire dai serbatoi fino ai punti di suministro più estremi;
- * le tubazioni sono state rappresentate riportando: diametri, velocità e portate nell'ora di massimo consumo;
- * i livelli dei serbatoi e lo stato di avvio/arresto delle pompe;
- * dal punto di vista qualitativo abbiamo analizzato la pressione verificando che soddisfacesse i valori minimi nell'ora di massimo consumo e i valori massimi nell'ora di minimo consumo in tutti i punti della rete;
- * l'altezza piezometrica per valutare le perdite di carico nelle tubazioni;
- * il rendimento globale della rete tenendo conto di tutti i settori parziali.

Simulazione di una situazione d'emergenza

Dall'analisi della rete attraverso lo scenario passato appena descritto, si è individuato un punto critico che presenta valori limiti per quanto riguarda la pressione massima nell'ora di massimo consumo; poichè in tale tratto è presente una valvola riduttrice di pressione si è pensato a una probabile rottura della valvola. La rottura è stata simulata con la chiusura totale della valvola. In seguito si è provati a trovare una soluzione al problema mettendoci nei panni dell'operatore che gestisce le operazioni di manovra, andando ad eseguire tempestivamente tutte le manovre necessarie per ripristinare il servizio.

Scenari tipici di utilizzo del modello idraulico

Agua de Valencia S.A., l'impresa privata che gestisce la rete di distribuzione, utilizza il modello quotidianamente in una delle seguenti situazioni:

- Conoscere le variabili idrauliche (pressione, portate, livelli) in tutti i punti della rete, anche in quelli dove non sono installati dispositivi telemetrici;
- Pianificare la manutenzione, andando a determinare in quali giorni conviene apportare modifiche alla rete;
- Progettare la rete in caso di espansione dovuta a una crescita della popolazione o a uno sviluppo industriale;
- Durante le situazioni di emergenza, per facilitare la localizzazione del danno e per prevedere come la rete reagirà nelle ore seguenti;
- Gestire la rete attraverso la settorizzazione della stessa per calcolare bilanci idrici di ciascun settore e per valutare successivamente l'efficienza di tutto il sistema.

Conclusioni e sviluppi futuri

L'elaborazione di questo lavoro, a partire dalla tutela delle risorse idriche (acqua intesa come elemento essenziale del territorio e del sistema ambientale nonché risorsa insostituibile per lo sviluppo di varie attività umane e il miglioramento della qualità della vita) per terminare con l'obiettivo fondamentale della presente tesi: la necessità dei modelli matematici per la gestione delle operazioni nelle reti di distribuzione dell'acqua; il modello rappresenta, oggi, uno strumento di estrema importanza per l'intera umanità. D'altra parte, l'uso di strumenti quali SCADA, GIS, EPANET, ci rendono ancora più abili nel riuscire a controllare le grandi reti di aree metropolitane. **Agua de Valencia S.A.**, a partire dal 1993, in collaborazione con l'Università Politecnica di Valencia, si è dedicata all'elaborazione del primo modello statico della rete arteriale della città, e dopo quasi 20 anni di ricerca e sviluppo è riuscita a costruire un modello idraulico, di cui ancora oggi non possono farne a meno.

L'utilità del modello si racchiude essenzialmente sotto 3 aspetti che, in generale, coincidono con gli obiettivi principali dell'impresa che ha il compito di soddisfare le esigenze degli utenti, ottimizzando i costi che permettono di garantire il servizio:

1. Migliorare la qualità del servizio all'utente;
2. Migliorare la capacità di risposta in condizioni di funzionamento anomalo;
3. Ridurre il costo di funzionamento attraverso l'ottimizzazione del consumo energetico.

Gli sviluppi futuri relativi alla gestione ottimale della rete, sono orientati in una prima fase verso l'analisi dei vari fattori che giustificano il consumo incontrollato come le connessioni illegali. Un'altra area di sviluppo futuro è mirata sul sistema di gestione dell'energia e l'ottimizzazione del consumo energetico delle fonti di approvvigionamento. La minimizzazione del consumo di energia in stazioni di pompaggio è un classico problema. Tuttavia, la gestione energetica prende in considerazione molti altri fattori quali la gestione dell'acqua destinata ai serbatoi in funzione del grado di riempimento, la regolazione delle valvole di controllo della pressione, l'impostazione del valore di pressione, la perdita per attrito nei tubi, la perdita di energia associata a perdite, ecc...

Thesis for degree in “Civil Hydraulic Engineering”

“THE USE OF MATHEMATICAL MODELS FOR THE MANAGEMENT OF OPERATIONS IN WATER DISTRIBUTION NETWORKS”

ABSTRACT

Water has always been an essential element of the territory and of the environmental system and is an irreplaceable asset for the development of various human activities and the improvement of quality of life.

Among the various uses of water, the one intended for human consumption is certainly of vital importance, as evidenced by the considerable efforts made by the men of the most ancient cultures in creating works aimed at the transport and distribution of potable water, even very complex, works of which few examples remain today (like Roman aqueducts).

The aqueducts therefore constitute one of the most important issues of hydraulic engineering, which has attracted more and more attention of researchers and engineers, due to the gradually increased amount of water required by humans to meet their needs and the consequent difficulties in finding new water resources, to ensure water of appropriate characteristics. The problem was exacerbated by the fact that water shortages for potable use, especially in the last decades, have been intensified due to the deterioration in the quality of resources, as a consequence of an augmented water demand (improvement of living standards, population growth, and development of human activities).

It is thus evident that good quality water is a limited asset, therefore, we have to do a rational use, with containment of leaks and waste, and the adoption of measures and actions needed for the protection of water resources from pollution.

The traditional public management policy that focused on ensuring a minimum quality of service regardless of the costs associated with the processes of catchment, treatment and distribution of water, in many cases even unknown, have evolved towards more efficient cost sensitive models. These new wholly or partly public funded management systems will not only improve the quality of service offered to users, but will also optimize resources by reducing the cost and causing a minimum environmental impact.

The new challenges raised by the European Water Framework Directive¹ by imposing cost recovery to improve water efficiency and environmental sustainability have led to a significant change at all levels of water management. Consequently, new priorities have been established in terms of infrastructure management that require the reduction of water losses and the improvement of the water efficiency in urban networks for human consumption.

This thesis aims to address the current problems of managing urban water networks by combining new information-processing-technologies with innovative network modelling techniques. It intends to facilitate the system diagnosis and extend the use of models on the decision-making process to provide better solutions to the management of urban water networks.

¹Directive (2000/60/CE) of the European Parliament, 23 October 2000, which establishes a European framework for community action in the water policy.

Chapter 1: General introduction

1.1 Scope of the project

Advances in information technology in the past two decades have seen innovations in the field of domestic and industrial computing that have led a paradigm shift in the management and operation of urban water systems by water utility companies.

A preliminary step for improving a system of water supply is to make an accurate diagnosis of the same. This is done for two main reasons: first, this is one of the requirements to improve the management and the second it allows the planning actions in the same direction. Indeed, the preparation of a mathematical model is one of the actions that contribute to this end.

The goal of this work is the elaboration of a strategic model that represents the water distribution network in the city of Valencia. This strategic model will allow us to represent a real scenario and a probable case of emergency in order to know where and how we have to operate for maintaining the network within the limits set and trying to ensure an adequate service to all users.

We must also keep in mind that this model may be the object of study and of great help to determine the behavior of the network in case of extension of the same network for future questions and then for the planning of new users, that will support this consumption.

1.2 Justification of the project

The evolution undergone in recent years in the use of mathematical modeling as a tool to support improved understanding and optimization of the exploitation of hydraulic systems has been and continues to be fast and very positive. The main advantages gained in using the information acquired during the process of modeling are indisputable. The experience gained in the past decade has demonstrated that the elaboration and application of models is valuable. These are becoming tools for support in relation to decision-making in a supply. The mathematical model is useful in the previous stage of search and selection of possible solutions, but also in monitoring and verification of its effectiveness upon deciding the application of one of them. A mathematical model is useful also for the planning of rehabilitation activities, for maintenance and restoration, for the simulation of emergency case and restrictions and then for planning improvements in safety and reliability.

Furthermore, the mathematical model has additional applications in the activities of design and system expansion project, installation of new elements of regulation, in studies of sectorization, in locating water lost and leaks and in the preparation of water quality models.

Also, it is noticeable that the elaboration of the model involves the collection of a large amount of information, which is a real properly structured and very useful database of hydraulic system characteristics, information that can be used and onward to be consulted at the disposal of the company.

1.3 Resources required for the work

In this work were used the following software tools:

- ❖ GisRed as a tool for collecting of data connected with geographical position;
- ❖ Sca-Red to simulate operation maneuvers that might be critical for the normal performance of the network;
- ❖ Data analysis Sca-Red to analyze historical data to be stored from SCADA capture;
- ❖ EPANET as simulation software for hydraulic scenarios.

1.4 Organization of the work

The work has been organized into 6 chapters, the aim and content of each of the chapters is as follows:

Chapter 1 introduces, in general terms, the contents of this project and the reasons that led me to deal with this subject; the various tools used during the study;

Chapter 2 deals the mathematical models: how are distinguished, how they develop and the programs that we use for their packaging;

Chapter 3 describes SCADA software, its fields of application focusing on the use made in this project;

Chapter 4 analyzes the application of SCADA software to the distribution network, or rather: SCA-Red, how it is structured and how is the connection between the model, the client and the real network;

Chapter 5 discusses the aqueduct of Valencia as a case study of this project, the development and use of strategic model for a real scenario and for an emergency case;

Chapter 6 summarizes the results of the case study focusing on the current utility of the hydraulic models and how they can make much more efficient a water distribution system.

Chapter 2: Models in water distribution networks

2.1 Introduction

The groundwork for computer modeling of distribution systems was laid by the numerical method developed by Hardy Cross in the 1930s for analyzing looped pipe networks. The first mainframe programs for pipe-networks analysis were based on this method (Adams, 1961), but these were soon replaced with codes that used the more powerful Newton-Raphson method for solving the nonlinear equations of pipe flow. Therefore pipe network flow analysis was among the first civil engineering applications programmed for solution on the early commercial mainframe computers in the 1960s. Since that time, advancements in analytical techniques and computing power have enabled us to solve systems with tens of thousands of pipes in seconds using desktop personal computers. Over the years, step by step, modern-day computers models are used to analyze the hydraulic and water-quality behaviour of distribution systems.

The classical pipe-network flow problem asks what are the flows and pressures are in a network of pipes subject to a known set of inflows and outflows. Two sets of equations are needed to solve this problem. The first set requires conservation of flow to be satisfied at each pipe junction; the second specifies a nonlinear relation between flow and headloss in each pipe, such as the Hazen-Williams or Darcy-Weisbach equation. Whenever a network contains loops or more than one fixed-head source, these equations form a coupled set of nonlinear equations. Such equations can be solved only by using iterative methods, which for all but the smallest-sized problems require the aid of a computer. Because most distribution systems of interest are looped, computer models have become a necessity for analyzing their behaviour.

2.2 Uses and benefits of water distribution models

Water distribution systems models are used in planning, engineering, operations, and management of water utilities. Some examples include the following:

- Network models are run to analyze what capital improvements will be needed to serve additional customers and maintain existing services in future years. They also can help a utility prepare for planned outages of specific system components, such as tanks and pump stations;
- Establishment of operation plans in case of possible faults or ruptures in strategic points of the network, previously simulated with the model. In this way, the system's most vulnerable simulations can be detected, and the necessary precautions taken;
- Network models are used to locate and size specific network components, such as new mains, storage tanks, pumping stations, and regulator valves;
- Pump scheduling, tank turnover analysis, energy optimization, and operator training are some ways in which network models can be used to improve system operations;
- Extensions to hydraulic models allow them to analyze a host of questions related to water quality. They can determine how water from different sources blends together throughout a system, how operational changes can reduce the time that water spends in the system, and what steps can be taken to maintain adequate disinfectant residuals without excessive levels of disinfection by-product formation throughout the system;
- Fire-flows studies are used to determine if adequate flow and pressure are available for fire-fighting purposes, as required for fire insurance ratings;

- Vulnerability studies are used to test a system's susceptibility to unforeseen occurrences, such as loss of power, major main breaks, extended drought periods, and intrusion of waterborne contamination.

Summing up, typical scenarios where we can find network models are:

- * Pressure reduction schemes;
- * Pressure enhancement schemes;
- * Emergency planning;
- * Maintenance planning;
- * DMA planning;
- * Mains rehabilitation;
- * News developments / additional demand.

Many benefits are gained from model building as well as model use. The construction and validation process involves the collection and analysis of a vast amount of data. Much will be learnt about the distribution system during this time and it provides an ideal opportunity to scrutinise and review the quality and accuracy of information available. This procedure itself may lead to changes in record systems and improved performances. Other more tangible benefits occur from monitoring the performance of devices and the identification of system deficiencies. Pump performance will be measured; major meters will be checked; and unknown closed valves may be discovered during field tests. The greater the effort employed in the data logging exercise the greater the return. A proportion of the irregularities found will be of little significance; the odd unknown closed valve in the distribution network is not unusual or often important in terms of system performance. However, there are many occasions when data logging reveals anomalies which, if not resolved, could lead to unnecessary capital expense or poor levels of service when changes are made.

Network models were often designed and constructed for a particular purpose, usually to arrive at an investment decision and/or solve an operational problem. The completed model not only served as a design tool for the engineer but also remained available for future problem solving. The value of this "by-product" relied upon the scope of the original model. Such models were often simplified and restricted in their area of coverage, and so limited subsequent use.

However, we must accept that even these detailed models will have limitations. They will not contain every aspect of the real system. Non-specialist users must take care to understand the information, which the model will present to them: results can only be provided within the framework of the original system data.

2.3 Description and classification of the mathematical models in distribution networks

The mathematical model of a network is the set of equations of hydraulic character and boundary conditions to simulate the different ways it can behave the distribution network without having physically experience. From the result of these simulations are then extracted consequences to be used in planning and network management.

The objective of any mathematical model is played back through a computer, as accurately as possible, the actual behaviour of the physical system it represents.

Hydraulic models can be classified, according to the mathematical approximation, in:

- Static models, or permanent status, which simulate the network in a single instant;

- Dynamic models that simulate the behaviour of the network analyzing an extended period.

According to the application of the model, these are classified as:

- * Planning models: they are used to evaluate the performance and impacts of different economic or quantitative pipe alternatives, changes in operational procedures or the behaviour of various elements, such as control valves, tanks storage, etc..
- * Operational models: they are used to predict the behaviour of the system in the short term (hours, days) to adjust pressure or flow, change levels, train operators, etc.. The aim is to assist in making decisions during system operation.

Depending on the degree of detail of the model, are distinguished in:

- ❖ Strategic or arterial models: these models incorporate only the main components in terms of their size, role model or final destination. This type of model is suitable as an instrument of planning, design and protection of the fundamental elements of the network for control in real time, the optimal location selection and measurement and control devices, and generally for the design and optimization of the control system, or to study the management of operations in emergency situations;
- ❖ Detailed models: To cover all the necessary requirements and take full advantage in aspects of project detail and for maintenance and regulation; in particular is necessary to use detailed models, which incorporate almost all the network elements, to reflect the behaviour of all elements of the system, especially for maintenance operations. Models are also required for the development of quality models.

According to the system variables, which are of interest, are classified as:

- Hydraulic models: Hydraulic models determine the flow rates and pressures in the network under a certain initial and boundary conditions;
- Quality models: they determine the temporal and spatial variation of a given water quality parameters such as the concentration of pollutants or disinfectants, the residence time of water in the network or the retention time in the tanks. Quality models require as a first step, the determination of the hydraulic variables of the system, through the use of a hydraulic model.

2.4 Design of a network mathematical model

Although in practice an analogue process is always followed for any network, it is important to point out that each one has its own peculiarities, which effect in a very significant way each one of these phases:

1. Compilation of the information;
2. Reduction of the network to a skeleton (obtaining a simplified model of the real network);
3. Analysis of the metered consumptions and their allocation to the nodes of the model;
4. Initial distribution of the “not registered” consumptions;
5. Measurements of the network’s parameters such as the pump’s characteristic curves, volume of storage tanks, the settings of the regulating valves, etc...

After processing this information, we will obtain an *Initial model* of the system, whose validity will be checked in the following phase:

6. Verification of the initial model, which implies processing the model for different network conditions, and taking measurements of the hydraulic variables (pressure and flow rates) in the real system for the same situations;

The analysis of the differences, which will almost definitely be between the calculated values and the measured ones, can lead us to find errors in the initial data, for instance in the definition of the network topology by having found some closed valves or by errors made in the interpretation of the connection of pipes. Once the possible error sources in the initial model have been found and rectified, the last phase in the preparation of the model can begin:

7. Calibration of the initial model, from the in situ field measurements. During this phase, the most “uncertain” parameters of the model will be conveniently modified. Generally these are pipe roughness, diameter of some conduits (the diameter may have reduced) and the consumptions assigned to the nodes, due to the uncertainty as far as “unregistered consumption” goes, and according to the hourly fluctuations of the flow rates.

After having satisfactorily concluded the last phase we will have the network’s *Definitive model*, which should be periodically updated and recalibrated so that it does not lose functionality. The use of databases that collect all of the system’s information will be very useful, for the preparation of the model as well as for its later updating.

2.5 Development of a hydraulic model for a network of water supply

The process of developing a hydraulic model involves gathering all the information existing network, and debug it to be assimilated by the existing analysis programs such as EPANET. The modeling phases are:

2.5.1 Collection of system data

One of the main points for the preparation of a hydraulic model of a network in service, and this is the first phase of its elaboration, is to compile the greatest quantity possible of information on the network and its operation.

This is a case of familiarizing oneself with the system with the object of knowing the issues that are presented. Apart from using the archived data, it will also be most important to count on the experience of the personnel specialized in the Organization or Company in charge of the operation of the network.

The most important data’s that should be compiled are:

- Topology: routes and connections of the pipes that make up the system, as well as location of the main valves. To avoid errors, it is advisable to use as much as detailed and up to date a plan as possible, with a scale between 1:500 and 1:5000;
- Elevations: nodes and tank elevations, and especially places where pressure measurements are taken. It is advisable that the contour lines should not be at more than 1 m spacing for the levels to be of use. If the mapping were not reliable it could be convenient to traverse between all the pressure measurements points, following where possible the water’s direction flow;
- Pipes: diameter, length, material, estimated roughness, years in service, state of conservation.

- Valves: location of the principal valves, diameter, type (regulating, reducing, sustaining, ect...), operation rules, material, state of conservation, etc...
- Storage systems: location of the network's tanks, as well as dimensions, base elevation, maximum and minimum levels, measurement and regulation devices, operation, etc...
- Production installations and pumping stations: general description of the installations, regulation equipment and how it is operated, measurement devices, characteristic and efficiency curves of the pumps, aspiration levels, etc...
- System input flows: as well as the accumulated values, it would be desirable to know the daily and seasonal evolution of the flows input from each of the inflow points, or at least an estimation of it based on the variation of the water levels in the storage tanks, hours that the pumps work, energy consumed, etc...
- Consumptions in the network: the maximum information available about the user's billed consumptions as well as estimations of public consumptions, leaks, meter errors, etc.. should be obtained. If possible the location and type of each consumer (domestic, industrial, etc..) should be detailed, indicating which pipe of the network is involved. It would also be desirable to obtain the demand modulation curves as a function of the time of day, day of the week, time of year and type of user, through a sample.

The rigorous determination of the starting data is going to be without doubt the most tedious task in the preparation of the model, and it will be a very important factor in the final model's reliability. On the other hand, having a graphical interface for entering model data can be an immeasurable help.

2.5.2 Simplification and skeletonization of the network

Skeletonization consists essentially in the preparation of a simplified diagram of the network, which will be the topological base of the model. It should depict with sufficient precision the assembly of all the elements and connections.

The degree of simplification depends on the quantity and importance of the pipes that forms the real network, as it does the model's goal: analysis, design, diagnosis, real time control, etc...

From a hydraulic point of view, when the fundamental use of the model is for analysis or design (prediction of the effect of a manoeuvre or fault, planning an expansion or improvement, etc...), going into great detail is a waste of time, as it is not normally necessary to know the pressure at each node and connection of the network, being on the other hand insignificant the hydraulic contribution of the services and lesser pipelines to the behaviour of the arterial network. For this reason many small pipelines can be eliminated from the real network without losing any accuracy in the calculations, and gaining in exchange speed in the execution and comfort in the handling of the data.

Among the most widely used techniques for simplifying the real network enough for its use in applications of analysis and design, we should mention:

- Unification of close nodes;
- Association of series pipes;
- Association of parallel pipes;
- Elimination of the branches, substituting them by their consumption at the point of connection with the network;
- Elimination of small diameter distribution pipes.

The unification of nodes contributes to the elimination of convergence problems, caused by short pipes of low resistance.

As for association of series and/or parallel pipes, the procedure to be followed consists in determining the equivalent length and diameter of the assembly. Evidently, the equivalent resultant

diameters will not correspond to normalized sizes, but this should not be a problem as the meaning of the pipe is that of a fictitious pipe that substitutes various real ones and behaves in a way analogous to the assembly that it came from.

The elimination of small diameter pipes is conditioned by the desired level of detail and by their relative importance in the supply system. A definitive criterion cannot be given, but it is important to realize that pipes that contribute significantly to the carrying capacity of the systems should not be eliminated. The further away a pipe is from the inflow point, the less it contributes to transporting the flow to other areas, and thus its elimination will be more justified. Therefore, not only diameter, but also the location of a pipe in the system, as well as the amount of supplied users, will be deciding factors when the necessary simplifications are to be made.

When a conduit is left out of service as a result of a fault, the pipes in the surrounding area can go on to have strategic importance, this means that is necessary to take this fact into account when the real system is being simplified. In general, it is better to over estimate the carrying capacity of the system, and, if in doubt, to include the pipe. In this way, generally the pressures calculated by the initial model will be greater than those measured. This fact will have to be corrected in the adjustment process, increasing roughness, decreasing diameters or conveniently resituating the uncontrolled consumption flows. In this way, if the calculated pressures were to show continuously smaller values than those measured, this could mean that an excessive simplification of the real physical system has taken place, necessitating then an increase of the carrying capacity of the model.

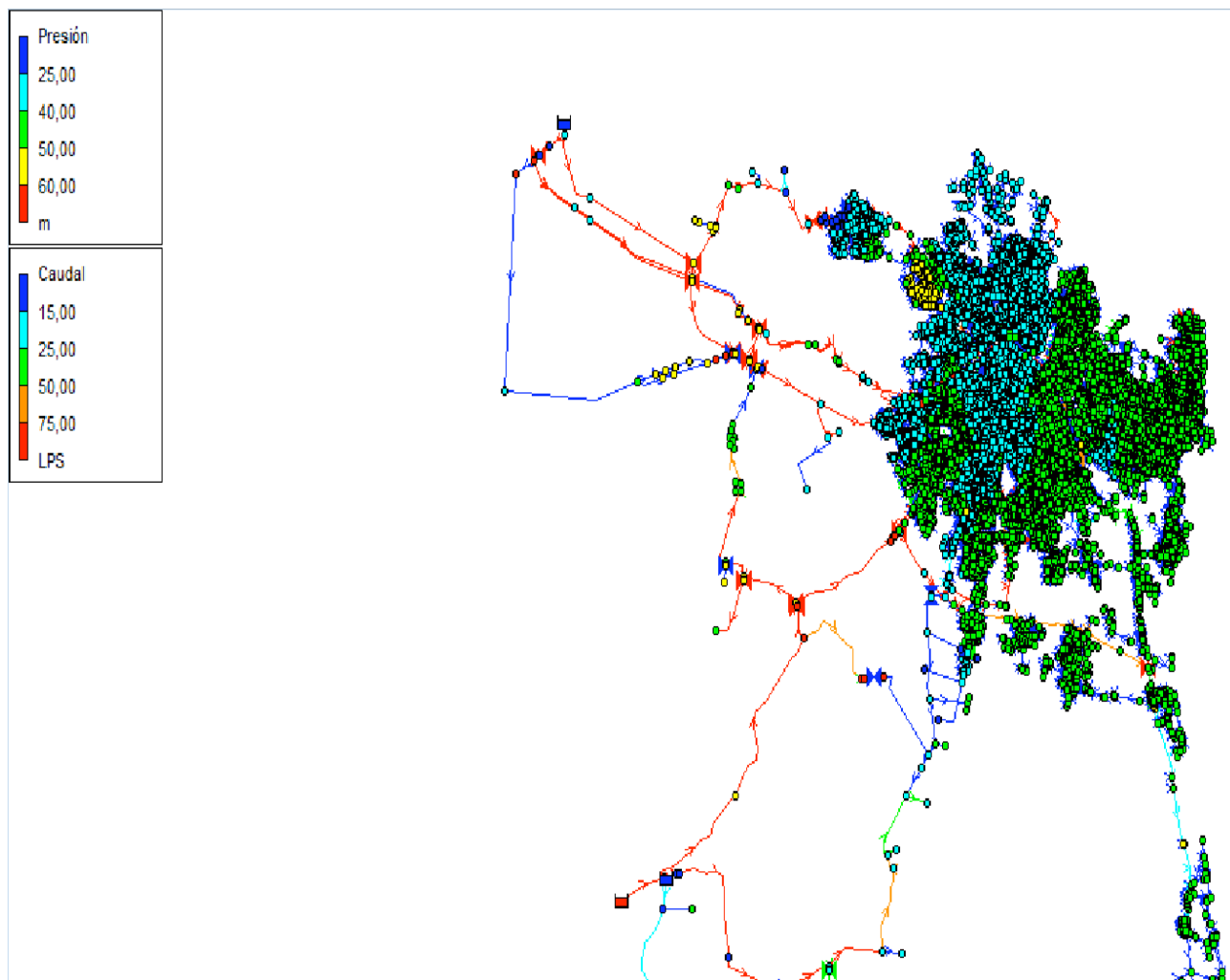


Fig.2.1:Image of real network (Detailed Model from Epanet)

Skeletonization is fundamental in the process of preparation of a mathematical model of a network and generally is a very delicate operation; its automation is extremely difficult as many simplifications depend on the engineer's judgement. In any case it is necessary to always have a

reliable database that contains information on the simplifications that have been made, relating the model's links to elements of the real network. In the same way, this database should bring together information on how the consumption at nodes is determined, as a function of the simplifications made to the system.

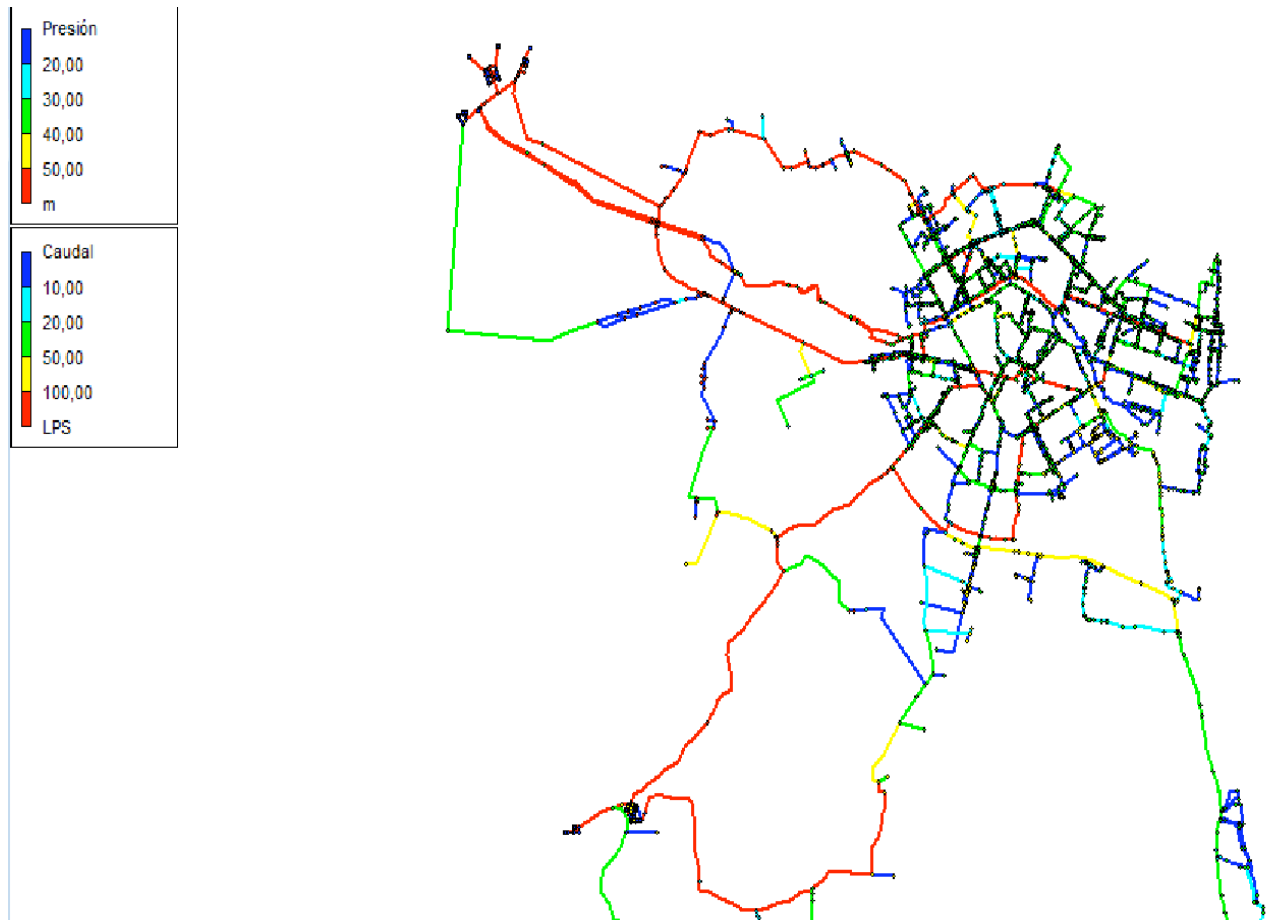


Fig.2.2:Image of simplified network (Strategic Model from Epanet)

Once the simplified model has been obtained, the next step is to enumerate the elements that make up the skeleton. An enumeration is recommended that makes a fast identification possible of the node or pipe that is being dealt with.

2.5.3 Consumption analysis: estimation of the demand. **Modulation of the demand**

In order to reproduce in an adequate fashion the working of a network through the use of its mathematical model, it is vital to know the flow required by each consumer or group of consumers for the situation that is to be analysed.

Generally consumption is simulated by outflows at the model's nodes, so that each node is responsible for one or more consumers. When the model does not go into an excessive degree of detail, approximate methods may be used for defining the consumptions, based on the definition of the consumption areas around each node, in the determination of lengths of pipes supplied from the different nodes of the model, or in the diameters of the pipes that supply the different sectors from the arterial network and the number of inhabitants or bills located in each sector.

However, in sector models it will be necessary to guesstimate as closely as possible to reality the distribution of consumption in the situations that the field measurements will take place in, with the object of contrasting the latter with the results that will be given by the model. The actual

uncertainty in the distribution of consumptions means that these can be considered as parameters to be adjusted. This uncertainty is not only imposed by hourly variations in consumption, but also by the existence of leaks, illegal connections, meter errors, etc... in short, by uncontrolled consumptions that should be distributed in some way among the system's nodes.

The reliability of the allocation of this flow (the model's total load) will increase with a larger amount of available information. It would be desirable to take into account:

- Meter readings: these give us the consumed volume for user in a specified time period. It is important to have this information on a magnetic band so that it can be related with network's databases and its simplified model's database. In short, it's a case of relating each user to a service pipe of the network, which in turn is related to one of the mathematical model's nodes. In this way each one of the users can be related to one of the skeleton's nodes, so that the model can be adequately loaded;
- Temporary evolution of demand: consumption is not constant throughout all hours of the day, nor throughout the week, nor for different times of year.

Consumption modulation exists, initially different for each user, and it depends on very different factors that should be mentioned:

- *Type of user*: generally classified as domestic, industrial, commercial and community services. This last type includes hospital, schools, irrigation of parks, street cleaning, etc...;
- *Socioeconomic level of the user*: this influences decisively not only the total consumed volume, but also how it is consumed;
- *Tourist areas*: this has a strong seasonal consumption component, more than half the annual consumption being concentrated in the three summer months;
- *Domestic storage*: the user's greater or lesser storage capacity influences decisively the hourly modulation slope. In many cases the user has storage tanks, so that the real demand does not correspond to the actual consumption at each moment. However, in the case of direct supply from service pipelines, the peak consumption that the network is subjected to are more pronounced;
- *Pressure levels in the network*: this influences strongly the value of instantaneous flow rate for those users that have a direct supply, as there is a large number of consumption devices in which the instantaneous flow rate is a function of pressure.

Generally, to determine the evolution of consumption it is indispensable to take a sample of different types of users, with the object of fixing a characteristic modulation slope for each one. Multiplying the total consumed volume by the modulation coefficient, which corresponds to the situation that is analyzed, we can obtain the instantaneous flow rate of each user.

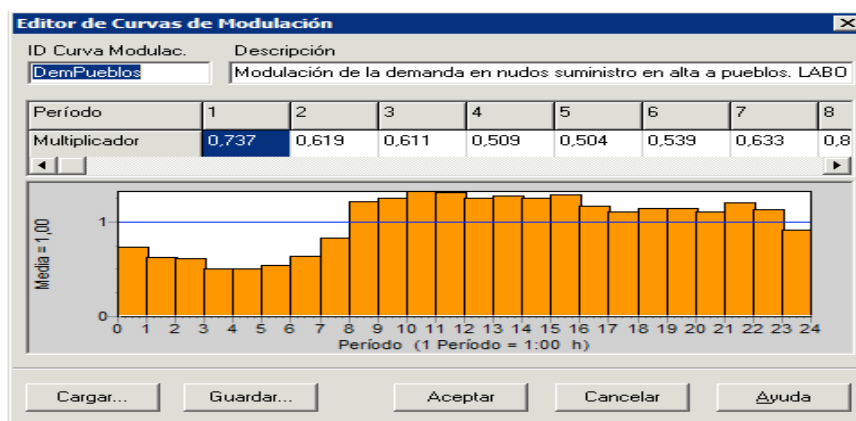


Fig.2.3:Modulation Curve of a DMA(District Meter Area)

- Important consumers: it is convenient to take in situ measurements of the flow supplied to large consumers (large industries, hospitals, ect...) so that we may have a consumption distribution that agrees with reality. The relative importance of these in the supply system assembly means that it is necessary to include a node for each one of them, that will be loaded according to the measurements that were taken;
- Uncontrolled consumptions, leaks: determining the volume of the water that is not registered in a supply system in the average time between two meter readings is relatively simple, as long as the total input volume is known. The difference between the latter and the volume of registered water will give us the uncontrolled volume, which to start with will include meter reading errors. The volume of registered water over the input volume at a certain moment in time is called the average efficiency of the network in this period. However, the absence of instantaneous consumption data in a supply system means that the uncontrolled instantaneous flow rate of water in a supply system cannot be determined with precision. This means that we must turn to guesstimates, and in the same way it is practically impossible to allocate it in a reliable manner between the model's nodes.

These uncontrolled flow rates are due to illegal connections, leaks, municipal consumption or services that cannot be measured, meter errors, etc... They also suffer modulations throughout the day or time of year; so for example, the leaks in a water supply system increase as pressures increase, generally in low consumption periods if the piezometric height at the beginning of the system is not reduced. Their spatial distribution is conditioned by factors such as the material used in their pipes and valves, their age and other more or less fortuitous phenomena. To estimate their situations it can be useful to have results of leak analyses that have been carried out on the system. In function of these it is possible to, for example, carry out a distribution that will be proportional to the metres of piping of each material.

In any case, an estimate of uncontrolled flow rates can serve as initial data when they are used as adjusting parameters. During the model's calibration process this distribution can be modified in such a way that, in some cases, areas of the system can be detected where the consumption is increased, which can mean a greater degree of leaks or of illegal connections. Evidently, it can be very useful to have the instantaneous flow rate values input to the system at each one of the network's sectors, as in this case the problem of distribution is sectional, so that the errors made in the initial estimates can be considerably less.

Taking into account all of these factors that have been mentioned, it is always possible to establish a method for assigning flow rates to the model's nodes. We must not forget that it always will be a guesstimate, whose reliability will increase as the initial data improves. We will thus return to what has been said in previous sections: the quality of a model is clearly influenced by the quality of the initial data.

2.5.4 Load of the model. Exportation of the model to hydraulic simulator

All nodes of connection between pipes or ends thereof are points of consumption. These nodes are declared automatically by tracing the pipes, by assigning the internal numbering scheme and default attributes. In the case of consumer nodes, the most relevant information for the purpose of hydraulic modeling is the base demand and the modulation time of demand.

Once constructed the mathematical model of the network with the support of GIS software, can be exported the file (.shp) to the hydraulic simulator Epanet, with the aid of which calibration is performed and run the simulations.

2.5.5 Calibration of the model. Adjustment of the parameters

The calibration of a mathematical model involves the correction or adjustment of various parameters of it, with the ultimate aim of having that the results of the simulation approaching as much as possible to the actual measured values.

The adjustable parameters during the calibration process are those likely to introduce a degree of uncertainty in the model. These are usually roughness of pipes, minor losses or localized, and in case as dynamic models like this, the control laws of valves and pumps. Also you can adjust the values of other parameters such as the height on some points of the network and the diameter of a pipe, but it is assumed that these variables are part of the group of network characteristic data obtained with sufficient reliability.

The calibration of a model with these features (with high numbers of tanks, with various regulating and control elements) is particularly complex and laborious. Before addressing the calibration of any model is recommended to set a certain strategy, a fact that, given the circumstances of the system that is intended to model, it becomes indispensable.

The calibration is done gradually, and we first need to simplify the problem, for which it acts in two ways:

1. Divide the general model into several smaller ones. These submodels calibrate first, so after completing the process, in all of them are moved the results of each model to the full model;
2. Reduce the maximum degrees of freedom of the model or sub-model is intended to calibrate. This involves forcing, hour by hour, the behavior of valves and pumps, as well as forcing all flows entry and exit to the system. This is achieved by ensuring that the circulating volume is adequate for the load assigned to the model, thus reducing the degree of uncertainty in the system. It is more reliable to make decisions and make adjustments when it knows that the incoming and outgoing flows are correct when they are not. The same applies to the behavior of valves and pumps. In addition, the calibration process of each sub-model is also develops gradually, so that the number of forced elements is reduced gradually, as the simulation results are getting better.

In general, the calibration process involves a series of actions on two types of variables: first, hydraulic parameters of the network, and secondly, on the control parameters of the pumping units or operated valves during the exploitation of the system.

These actions involve the introduction of new information in the model, as well as the modification of an existing: mainly in pipes, valves, pumps and nodes. The following are the most common changes that occur during the adjustment process of the calibration itself:

- * *Setpoints*: these values define the operation of valves and pumps. In some instances, actual values are known and as such it is sufficient to incorporate the model. In other cases, the values are known but should be adjusted if you want to reproduce with sufficient accuracy the performance of the element in question, since the actual value is not achieved the latter. There is also the possibility that the setpoints are to be estimated, though for two separate cases: they are not known but are estimated basing on indirectly controlled hydraulic variables, such as levels in tanks or water flows, or they are not known because not really exist. The latter case corresponds to the case of valves in the model are defined by a distinct typology of real: one regulating valve can be incorporated into the model as a pressure reducing valve if it is proved that the pressure downstream of it just varies in time;
- * *Control laws*: these laws are extremely useful when receiving orders simulate the operation of the system elements: like pumps and valves. In some cases control laws attempt to

reproduce the commands scheduled at various local automation, devices that control the operation of all elements basing on records of specific hydraulic parameters. In other cases, the control laws try to simulate the actions ordered by a person who oversees the system from a control station;

- * *Typologies of the valves*: they get approach the behavior of the model to real network operation, improving the results of the simulation;
- * *Lower losses*: by default, all the pipes are assigned an initial value of zero coefficient lower losses. May occur that their respective piping head losses are different from those initially resulting from the simulation carried out. The modification of this divergence between the model and reality may be due to several reasons: one is that the losses in the pipe are lower than expected, which can be explained by not having considered some peculiarity in the way or because the roughness assigned to be different from real; the second reason to change the coefficient of minor losses initially allocated is to reduce the current flow through the pipe to nearest other values are estimated as real;
- * *Heights*: dimension values assigned during the making of the model come from measurements made at the field level, however most of the installations run at some depth so that the assignment of dimensions may take some error both for the height difference both for insufficient levels of measurement points.

During the calibration of the model have been introduced a number of changes in the different parameters of the model definition, have been introduced and a number of discrepancies between the model in Epanet and the file obtained in GIS have been generated. It will therefore be necessary to introduce all the changes that were made during the calibration procedure into the GIS base data. This will allow us to re-export the model of Epanet directly from GIS, in a simpler way.

2.6 Framework required for connection and management of hydraulic models

Modern software tools are necessary for solution problems with operation of water supply system such as hydraulic, qualitative, and economic and safety problems.

Management is complex tool for administration and operation of water supply system. It contains modern software tools divided in of three groups:

1. Mathematical model;
2. GIS;
3. SCADA.

These processes allowed us manage whole system more effective with information in real time. All three systems works with information data of conditions of water supply system.

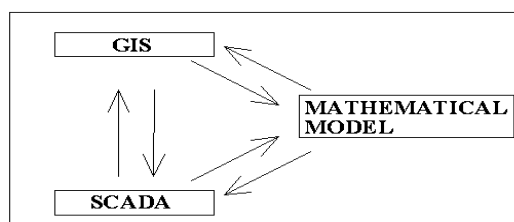


Fig.2.4:Connection between tools

2.7 Software for the simulation:EPANET 2.0

EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps.

In addition to chemical species, water age and source tracing can also be simulated.

EPANET is designed to be a research tool for improving our understanding of the movement and fate of drinking water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis. Sampling program design, hydraulic model calibration, chlorine residual analysis, and consumer exposure assessment are some examples. EPANET can help assess alternative management strategies for improving water quality throughout a system. EPANET provides an integrated environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. These include color-coded network maps, data tables, time series graphs, and contour plots.

2.7.1 Program features of EPANET

Full-featured and accurate hydraulic modeling is a prerequisite for doing effective water quality modeling. EPANET contains a state-of-the-art hydraulic analysis engine that includes the following capabilities:

- Places no limit on the size of the network that can be analyzed;
- Computes friction headloss using the Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas;
- Includes minor head losses for bends, fittings, etc;
- Models constant or variable speed pumps;
- Computes pumping energy and cost;
- Models various types of valves including shutoff, check, pressure regulating, and flow control valves;
- Allows storage tanks to have any shape (i.e., diameter can vary with height);
- Considers multiple demand categories at nodes, each with its own pattern of time variation;
- Models pressure-dependent flow issuing from emitters (sprinkler heads);
- Can base system operation on both simple tank level or timer controls and on complex rule based controls.

2.7.2 Steps in using EPANET

One typically carries out the following steps when using EPANET to model a water distribution system:

1. Draw a network representation of your distribution system or import a basic description of the network placed in a text file;
2. Edit the properties of the objects that make up the system;
3. Describe how the system is operated;
4. Select a set of analysis options;
5. Run a hydraulic/water quality analysis;
6. View the results of the analysis.

2.7.3 Physical components in water distribution systems

EPANET models a water distribution system as a collection of links connected to nodes. The links represent pipes, pumps, and control valves. The nodes represent junctions, tanks, and reservoirs. The figure below illustrates how these objects can be connected to one another to form a network.

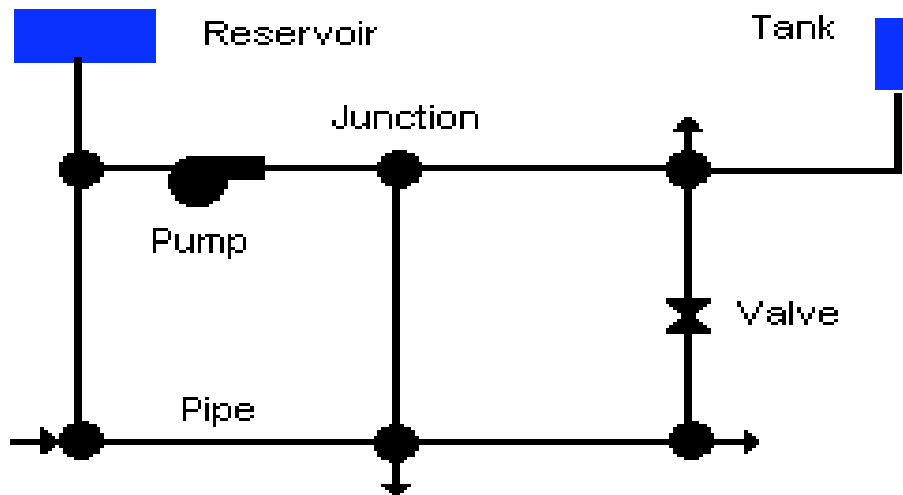


Fig.2.5:Representation of a water distribution system

Junction

Junctions are points in the network where links join together and where water enters or leaves the network. The basic input data required for junctions are:

- elevation above some reference (usually mean sea level);
- water demand (rate of withdrawal from the network);
- initial water quality.

The output results computed for junctions at all time periods of a simulation are:

- hydraulic head (internal energy per unit weight of fluid);
- pressure;
- water quality.

Junctions can also:

- * have their demand vary with time;
- * have multiple categories of demands assigned to them;
- * have negative demands indicating that water is entering the network;
- * be water quality sources where constituents enter the network.

Reservoirs

Reservoirs are nodes that represent an infinite external source or sink of water to the network. They are used to model such things as lakes, rivers, groundwater aquifers, and tie-ins to other systems. Reservoirs can also serve as water quality source points. The primary input properties for a reservoir are its hydraulic head (equal to the water surface elevation if the reservoir is not under pressure) and

its initial quality for water quality analysis.

Because a reservoir is a boundary point to a network, its head and water quality cannot be affected by what happens within the network. Therefore it has no computed output properties. However its head can be made to vary with time by assigning a time pattern to it.

Tanks

Tanks are nodes with storage capacity, where the volume of stored water can vary with time during a simulation. The primary input properties for tanks are:

- bottom elevation (where water level is zero);
- diameter (or shape if non-cylindrical);
- initial, minimum and maximum water levels;
- initial water quality.

The principal outputs computed over time are:

- hydraulic head (water surface elevation);
- water quality.

Tanks are required to operate within their minimum and maximum levels. EPANET stops outflow if a tank is at its minimum level and stops inflow if it is at its maximum level. Tanks can also serve as water quality source points.

Pipes

Pipes are links that convey water from one point in the network to another. EPANET assumes that all pipes are full at all times. Flow direction is from the end at higher hydraulic head (internal energy per weight of water) to that at lower head.

The principal hydraulic input parameters for pipes are:

- ❖ start and end nodes;
- ❖ diameter;
- ❖ length;
- ❖ roughness coefficient (for determining headloss);
- ❖ status (open, closed, or contains a check valve).

The status parameter allows pipes to implicitly contain shutoff (gate) valves and check (non-return) valves (which allow flow in only one direction).

Computed outputs for pipes include:

- flow rate;
- velocity;
- headloss;
- Darcy-Weisbach friction factor;
- average reaction rate (over the pipe length);
- average water quality (over the pipe length).

The hydraulic head lost by water flowing in a pipe due to friction with the pipe walls can be computed using one of three different formulas:

- Hazen-Williams formula;
- Darcy-Weisbach;
- Chezy-Manning.

Each formula uses the following equation to compute headloss between the start and end node of the pipe:

$$\Delta h = A \cdot (q^B)$$

where: Δh : headloss (length); A: resistance coefficient; q: flow rate (Volume/Time); B: flow exponent.

Each formula uses a different pipe roughness coefficient that must be determined empirically. Be aware that a pipe's roughness coefficient can change considerably with age.

The Darcy-Weisbach formula is the most theoretically correct. It applies over all flow regimes and to all liquids. With the Darcy-Weisbach formula EPANET uses different methods to compute the friction factor f depending on the flow regime:

- The Hagen–Poiseuille formula is used for laminar flow ($Re < 2,000$);
- The Swamee and Jain approximation to the Colebrook-White equation is used for fully turbulent flow ($Re > 4,000$);
- A cubic interpolation from the Moody Diagram is used for transitional flow ($2,000 < Re < 4,000$).

<i>Formula</i>	<i>Resistance Coefficient (A)</i>	<i>Flow Exponent (B)</i>
Hazen-Williams	$4.727 C^{-1.852} d^{-4.871} L$	1.852
Darcy-Weisbach	$0.0252 f(\epsilon, d, q) d^{-5} L$	2
Chezy-Manning	$4.66 n^2 d^{-5.33} L$	2

Notes: C = Hazen-Williams roughness coefficient
 ϵ = Darcy-Weisbach roughness coefficient (ft)
 f = friction factor (dependent on ϵ , d, and q)
 n = Manning roughness coefficient
 d = pipe diameter (ft)
 L = pipe length (ft)
 q = flow rate (cfs)

Fig.2.6:Pipe Headloss Formulas for full flow(for headloss in feet and flow rate in cfs)

<i>Material</i>	<i>Hazen-Williams C (unitless)</i>	<i>Darcy-Weisbach ϵ (feet x 10⁻³)</i>	<i>Manning's n (unitless)</i>
Cast Iron	130 – 140	0.85	0.012 - 0.015
Concrete or Concrete Lined	120 – 140	1.0 - 10	0.012 - 0.017
Galvanized Iron	120	0.5	0.015 - 0.017
Plastic	140 – 150	0.005	0.011 - 0.015
Steel	140 – 150	0.15	0.015 - 0.017
Vitrified Clay	110		0.013 - 0.015

Fig.2.7:Roughness Coefficients for new Pipe

Pipes can be set open or closed at preset times or when specific conditions exist, such as when tank levels fall below or above certain set points, or when nodal pressures fall below or above certain values.

Minor Losses

Minor head losses (also called local losses) are caused by the added turbulence that occurs at bends and fittings. The importance of including such losses depends on the layout of the network and the degree of accuracy required. They can be accounted for by assigning the pipe a minor loss coefficient. The minor headloss becomes the product of this coefficient and the velocity head of the pipe, i.e.,

$$\Delta h = K \cdot \left(\frac{v^2}{2g} \right)$$

where: Δh : local losses;

K: minor loss coefficient;

v: flow velocity (Length/Time);

g: acceleration of gravity (Length/Time²)

<i>FITTING</i>	<i>LOSS COEFFICIENT</i>
Globe valve, fully open	10.0
Angle valve, fully open	5.0
Swing check valve, fully open	2.5
Gate valve, fully open	0.2
Short-radius elbow	0.9
Medium-radius elbow	0.8
Long-radius elbow	0.6
45 degree elbow	0.4
Closed return bend	2.2
Standard tee - flow through run	0.6
Standard tee - flow through branch	1.8
Square entrance	0.5
Exit	1.0

Fig.2.8: Minor Loss Coefficients for selected fittings

Pumps

Pumps are links that impart energy to a fluid thereby raising its hydraulic head. The principal input parameters for a pump are its start and end nodes and its pump curve (the combination of heads and flows that the pump can produce). In lieu of a pump curve, the pump could be represented as a constant energy device, one that supplies a constant amount of energy (horsepower or kilowatts) to the fluid for all combinations of flow and head.

The principal output parameters are flow and head gain. Flow through a pump is unidirectional and EPANET will not allow a pump to operate outside the range of its pump curve.

Variable speed pumps can also be considered by specifying that their speed setting be changed under these same types of conditions. By definition, the original pump curve supplied to the program has a relative speed setting of 1. If the pump speed doubles, then the relative setting would be 2; if run at half speed, the relative setting is 0.5 and so on. Changing the pump speed shifts the position and shape of the pump curve.

As with pipes, pumps can be turned on and off at preset times or when certain conditions exist in the network. A pump's operation can also be described by assigning it a time pattern of relative speed settings. EPANET can also compute the energy consumption and cost of a pump. Each pump can be assigned an efficiency curve and schedule of energy prices. If these are not supplied then a set of global energy options will be used.

Flow through a pump is unidirectional. If system conditions require more head than the pump can produce, EPANET shuts the pump off. If more than the maximum flow is required, EPANET extrapolates the pump curve to the required flow, even if this produces a negative head. In both cases a warning message will be issued.

Valves

Valves are links that limit the pressure or flow at a specific point in the network. Their principal input parameters include:

- * start and end nodes;
- * diameter;
- * setting;
- * status.

The computed outputs for a valve are flow rate and headloss.

The different types of valves included in EPANET are:

- Pressure Reducing Valve (PRV);
- Pressure Sustaining Valve (PSV);
- Pressure Breaker Valve (PBV);
- Flow Control Valve (FCV);
- Throttle Control Valve (TCV);
- General Purpose Valve (GPV).

PRVs limit the pressure at a point in the pipe network. EPANET computes in which of these three different states a PRV can be in:

- partially opened to achieve its pressure setting on its downstream side when the upstream pressure is above the setting;
- fully open if the upstream pressure is below the setting;
- closed if the pressure on the downstream side exceeds that on the upstream side (reverse flow is not allowed).

PSVs maintain a set pressure at a specific point in the pipe network. EPANET computes in which of these three different states a PSV can be in:

- partially opened to maintain its pressure setting on its upstream side when the downstream pressure is below this value;
- fully open if the downstream pressure is above the setting;
- closed if the pressure on the downstream side exceeds that on the upstream side (reverse flow is not allowed).

PBVs force a specified pressure loss to occur across the valve. Flow through the valve can be in either direction. PBV's are not true physical devices but can be used to model situations where a particular pressure drop is known to exist.

FCVs limit the flow to a specified amount. The program produces a warning message if this flow cannot be maintained without having to add additional head at the valve (i.e., the flow cannot be maintained even with the valve fully open).

TCVs simulate a partially closed valve by adjusting the minor head loss coefficient of the valve. A relationship between the degree to which a valve is closed and the resulting head loss coefficient is usually available from the valve manufacturer.

GPVs are used to represent a link where the user supplies a special flow - head loss relationship instead of following one of the standard hydraulic formulas. They can be used to model turbines, well draw-down or reduced-flow backflow prevention valves.

Shutoff (gate) valves and check (non-return) valves, which completely open or close pipes, are not considered as separate valve links but are instead included as a property of the pipe in which they are placed.

Each type of valve has a different type of setting parameter that describes its operating point (pressure for PRVs, PSVs, and PBVs; flow for FCVs; loss coefficient for TCVs, and head loss curve for GPVs).

Valves can have their control status overridden by specifying they be either completely open or completely closed. A valve's status and its setting can be changed during the simulation by using control statements.

Because of the ways in which valves are modeled the following rules apply when adding valves to a network:

- * a PRV, PSV or FCV cannot be directly connected to a reservoir or tank (use a length of pipe to separate the two);
- * PRVs cannot share the same downstream node or be linked in series;
- * two PSVs cannot share the same upstream node or be linked in series;
- * a PSV cannot be connected to the downstream node of a PRV.

2.7.4 Not-physical components: curves, time patterns and controls

In addition to physical components, EPANET employs three types of informational objects – curves, time patterns, and controls - that describe the behavior and operational aspects of a distribution system.

Curves

Curves are objects that contain data pairs representing a relationship between two utilize the following types of curves:

- ❖ Pump Curve;
- ❖ Efficiency Curve;
- ❖ Volume Curve;
- ❖ Head Loss Curve.

Pump Curve represents the relationship between the head and flow rate that a pump can deliver at its nominal speed setting. Head is the head gain imparted to the water by the pump and is plotted on the vertical (Y) axis of the curve in feet (meters).

Flow rate is plotted on the horizontal (X) axis in flow units. A valid pump curve must have decreasing head with increasing flow. EPANET will use a different shape of pump curve depending on the number of points supplied:

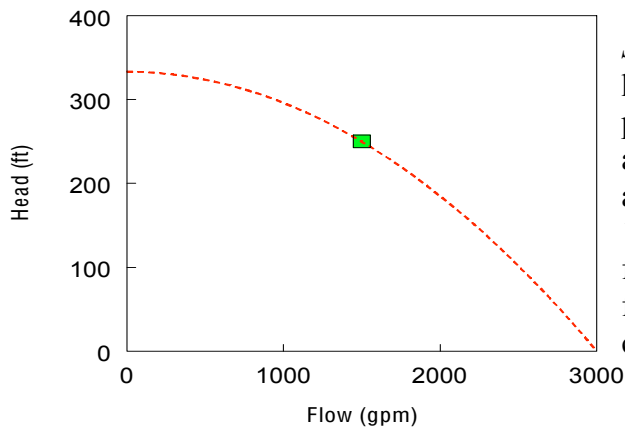


Fig.2.9:Single-Point Pump Curve

Single-Point Curve is defined by a single head-flow combination that represents a pump's desired operating point. EPANET adds two more points to the curve by assuming a shutoff head at zero flow equal to 133% of the design head and a maximum flow at zero head equal to twice the design flow. It then treats the curve as a three-point curve.

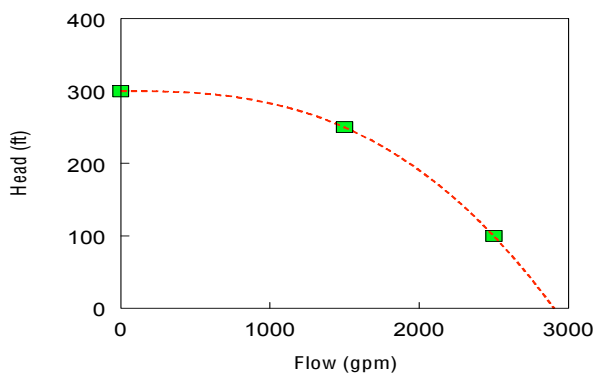
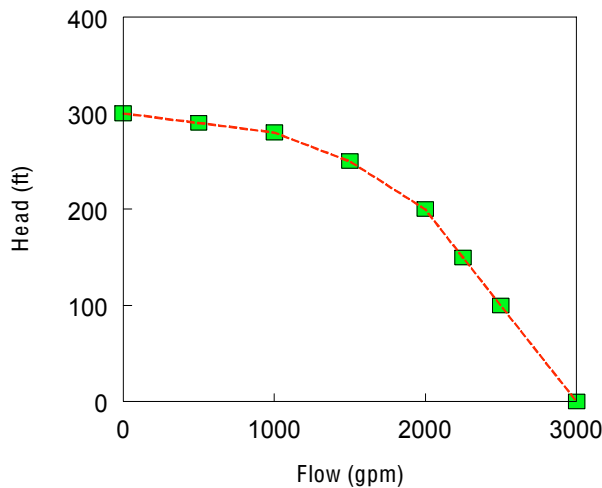


Fig.2.10:Three-Point Pump Curve

Three-Point Curve is defined by three operating points: a Low Flow point, a Design Flow point, and a Maximum Flow point. EPANET tries to fit a continuous function of the form:

$$h = A - B \cdot q^C$$

through the three points to define the entire pump curve. In this function, h = head gain, q = flow rate, and A , B , and C are constants.



Multi-Point Curve is defined by providing either a pair of head-flow points or four or more such points. EPANET creates a complete curve by connecting the points with straight-line segments. For variable speed pumps, the pump curve shifts as the speed changes. The relationships between flow (Q) and head (H) at speeds N1 and N2 are:

$$\frac{Q1}{Q2} = \frac{N1}{N2} ; \frac{H1}{H2} = \left(\frac{N1}{N2}\right)^2$$

Fig.2.11:Multi-Point Pump Curve

Efficiency Curve determines pump efficiency (Y in percent) as a function of pump flow rate (X in flow units). Efficiency should represent wire-to-water efficiency that takes into account mechanical losses in the pump itself as well as electrical losses in the pump's motor. The curve is used only for energy calculations. If not supplied for a specific pump then a fixed global pump efficiency will be used.

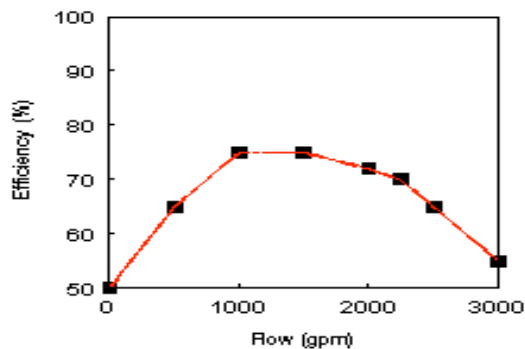


Fig.2.12:Pump Efficiency Curve

Volume Curve determines how storage tank volume (Y in cubic feet or cubic meters) varies as a function of water level (X in feet or meters). It is used when it is necessary to accurately represent tanks whose cross-sectional area varies with height. The lower and upper water levels supplied for the curve must contain the lower and upper levels between which the tank operates. An example of a tank volume curve is given below.

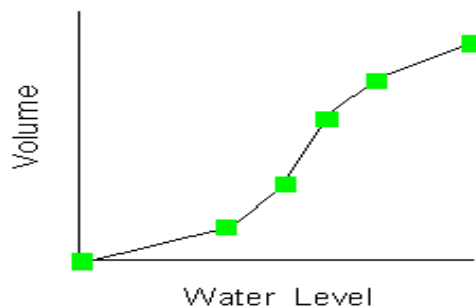


Fig.2.13:Tank Volume Curve

Headloss Curve is used to describe the headloss (Y in feet or meters) through a General Purpose Valve (GPV) as a function of flow rate (X in flow units). It provides the capability to model devices and situations with unique headloss-flow relationships, such as reduced flow - backflow prevention valves, turbines, and well draw-down behavior.

Time patterns

A Time Pattern is a collection of multipliers that can be applied to a quantity to allow it to vary over time. Nodal demands, reservoir heads, pump schedules, and water quality source inputs can all have time patterns associated with them. The time interval used in all patterns is a fixed value, set with the project's Time Options. Within this interval a quantity remains at a constant level, equal to the product of its nominal value and the pattern's multiplier for that time period. Although all time patterns must utilize the same time interval, each can have a different number of periods. When the simulation clock exceeds the number of periods in a pattern, the pattern wraps around to its first period again.

Controls

Controls are statements that determine how the network is operated over time. They specify the status of selected links as a function of time, tank water levels, and pressures at select points within the network. There are two categories of controls that can be used:

1. Simple Controls;
2. Rule-Based Controls.

Simple Controls change the status or setting of a link based on:

- the water level in a tank;
- the pressure at a junction;
- the time into the simulation;
- the time of day.

Level controls are stated in terms of the height of water above the tank bottom, not the elevation (total head) of the water surface.

Using a pair of pressure controls to open and close a link can cause the system to become unstable if the pressure settings are too close to one another. In this case using a pair of Rule-Based controls might provide more stability.

Rule-Based Controls allow link status and settings to be based on a combination of conditions that might exist in the network after an initial hydraulic state of the system is computed.

2.7.5 Hydraulic simulation model

EPANET's hydraulic simulation model computes junction heads and link flows for a fixed set of reservoir levels, tank levels, and water demands over a succession of points in time. From one time step to the next reservoir levels and junction demands are updated according to their prescribed time patterns while tank levels are updated using the current flow solution. The solution for heads and flows at a particular point in time involves solving simultaneously the conservation of flow equation for each junction and the headloss relationship across each link in the network. This process, known as "hydraulically balancing" the network, requires using an iterative technique to solve the nonlinear equations involved. EPANET employs the "Gradient Algorithm" for this purpose. The hydraulic time step used for extended period simulation (EPS) can be set by the user.

A typical value is 1 hour. Shorter time steps than normal will occur automatically whenever one of the following events occurs:

- * the next output reporting time period occurs;
- * the next time pattern period occurs;
- * a tank becomes empty or full;
- * a simple control or rule-based control is activated.

2.7.6 Viewing results: map, graph, table and special reports

The basic EPANET workspace consists of the following user interface elements: a Menu Bar, two Toolbars, a Status Bar, the Network Map window, a Browser window, and a Property Editor window:

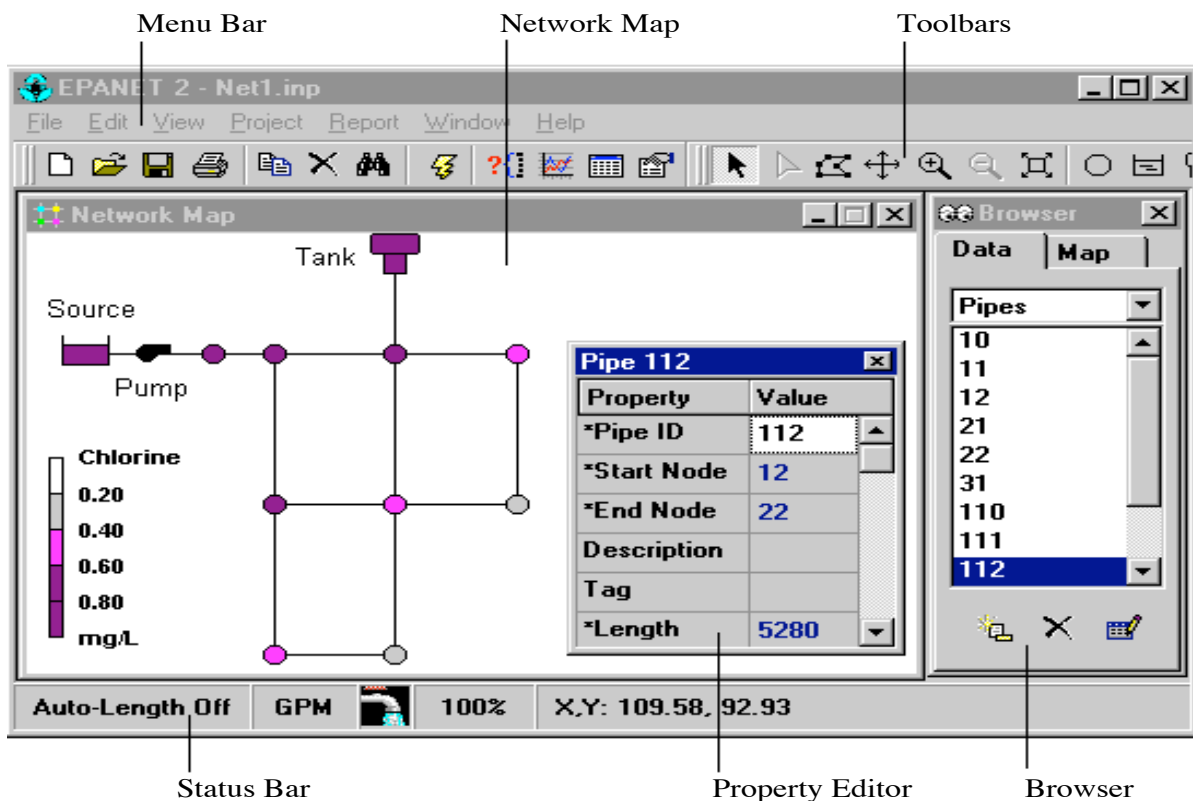


Fig.2.14:User interface elements

Viewing results on the map

There are several ways in which database values and results of a simulation can be viewed directly on the Network Map:

- For the current settings on the Map Browser, the nodes and links of the map will be colored according to the color-coding used in the Map Legends. The map's coloring will be updated as a new time period is selected in the Browser;
- When the Flyover Map Labeling program preference is selected, moving the mouse over any node or link will display its ID label and the value of the current viewing parameter for that node or link in a hint-style box;
- ID labels and viewing parameter values can be displayed next to all nodes and/or links by selecting the appropriate options on the Notation page of the Map Options dialog form;
- Nodes or links meeting a specific criterion can be identified by submitting a Map Query (see below);
- You can animate the display of results on the network map either forward or backward in time by using the Animation buttons on the Map Browser. Animation is only available when a node or link viewing parameter is a computed value (link flow rate can be animated but diameter cannot);
- The map can be printed, copied to the Windows clipboard, or saved as a DXF file or Windows metafile.

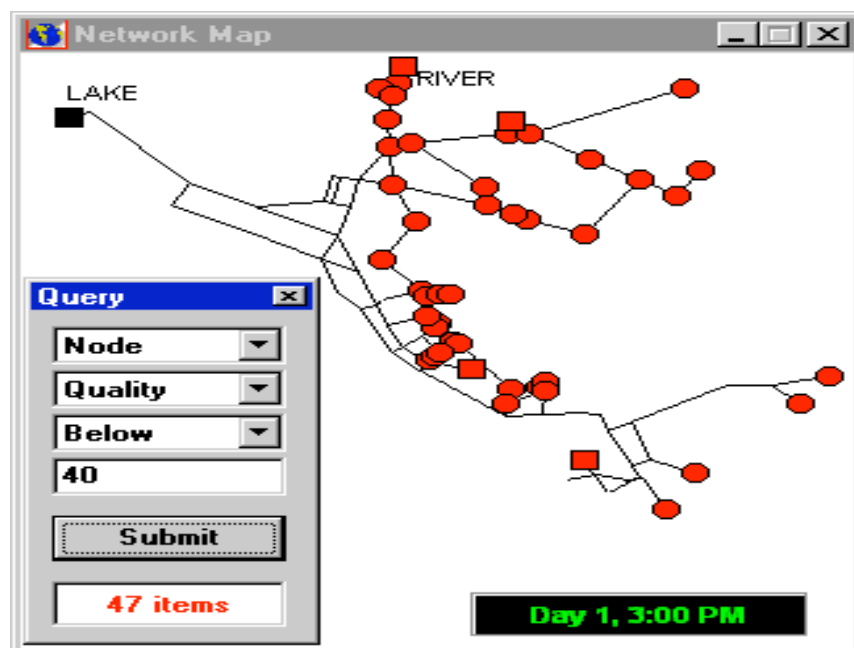


Fig.2.15:Results of a Map Query

Viewing results with a graph

Analysis results, as well as some design parameters, can be viewed using several different types of graphs. Graphs can be printed, copied to the Windows clipboard, or saved as a data file or Windows metafile.

The following types of graphs can be used to view values for a selected parameter.

<i>Type of Plot</i>	<i>Description</i>	<i>Applies To</i>
Time Series Plot	Plots value versus time	Specific nodes or links over all time periods
Profile Plot	Plots value versus distance	A list of nodes at a specific time
Contour Plot	Shows regions of the map where values fall within specific intervals	All nodes at a specific time
Frequency Plot	Plots value versus fraction of objects at or below the value	All nodes or links at a specific time
System Flow	Plots total system production and consumption versus time	Water demand for all nodes over all time periods

Fig.2.16:Different types of graphs for a selected parameter

The Graph Selection dialog is used to select a type of graph and its contents to display. The choices available in the dialog consist of the following:

<i>Item</i>	<i>Description</i>
Graph Type	Selects a graph type
Parameter	Selects a parameter to graph
Time Period	Selects a time period to graph (does not apply to Time Series plots)
Object Type	Selects either Nodes or Links (only Nodes can be graphed on Profile and Contour plots)
Items to Graph	Selects items to graph (applies only to Time Series and Profile plots)

Fig.2.17:Steps for select a graph

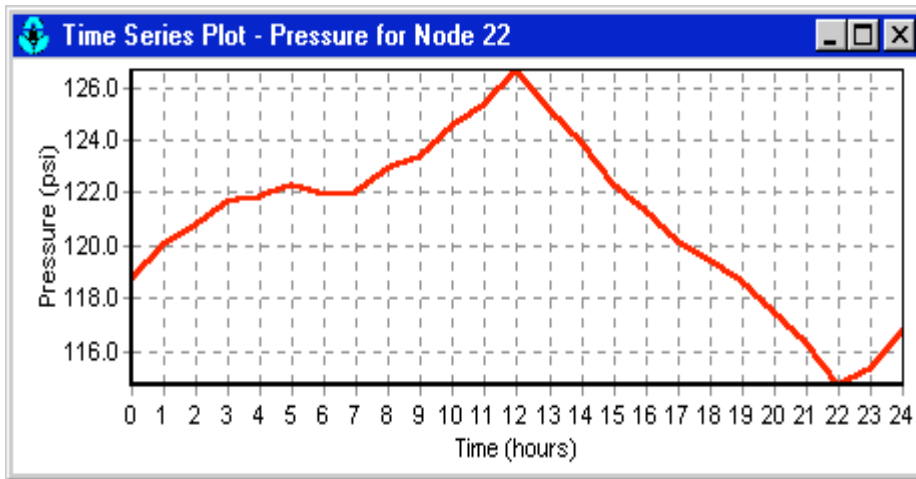


Fig.2.18:Graph Pressure-Time

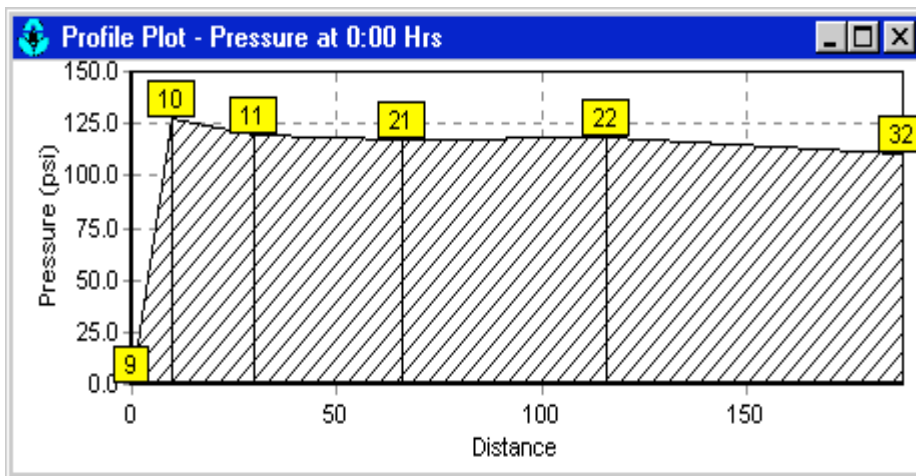


Fig.2.19:Graph Pressure-Distance

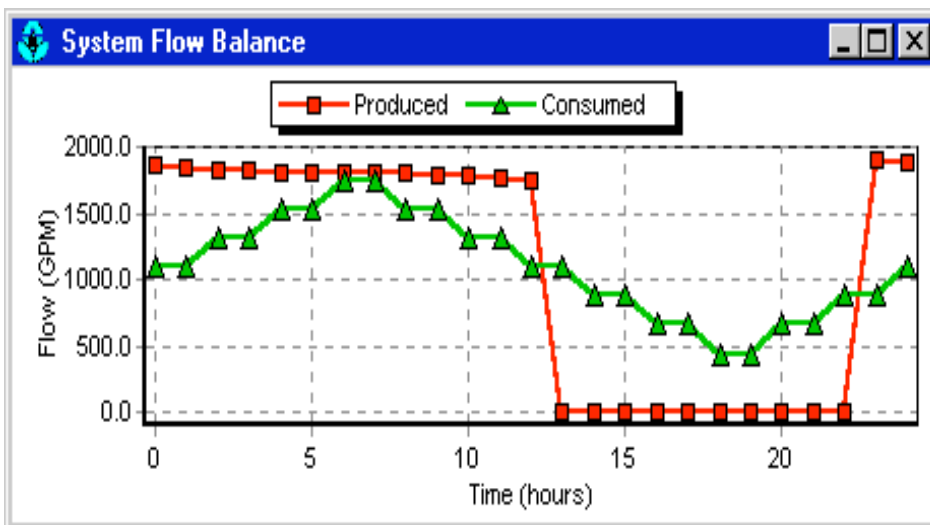


Fig.2.20:Graph Flow-Time

Viewing results with a table

EPANET allows you to view selected project data and analysis results in a tabular format:

- a network table lists properties and results for all nodes or links at a specific period of time;
- a time series table lists proprieties and results for a specific node or link in all time periods.

Node ID	Demand GPM	Head ft	Pressure psi	Chlorine mg/L
Jun 10	0.00	1010.67	130.28	1.00
Jun 11	210.00	992.42	122.37	0.85
Jun 12	210.00	980.17	121.40	0.78
Jun 13	140.00	977.08	122.23	0.30
Jun 21	210.00	977.24	120.13	0.74
Jun 22	280.00	976.29	121.88	0.49
Jun 23	210.00	975.76	123.82	0.30
Jun 31	140.00	970.32	117.13	0.53

Fig.2.21:Example of a Network Nodes Table

Viewing special reports

In addition to graphs and tables, EPANET can generate several other specialized reports. These include:

- Status Report;
- Energy Report;
- Calibration Report;
- Full Report.

Status Report: all error and warning messages generated during an analysis to a Status Report. Additional information on when network objects change status is also written to this report file if the Status Report option in the project's Hydraulics Options was set to Yes or Full.

Energy Report: displays statistics about the energy consumed by each pump and the cost of this energy usage over the duration of a simulation. The report has two tabbed pages. One displays energy usage by pump in a tabular format; the second compares a selected energy statistic between pumps using a bar chart.

Calibration Report: show how well EPANET's simulated results match measurements taken from the system being model. A sample Calibration Report contains three tabbed pages: Statistics, Correlation Plot and Mean Comparisons.

The Statistics Page of a Calibration Report lists various error statistics between simulated and observed values at each measurement location and for the network as a whole. If a measured value at a location was taken at a time in between the simulation's reporting time intervals then a simulated value for that time is found by interpolating between the simulated values at either end of the interval.

The statistics listed for each measurement location are:

- * Number of observations;
- * Mean of the observed values;
- * Mean of the simulated values;
- * Mean absolute error between each observed and simulated value;
- * Root mean square error (square root of the mean of the squared errors between the observed and simulated values).

These statistics are also provided for the network as a whole (all measurements and model errors pooled together). Also listed is the correlation between means (correlation coefficient between the mean observed value and mean simulated value at each location).

The Correlation Plot page of a Calibration Report displays a scatter plot of the observed and simulated values for each measurement made at each location. Each location is assigned a different color in the plot. The closer that the points come to the 45-degree angle line on the plot the closer is the match between observed and simulated values.

The Mean Comparisons page of a Calibration Report presents a bar chart that compares the observed and simulated mean values for a calibration parameter at each location where measurements were taken.

Full Report: can be viewed or printed outside of EPANET using any text editor or word processor, contains the following information:

- Project title and notes;
- Table listing the end nodes, length, and diameter of each link;
- Table listing energy usage statistics for each pump;
- Tables for each time period listing computed values for each node (demand, head, pressure and quality) and for each link (flow, velocity, headloss and status).

This feature is useful mainly for documenting the final results of a network analysis on small to moderately sized networks (full report files for large networks analyzed over many time periods can easily consume dozens of megabytes of disk space).

2.8 GIS (Geographic Information Systems)

GIS (Geographic information systems) is used since 1960. Operations which is using have been done manually also before 100 years, but single history of GIS started with development of computer techniques. Over the last decade, GIS use has grown dramatically in government, utilities, business, and academia where it is being used for many diverse applications. Consequently, a variety of GIS terms and definitions has developed.

GIS is a computer based tool that is used to capture, store, update, manipulate, retrieve, analyze, display, print, and otherwise manage large amounts of geographic and attribute data. Geographic information system is set of technical and programmatic tools for storing, processing and using geographic information's in two forms - graphic and database, mutually linked and topologically ordered. Geography is a discipline that looks at things within their spatial context; an information system is a sequence of operations that begins with planning and collection data, continues with storage and analysis of the data, and ends with the use of the derived information in some decision-making process. Originally, these tools were developed to ease cartography, but they are currently being used for diverse applications such as, planning, facilities management, and hydrologic and hydraulic modeling.

Additional GIS definitions are given below:

- * A computer system capable of holding and using data describing places on the earth's surface;
- * A computer-based tool for mapping and analyzing things that exist and events that happen on earth;
- * An organized collection of computer hardware, software, spatial data, and personnel designed to effectively capture, store, update, manipulate, analyze and display all forms of geographically referenced information;
- * A technology that integrates common database operations, such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps;
- * A GIS is a system for organization, analysis, and rendering of spatial data used in a problem solving process.

2.8.1 GIS Basics

An application of GIS technology has three general areas: creation and displaying of maps - GIS as a tool for administration with map underlayer; creation and processing of maps - GIS as a tool for collecting of data connected with geographical position; analytic function - GIS as a tool for spatial analyzes and synthesis of data.

Every GIS is developed for people including both the general public and the GIS professionals. The main reason for creating any GIS is to make the life of public easier. Once created, even the most sophisticated GIS with the best quality of data cannot survive if it lacks a team of trained and skilled professionals to manage and maintain it. People are, therefore, an important part of GIS and should be included in every GIS definition.

According to above definitions, a GIS performs 7 major functions:

1. Data Capture: importing data from digitizers, scanners, or image processing systems and creating new data through internal operations;
2. Storage: includes storage and management of both spatial and attribute data;
3. Manipulation: allows transformation of map projection, orientation, or scale to facilitate

- analysis across different data layers;
4. **Query:** provides utilities for finding specific geographic features based on their location or attribute data;
 5. **Analysis:** relates spatial and non-spatial data, within a specified neighborhood or across multiple layers, to determine spatial conditions, spatial relations, or spatial trends;
 6. **Display:** provides tools for computer display of geographic features and the analysis results using a variety of symbols and colors;
 7. **Output:** allows the production of printed maps of geographic features and reports and graphs of the analysis results.

As described above, a GIS contains two types of information: geographic and descriptive. The geographic data describe the location of real-world objects and entities on the earth's surface, such as water mains, sewer lines, and parcels. The descriptive data describe the characteristics of those same objects, such as installation date of a water main, sewer size, or parcel owner.

2.8.2 GIS Application in this project:Modeling integration

Originally, the primary function of a GIS for a water or wastewater utility was to map capital assets. However, a GIS is much more than just a mapping application; it offers an extensive set of tools for spatial analysis and data management that, when integrated with a hydraulic model, can provide tremendous operational advantages. Integration of a GIS and hydraulic modeling is the process by which new, updated, or abandoned elements are synchronized between the GIS database and the hydraulic model. Typically, the GIS database is likely to be more up-to-date than a utility's hydraulic model, since GIS supports a variety of applications (mapping, planning, spatial analysis, asset management, etc...) requiring on-demand services and current system information.

2.8.3 Water System Applications:GisRed

The GIS applications that are of particular importance for water utilities include mapping, facilities management, work order management, and short and long-term planning. The planning activities of a water distribution system can be greatly improved through the integration of these applications. By using information obtained with these applications, a water system manager can develop a detailed capital improvement program or operations and maintenance plan.

The application used in the building of these models was developed in Institute of Water and Environmental Engineering at University Polytechnic of Valencia and is called GisRed. GisRed is an extension to ArcView GIS software that integrates the widely used hydraulic modelling software EPANET, keeping all the original GIS options. Consequently, this add-in application may be used to perform single tasks such as drawing a basic network model from scratch or much more complex as importing a whole dataset from an external source, creating an integrated database, building a network model and calibrating it.

GisRed have wide applicability to water supply system studies. Some typical examples are listed below:

- ❖ Management of multiple GisRed projects using the customized Project Manager;
- ❖ Estimating node demands from land use;
- ❖ Estimating node elevations from digital elevation model data;
- ❖ Network calibration using a Genetic Algorithm search method;
- ❖ Definition of as many calibration configurations as required;
- ❖ Running extended period simulations and retrieving the results showing them on the scenario;

- ❖ Network queries and see the result in a specific featured theme;
- ❖ Checking the connectivity of the network based upon graph theory algorithms.

2.8.4 Steps in using GisRed

1. Draw a network representation of your distribution system from scratch using the extension tools or import a basic description of the network placed in a CAD file, a shapefile or Epanet input file;
2. Check importation errors in case of importing;
3. Simply the network (if required);
4. Edit the properties of the objects that make up the system;
5. Describe how the system is operated by means of demand patterns, pump curves, control rules, etc...;
6. Interpolate elevations at selected nodes;
7. Allocate demands;
8. Calibrate the network manually as a first approach;
9. Exportation of the model to the software for the simulation: EPANET.

Chapter 3: Integration of models in SCADA System

3.1 Introduction

At the present there are a variety of systems used to control processes that occur in the real world, and the number of such systems is constantly growing.

There are a lot of systems for air traffic control, water distribution and wastewater collection systems, oil and gas pipelines, electrical utility transmission and distribution systems, and rail and other public transportation systems.

Such systems, called Real Time, whose main function is communication with the physical world, rather than to a human operator, which implies that they must perform their functions in accordance with the events that occur in the real world. Water utilities typically use human operators to monitor the pulse of the water distribution system. To do their job, operators need information about tank levels, pressures, flows, and so forth. For most utilities, SCADA systems provide this information.

3.2 What's a SCADA System

A SCADA system is a collection of field instrumentation, communications systems, and hardware and software systems that permit a system's behavior to be monitored and controlled, typically from a remote site. SCADA is a type of industrial control system (ICS). Industrial control systems are computer controlled systems that monitor and control industrial processes that exist in the physical world. SCADA systems historically distinguish themselves from other ICS systems by being large scale processes that can include multiple sites, and large distances.

SCADA systems are used wherever there is a need to monitor or control a process. This spans many other industries, including other utilities. The common theme is to monitor the behavior of a process or a system and to feed that information back to a central location where decisions can be made and actions can be taken. These processes include industrial, infrastructure, and facility-based processes, as described below:

- *Industrial processes* include those of manufacturing, production, power generation, fabrication, and refining, and may run in continuous, batch, repetitive, or discrete modes;
- *Infrastructure processes* may be public or private, and include water treatment and distribution, wastewater collection and treatment, oil and gas pipelines, electrical power transmission and distribution, wind farms, civil defense siren systems, and large communication systems;
- *Facility processes* occur both in public facilities and private ones, including buildings, airports, ships, and space stations. They monitor and control heating, ventilation, and air conditioning systems (HVAC), access, and energy consumption.

3.3 Program features of a SCADA System: targets, performances, and benefits

SCADA systems are designed primarily as a tool of supervision and control. Its targets can highlight:

- Economy: it is easier to see what happens in the installation from the office to send a operator to perform the task. Certain revisions will turn into unnecessary;
- Accessibility: a full water supply system (pressures, flows, levels), we have it at a click of mouse above the work table. Will be possible to modify the parameters of operation of each valve, check the status of pumps, etc...;
- Maintenance: the data acquisition materializes the possibility of obtaining data from one process, store and present them intelligible for a non-specialist user in order to highlight those values or those moments when a tool detects anomalous values;
- Ergonomics: is the science that seeks to make the relationship between the user and the process as less tight as possible;
- Management: all data collected can be measured by multiple ways using statistical tools, charts, tabulated values, etc...to exploit the system with the best performance;
- Flexibility: any modification of any of the characteristics of the display system does not mean spending time, as there are physical changes that require the installation of wiring or counter.

SCADA, in his tool strand of man-machine interface, includes a number of features aimed at establishing a communication as clear as possible between the process and the operator. Among the performances of such a tool include:

- * *Monitoring*: representation of real-time data to plant operators;
- * *Supervision*: control and data acquisition and process management tools for decision making;
- * *Alarms and Events*: recognition of exceptional events and his immediate knowledge of the operators to carry out the appropriate corrective actions;
- * *Command*: possibility that operators can change setpoints or other key process data directly from the computer;
- * *Data security*: both the sending and the reception of data must be sufficiently protected from unwanted influences, intentional or not.

When we speak of a SCADA system must not forget that there is something more than the displays that tell us how things are going in our installation. After these elements are a multitude of adjustment and control, communications systems and multiple software utilities that want the system to work efficiently and safely. The most obvious benefits of automated control systems and supervised can list them here:

- creation of functional applications without needing to be an expert in the subject;
- through diagnostic tools achieves a faster location fixes (minimizing downtimes in utilities and reducing maintenance costs);
- visualization programs can provide all kinds of help to the user, from the appearance of an alarm to the location of the cause or the electric schema involved in the same;
- reduction of personnel allows lower number of maintenance equipment, more reduced and better coordinated through the information from the remote stations, evaluated at the control center;
- integration in SCADA between field and management levels.

3.4 Structure of a SCADA System

A SCADA System's components are comprised of one or more CPU's (Central Processing Units), RTU's (Radio Telemetry or Remote Terminal Units), I/O Subsystems, Video monitors, Field Sensors, Control Devices and lots of software that drives the I/O, runs the control algorithms, generates control outputs, displays graphics and monitored values, senses alarm statuses, and stores themonitored points in a series of data files that can be archived and recalled at a later time for analysis or process verification.

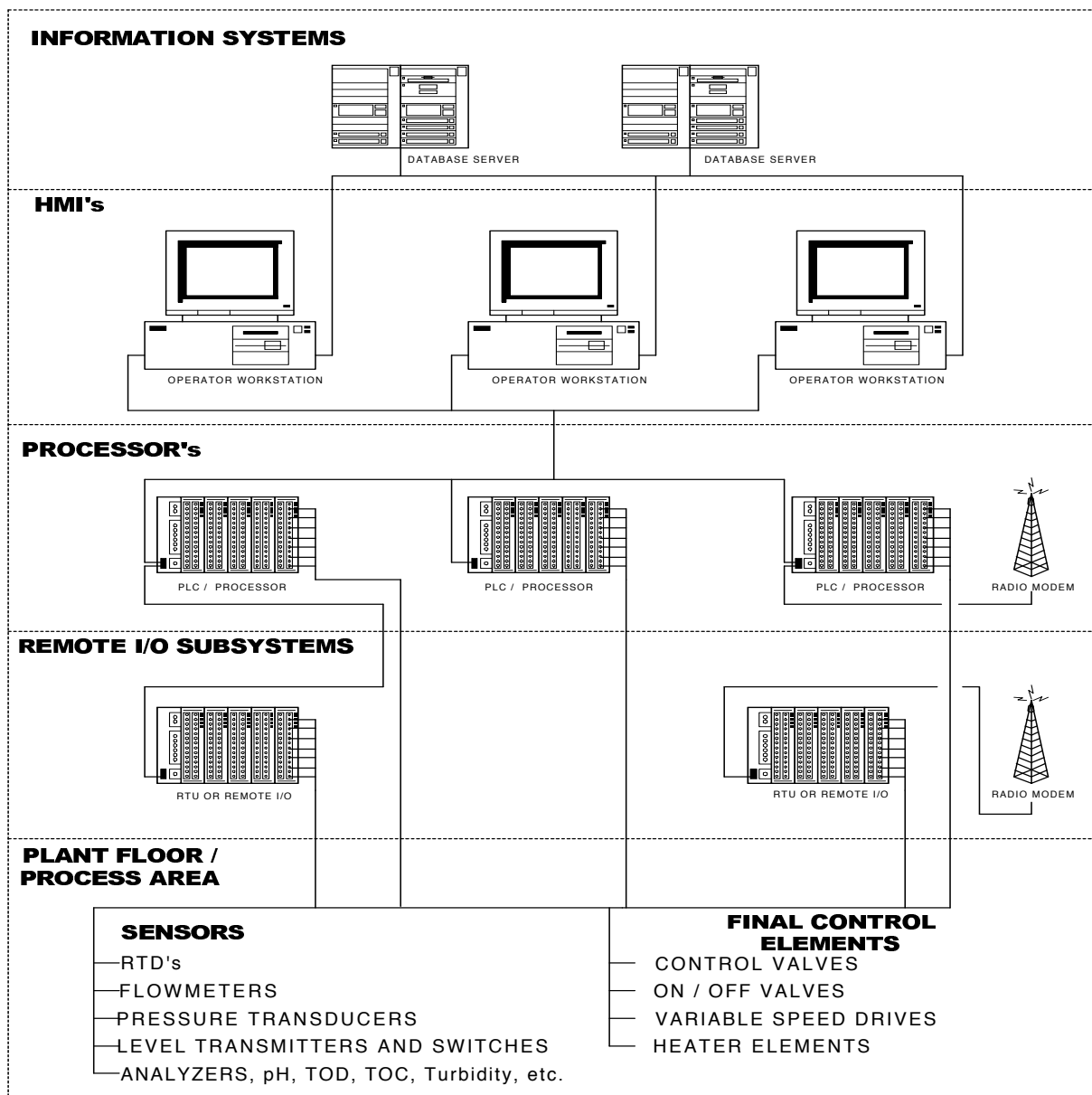


Fig.3.1:Generalized SCADA System Architecture

The heart of any SCADA system is the central processing unit or units, (CPU's). This single feature provides the largest basis for comparison between systems.

PC based systems: these systems utilize one or more Personal Computers to provide the graphical displays as well as the necessary computational and networking horsepower. The SCADA software is usually some type of Commercial Off-the-Shelf software like Wonderware, RSView, Intellution, Citect, or Iconics. These packages still must operate within the bounds of the PC operating system software, namely Windows, so care must be taken to run a form of Windows that is stable and robust.

VME-bus systems: VME-Bus hardware is a rack mounted system that allows different processor boards, communications boards, and I/O boards to be loaded into a commonly powered backplane and programmed in a highly configurable and flexible fashion.

Controllers: PLCs or Programmable Logic Controllers are control devices that originally gained popularity as economical replacements for the hardwired relay panels that were prevalent in early years of process automation. Then, because of their flexibility and ease of programming, they became popular for control of discrete manufacturing and motion control applications. As a result, these controllers are evolving into very capable and cost effective process controllers and are rapidly becoming very popular for nearly all process control applications including serving as RTU's for SCADA systems.

RTU's: in some applications it is required that monitoring devices be located far out in the field at isolated equipment sites, at pump stations, wells, or along a distant stretch of pipeline. A remote monitoring device exists but it uses traditional electrical cabling to convey the data signals to the Host.

Operator interfaces: If the CPU is the heart of the SCADA system, the operator interface would have to be considered the eyes and ears. It is through the Operator Interface that humans interact with the process being controlled. The small displays are typically used as local interfaces mounted out at the process equipment so that the operator can make allowed process changes from that location. The large displays are typically located in a central control room that is staffed by personnel responsible for overseeing the entire operation and keeping everything running smoothly. All the display types share the same mission though, which is to convey the status of the process being monitored to a human operator, to alert him or her to the existence of any problems in the system, and to give that operator the means with which to effect changes to the process.

I/O Subsystems: Any type of SCADA system, including laboratory-sized, plant-sized or a county-wide distributed system, is going to consist of measurement points or variables that need to be monitored. The measurements will be made using electronic sensors and instrumentation, (pressure, temperature, flow, position, etc) and will be brought into the SCADA system through the Input/Output, (I/O), Subsystem.

3.5 Connections between computer tools

The components previously mentioned all need to be connected together and function as one system for the application to be successful. Depending on the size and scope of the system, this can be somewhat challenging. Typical hardware includes an MTU (Master Terminal Units) placed at a control center, communications equipment (e.g., radio, telephone line, cable, or satellite), and one or more geographically distributed field sites consisting of either an RTU (Remote Terminal Units) or a PLC, which controls actuators and/or monitors sensors. The MTU stores and processes the information from RTU inputs and outputs, while the RTU or PLC controls the local process. The communications hardware allows the transfer of information and data back and forth between the MTU and the RTUs or PLCs. The software is programmed to tell the system what and when to monitor, what parameter ranges are acceptable, and what response to initiate when parameters go outside acceptable values. An IED, such as a protective relay, may communicate directly to the SCADA master station, or a local RTU may poll the IEDs to collect the data and pass it to the SCADA master station. IEDs provide a direct interface to control and monitor equipment and sensors. IEDs may be directly polled and controlled by the SCADA master station and in most cases have local programming that allows for the IED to act without direct instructions from the SCADA control center. SCADA systems are usually designed to be fault-tolerant systems with significant redundancy built into the system architecture.

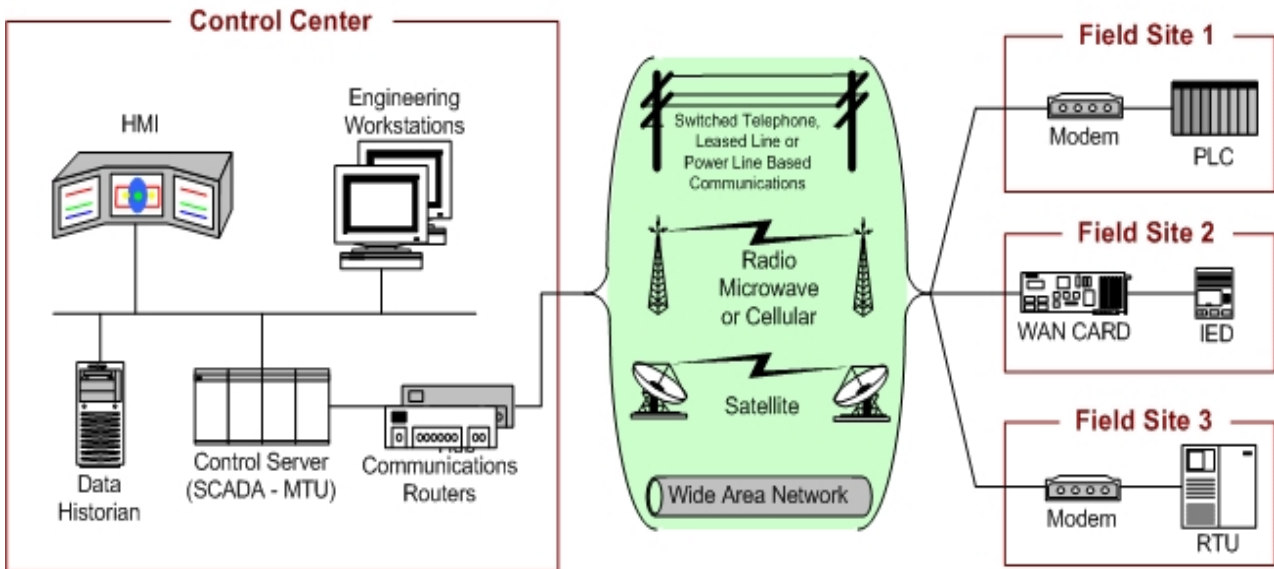


Fig.3.2:SCADA System General Layout

The control center houses a control server (MTU) and the communications routers. Other control center components include the HMI, engineering workstations, and the data historian, which are all connected by a LAN. The control center collects and logs information gathered by the field sites, displays information to the HMI, and may generate actions based upon detected events. The control center is also responsible for centralized alarming, trend analyses, and reporting. The field site performs local control of actuators and monitors sensors. Field sites are often equipped with a remote access capability to allow field operators to perform remote diagnostics and repairs usually over a separate dial up or WAN connection. Standard and proprietary communication protocols running over serial communications are used to transport information between the control center and field sites using telemetry techniques such as telephone line, cable, fiber, and radio frequency such as broadcast, microwave and satellite.

Another aspect of great importance is the possibility of being able to connect SCADA with other information technologies: Geographic Information Systems, (GIS), and Computer Aided Facilities Management, (CAFM) are applications that provide a graphical user interface into a database of information for a geographic region or manufacturing facility. The interface is a series of maps or plan views of the region or facility. The user may select a section of the map or floor plan on which to “zoom in”. Underlying data relevant to that selected area is then accessed from the database and displayed. Currently, these tools are used to display relatively fixed or static information such as the depth of the water table at a specific point, or the age of the well at that site, or the concentration of a marker chemical at that site. There is so the possibility to integrate these databases with real time process control systems so that in addition to the static support data, access will be available to realtime process data that would be useful for gauging the operational status and process conditions at the monitored points. This feature will afford a comprehensive view of an entire enterprise, and will provide the ability to perform diagnostics and troubleshooting with all of the relevant data by hand.

3.6 The SCADA application in a water supply system

Suppose that we have been asked to operate a water supply network that utilizes a SCADA system to provide monitoring and control. We have a computer screen in front of us that we use to view the status of the distribution system and its components. For example, we can use the SCADA system to display current water levels in each elevated or ground-storage tank. Because some systems use touch screens, we might even be able to touch a tank on the screen and the SCADA system would draw a chart showing the water levels in the tank for the past 24h.

Suppose that during our shift, we notice that the water level in a particular tank falls below half full. We know from experience that whenever water levels in this particular tank fall below half full, pressures in some parts of the pressure zone served by the tank are unacceptably low. So from our control panel, we place a booster station into service by pressing the ON button for this pump station. In short order, we can see that the tank water level has begun to rise and, as a result, the pressures in the pressure zone are kept within acceptable levels.

Some water utilities have SCADA systems that provide process monitoring and control for both the water treatment facilities and the water distribution system. Much of the boundary information for a water distribution system hydraulic model can be obtained from a SCADA system. Such information might include tank water levels, pump on/off status, pump speed, and valve status. If a utility wishes to conduct realtime simulations, for example in support of an emergency response, then up-to-date boundary information can be obtained from the SCADA system quickly and easily. Another valuable use of the information provided by a SCADA system is model calibration. Since many SCADA systems archive data for some period of time, historical information can be obtained.

Control Functions

The three levels of control that can also be adapted to water distribution systems are the following:

1. Supervisory control: a human operator monitors the behavior of the water distribution system 24h a day, 7 days a week to make certain the system is operating properly. The operator makes decisions based on his or her knowledge and experience; these decisions are then implemented manually by adjusting controls or pressing buttons;
2. Automatic control: represents the case where instrumentation and control equipment are used to control the distribution system automatically. Such control can be implemented either locally at the facility or throughout the system. Typically, simple operating rules are used to determine which component is operated and how it is operated;
3. Advanced control: systems that rely on advanced control use optimization algorithms, decision support systems, artificial intelligence, or control logic to control the distribution system. These systems are capable of running standard control algorithms like P, PI, and PID regulatory control algorithms for maintaining specific levels in tanks, maintaining prescribed flow rates, and maintaining processes at specific temperatures and pressures.

Data Logging Functions

Once data has been brought into the system, the SCADA system will archive selected data into electronic records that may be recalled and reviewed at a later time. SCADA systems offer data retrieval features that allow historical information describing the performance of the system to be displayed. Data archiving can be a valuable asset when training operators, or hindcasting and possibly for litigation. For instance, the actual response of the operations staff can be cataloged and retrieved at a later date to determine whether the appropriate course of action was taken. Similarly, information about the behavior of the system in response to a particular emergency can be used to train new operators. Finally, data on system performance can be used to calibrate mathematical models that simulate system performance.

Alarming Functions

Integrated into the data and graphical displays are alarm functions that can raise and displays alarms as they occur. On some systems they can be tied into Auto-Paging and Auto-Phone-dialing features that will automatically notify operating personnel of a problem.

Diagnostic Functions

Some SCADA systems have incorporated statistical packages that can be used for online analysis of process data to detect when something has changed for no reason. Such changes can be often tied to drifts in calibration of instruments and/or imminent failures of control components.

Chapter 4: Software for the management of the simulation: SCA-Red

4.1 Abstract

SCA-Red is a software application developed under the environment of the SCADA systems in charge of the real time control of water distribution systems, whose aim is to use the hydraulic model of the network as a background in order to help network operators to take more reliable decision by increasing the amount of information on the system, by anticipating the results for immediate actions, by playing back past scenarios for training or by suggesting the future actions to take in the next hours.

One of the more outstanding features of SCA-Red is its general purpose conception, in order to be installed as a complement of any real existing SCADA, thanks to the component oriented conception, the client-server architecture, and the connection with the main SCADA via OPC. So, multiple managers or operators can take benefit simultaneously of this assistant. Currently SCA-Red is being implemented for Aguas de Valencia water company, to manage a network of 1,200 Km of pipe length, which supplies water approximately to a population of 1,5 millions.

Most water utilities have nowadays installed a SCADA (Supervisory Control and Data Acquisition) system to either keep track of the current status of the most relevant hydraulic field variables such as levels, pressures and flows (telemetry), to send commands when needed to the regulating devices such as pumps or valves in order to keep the system under control (remote operation), to show graphs or make summarizes of the evolution of the different field variables monitored or to manage the alarm system. Usually historic data of field variables are recorded either in fast access memory systems or in databases. However, it is unusual to find SCADA systems capable of being used as a real time Decision Support System (DSS) assisted by a hydraulic model of real network.

SCA-Red was developed just thinking to help network operator in the making decision process by using in real time a reliable hydraulic model of the system to be controlled.

SCA-Red works on the same environment of the real SCADA and uses the same synoptic the operator manages routinely as interface. Nevertheless, SCA-Red is not foreseen to operate directly on the system. It works in parallel with the main SCADA of the company, just having access to field measurements in real time via OPC (Ole for Process Control). SCA-Red manages its own database, selects the appropriate network model and connects with the EPANET Toolkit to carry out on-line or off-line simulations. The results can be analyzed directly on the synoptic or exported to EPANET to have a full control of the network behaviour or to simulate control operations not directly available from the SCADA interface. The main menu of SCA-Red, which allow manage all its performances, is located at the bottom of the general synoptic.

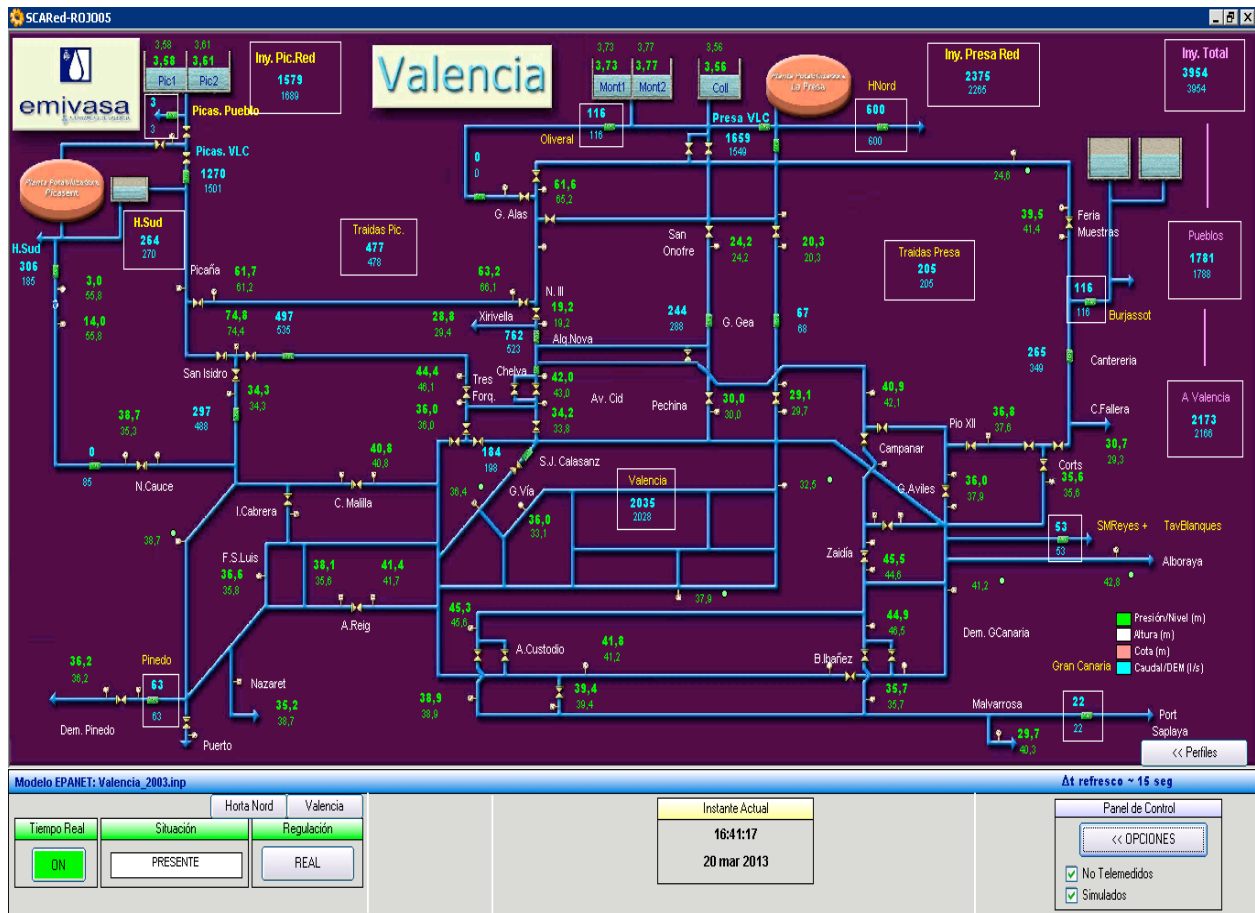


Fig.4.1: Main screen of SCA-Red working on line

The main screen shows real and simulated values for the most relevant variables, the simulated values for the non-measured variables (marked with a dot), and the most significant flow balances. The foot band of screen allocates the main menu, the time manager, the simulate, query and exporting buttons and the options menu.

The synoptic shows a sketch of the most important pipes and control devices of the Valencia water supply system, located in the east coastal border of Spain. It is fed totally by surface water from two treatment plants named Manises (La Presa) and Picassent, where the main reservoirs of the city are located (on the top of the sketch). Water is pumped from the clear wells of each plant either directly to the city or to the city and to the reservoirs, depending on the time of the day, in such a way that both reservoirs work as balance tanks. From the hydraulic point of view the whole system is fed by gravity from both plants, being the injected volume from each plant and the distribution of pressures through the network depending on the remote operation of about 40 valves, most of them operated hourly from the central control room.

At current time valves are not automated but they are remotely operated instead. As a consequence, one of the interest points of the company is to anticipate the effect of any operation by previously simulating it.

4.2 Main features of SCA-Red

The application does not act directly on the physical elements of the network, but it allows monitoring the status of the hydraulic variables of the tele-metered points of the SCADA system in real time. Besides, by means of the integration with the hydraulic simulator, it allows to determine the status of non-telemetered points at any time, in addition to simulate past scenarios and predict future situations.

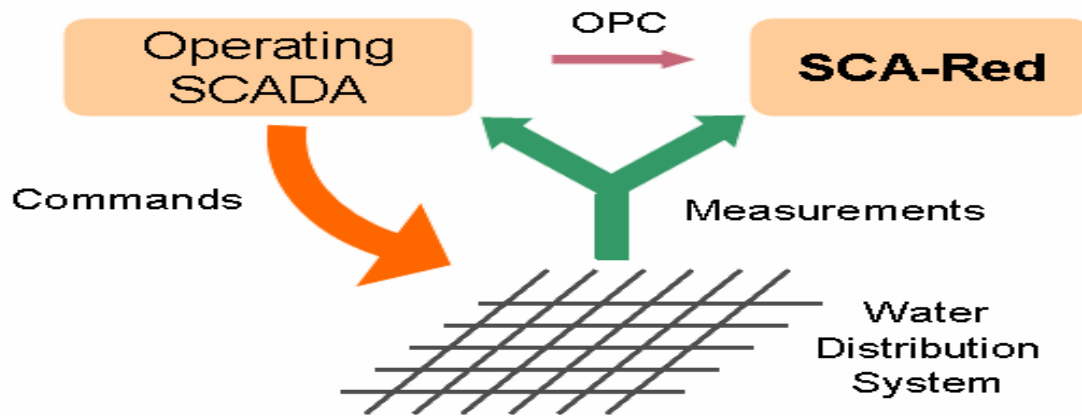


Fig.4.2:Connection between the operating SCADA and SCA-Red

The main features of the program, from the client point of view, can be summarized in the next items:

- Comparing in real time field data with simulated ones calculated by using the hydraulic model, so informing the operators at each time on the goodness of models results;
- Estimating values for non-telemetered hydraulic variables as model results, supplying in this way additional information to the operators while the equipment costs for this points are saved;
- As a particular application, flow balances for demand areas or head profiles for particular paths can be show in real time;
- Frozing the current time and exporting an EPANET file for this particular time;
- Evaluating specific control actions to be taken at the immediate time, by previously simulating their impact in the network behaviour before putting them in practice;
- Playing back past scenarios that took place in the network, enabling the managers to analyze in detail any particular event;
- Interfere on the real past scenarios, enabling the operator to simulate control actions that overlap real ones, thus being useful as a training tool or to find a better response for similar situations in the future;
- Plan the best actions to be taken in the next future (24 hours or more), by overriding the real demands and controls observed in a similar period of the past, and taken as default;
- Exporting a full EPANET file to reproduce any to the previous scenarios as an EPS (Extended Period Simulation),in order to observe other variables or to make some changes not available from the SCA-Red interface(ex.closing a pipe).

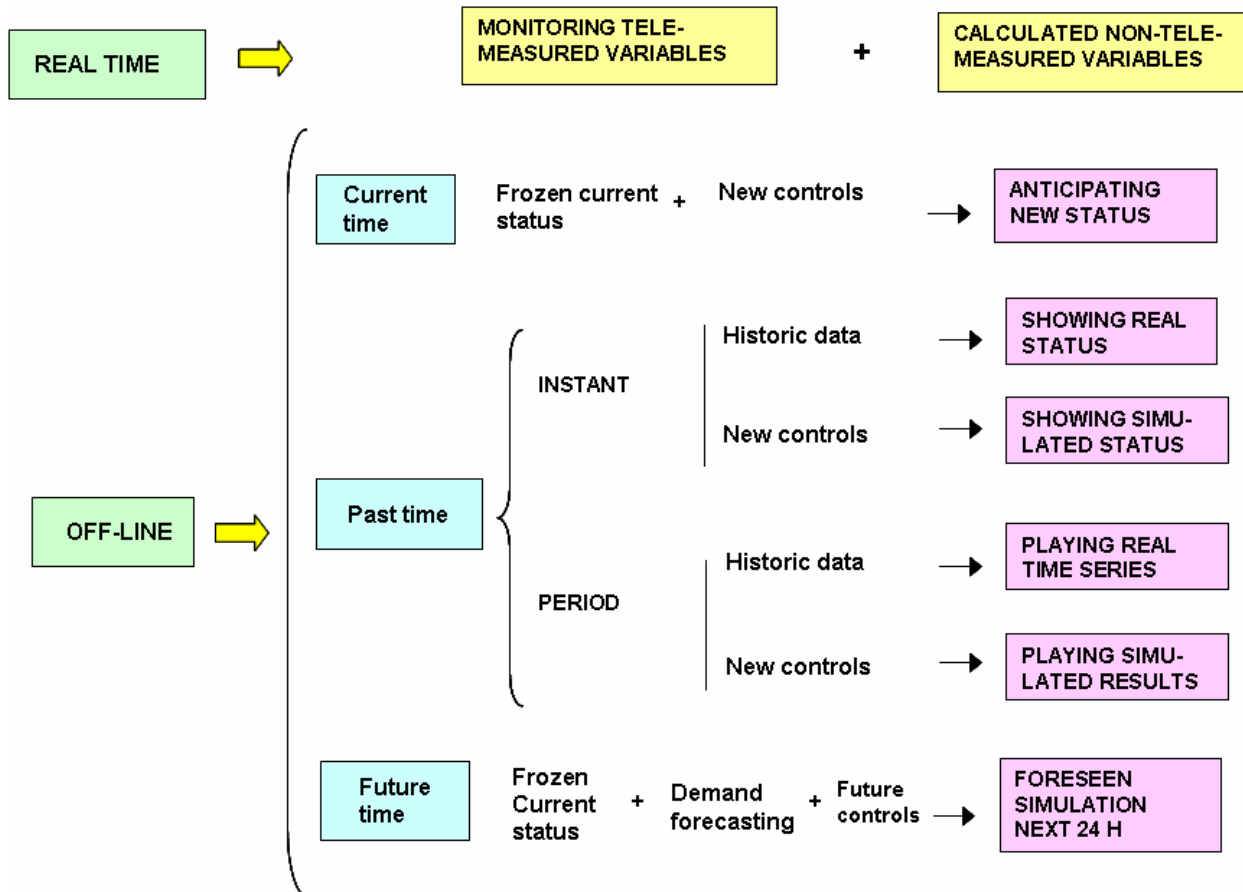


Fig.4.3: Operation modes of SCA-Red

4.3 The SCA-Red interface

All these choices are conducted through the SCA-Red interface, composed by the synoptic map, which is mouse-sensitive, and the operation control panel located at the bottom. Not all SCADA tags (variables) are shown in the synoptic for simplicity, just the most important. However, through the remote stations windows all kind of information is available for the user. These windows are opened by clicking on the corresponding valves in the synoptic.

The main menu, on the left side at the bottom, shows three main buttons:

- * *Real-time: ON/OFF.* While it is ON the synoptic is synchronized with the field measurements, read directly from the master PLC or from the operating SCADA via OPC, and refreshed every 10 seconds. Besides updating the real measurements, at each clock time the hydraulic model is launched using the real data as boundary conditions (demands, tank levels and pump/valve status) and results are shown for the synoptic variables, including the non-measured points. Also flow balances for district metered areas are done in real time. While this button is ON all other options are disabled and just the current time is shown at the center of the bar. When pressed it turns OFF, and the current status is frozen, while other options like Time period and Operation mode are enabled in order to carry out simulations or export EPANET files. When the Real Time button is turned again to ON, the main screen and any other auxiliaries are resumed to the most recent field values;
- * *Time period and Operation mode.* Being the Real Time button OFF, the Time Period button offers the user three choices for further analysis: PRESENT TIME, PAST TIME or FUTURE

TIME. By default present time is shown, enabling the used to export an EPANET file for the current status by pressing the lower-right button. Furthermore, in order to simulate a control action for the current time, the third button of the main menu concerning the Operation mode must be pressed. This button toggles between playing the real scenario or simulate a new scenario by changing some controls.

New controls are declared in the framework of the remote station windows. Clicking on the synoptic for the station where the controls to changed are located, a window such as that shown in figure 4.2 is opened. The grid in the upper-right corner allocates the valves of this particular station, which can be operated. Columns show by order the IdValve, the type of valve assumed for simulation purposes, the current settings, the new settings (the only one editable column) and the maximum and minimum values acceptable for them. Once all new controls are fixed for this and other stations if case, the Running button must be pressed to get the new results, which can be compared with the current ones in order to take a decision or try for new controls. Each new scenario can be exported anywhere to EPANET.

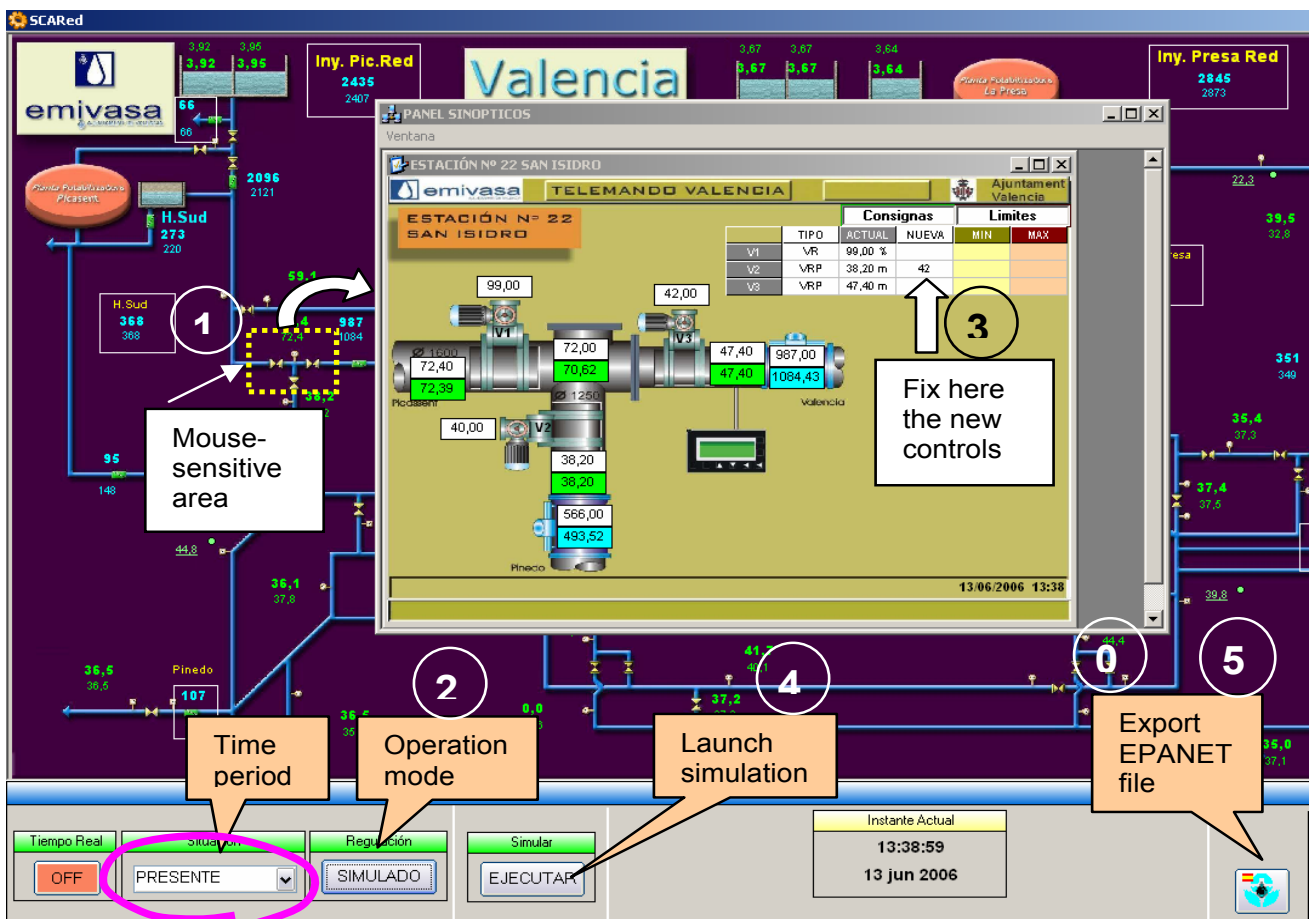


Fig.4.4: Simulating a control action for the current time

When the past time is chosen the time bar automatically expand to fix the starting time and the end time of the past period to be analyzed. By default the last 24 hours are selected, but user can change both the start or end time with the help of a calendar. Once the query period is selected, clicking on the magnifier button a query to the filtered SCA-Red database is launched and both the field data and the simulated results given by the model for those data will be shown on the synoptic for the given time (shown at the center). A slider bar at the bottom allows navigate through the queried period in order to review the variables values at any time.

User can also click on any remote station to show in a graph window the time series for the selected variable, comparing both real and calculated values provided by the model. Each graph windows has its own controls to customize the appearance, zooming or scrolling along both axis; on the other hand, all opened graph windows are allocated in a unique main window which contained graph windows can be allocated (tiles, cascade,..), and closed, minimized or maximized with just one click.

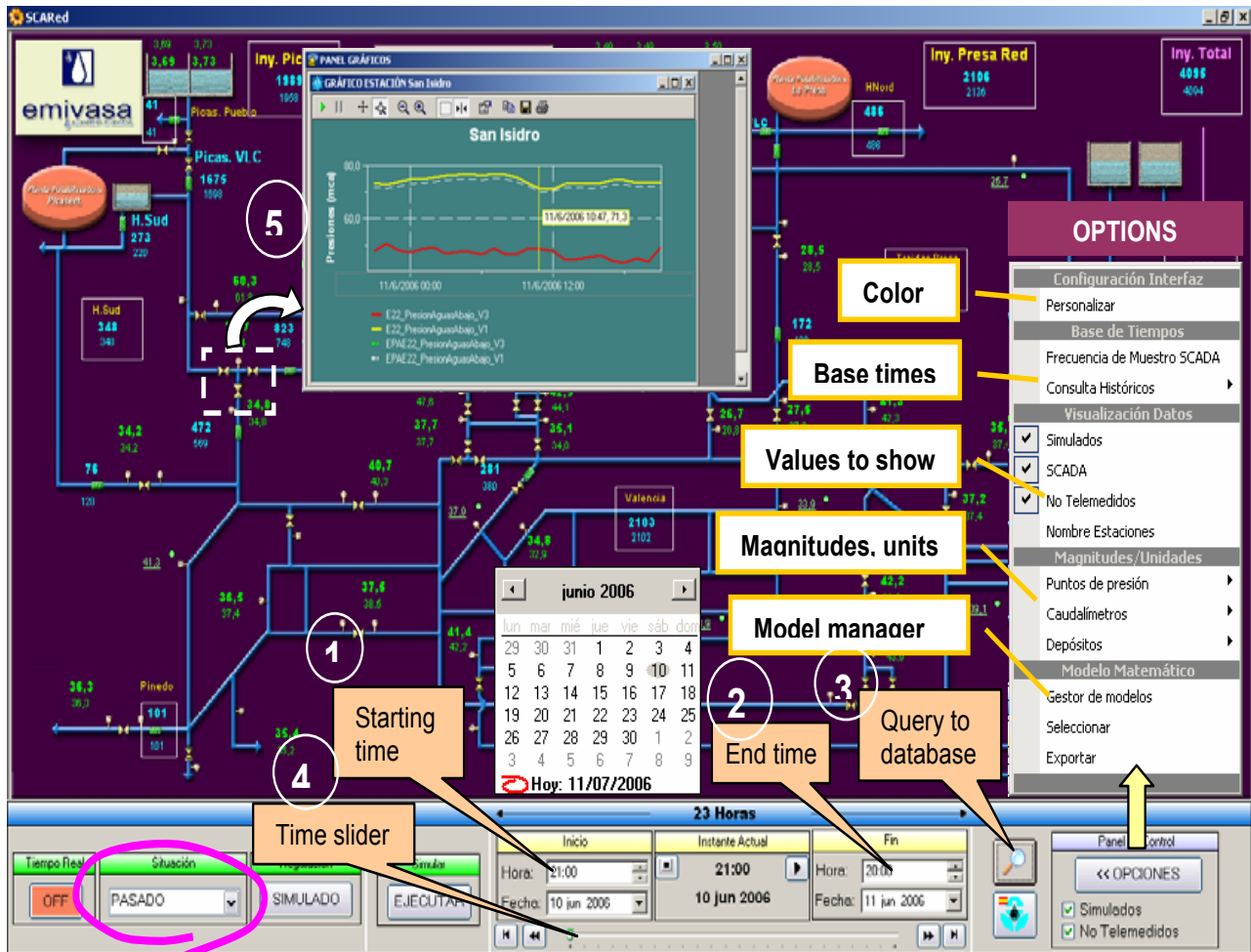


Fig.4.5:Playing back a past period

In past time either real time series for field data or simulated time series for new controls can be played, depending on the status of the Operation mode button. By default reality is played and compared with results provided by the model for the same demands and controls. When the Operation button is pressed it turns into the simulated mode and new controls can be fixed for any valve or pump and for any time of the simulated period, in a similar way than for the present time, but now the opened station windows are synchronized with the time slider allowing to fix controls for any time. After running the model the time series of the graph windows will be updated, comparing the new time series versus the real ones.

At any time user can export the current model to EPANET as an EPS model (Extended Period Simulation) and run the file in the SCA-Red environment (figure 4.3). The selected time for past periods can span from just one hour (starting time = end time) to several days or even a full year. Trials for 365 days have work satisfactorily. The Valencia network model used in this case study was obtained from GIS and has 4500 nodes, 4 reservoirs, 5 tanks, 20 pumps and 82 valves, 40 of them remotely operated hour by hour, giving $(20+40) \times 24 \times 365 = 525.600$ control rules and 11 demand patterns of 8760 factors each for a full year simulation.

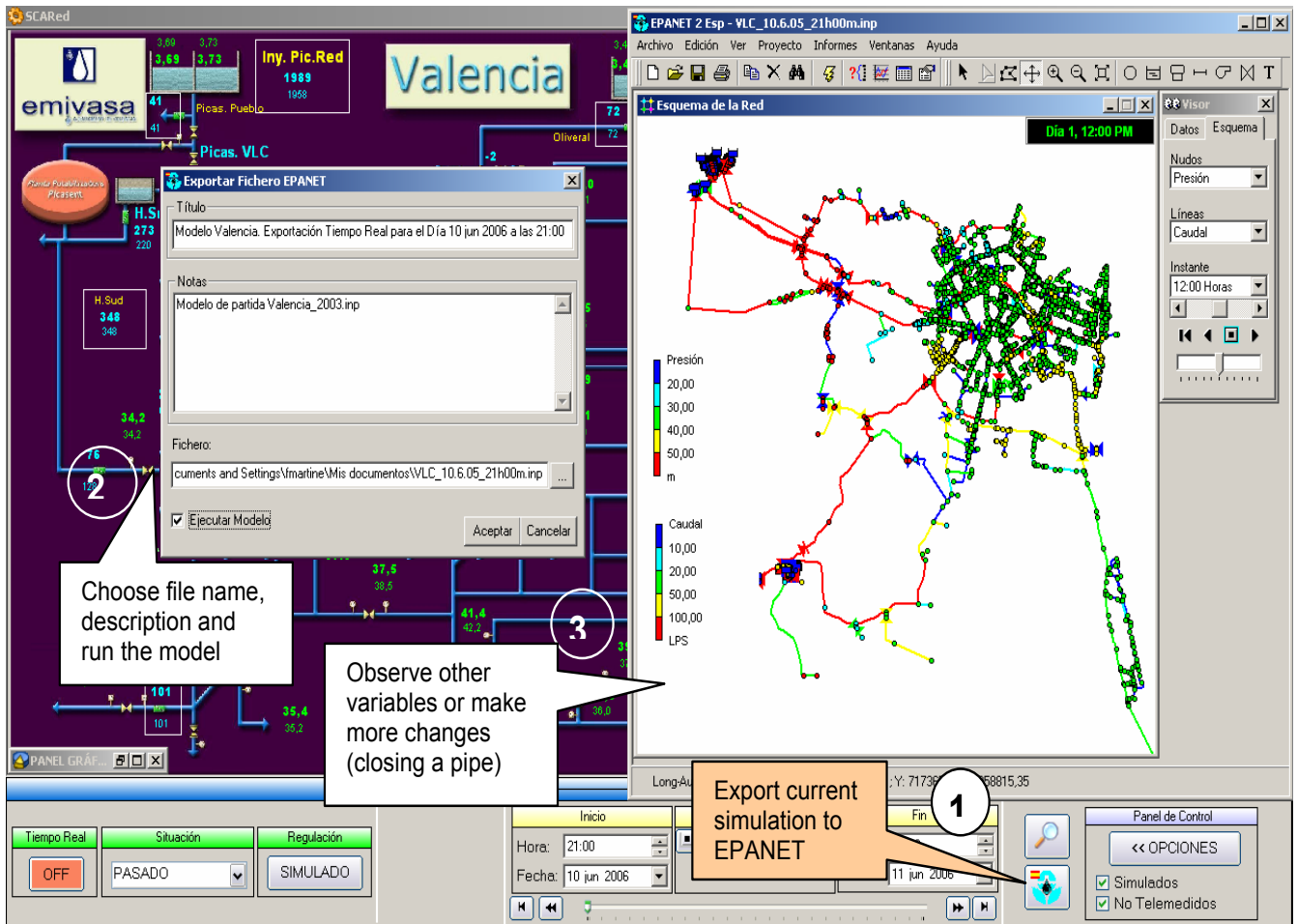


Fig.4.6:Exporting the current model to EPANET for more changes

When the user selects future time the Operation button is fixed to simulation mode. By default next 24 hours from current time is selected as simulation period. Foreseen demands and controls for this period will require implementing both a demand forecasting routine and a control optimizer to define all parameters needed to carry out a simulation. However, at current time SCA-Red doesn't implement any of them; on the other hand, declaring all these parameters one by one would be inconceivable, so past values for a similar period are taken as reference instead. Proceeding in this way is also possible carry out simulations for far future, for instance simulate a repair programmed during a weekend in two months.

For near future simulations (next 24 or 48 hours) the demands and settings for a similar day of the last week are taken as reference, while the current tank levels are taken as the starting point.

For far future simulations the adopted criteria is to choose as reference those demands, settings and initial tank levels for a similar day of the last year. Nevertheless, user can choose another day as reference for both.

Once the basic settings are chosen the procedure to fix new controls and export the EPANET file if needed is similar to the previously described. Additionally now is possible to apply a demand factor to the whole demand or to demands by zones.

Finally, for any simulation in extended period a choice for playing animations have been foreseen (figure 4.5).

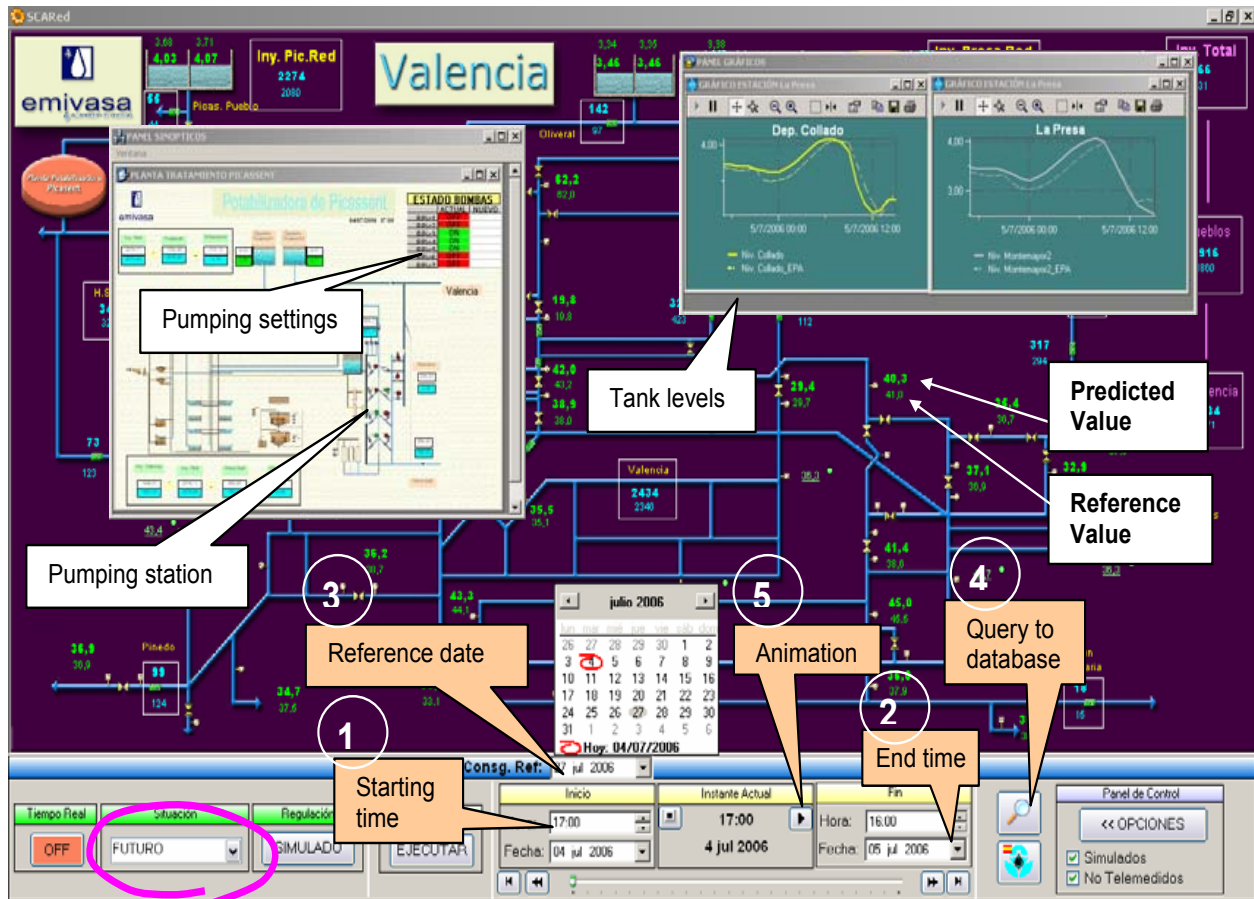


Fig.4.7: Simulating a future period

Additionally to these capabilities, SCA-Red offers several Options from the right side of the control panel. Two of them are permanently accessible: show or not simulated values provided by the model and show or not the non-telemetered estimated values.

Other options available from the dropped menu are:

- ❖ Modify the time basis for sampling field data. While SCA-Red is working on-line, the refresh time can be customized, being by default 10 seconds (the minimum available). When it works off- line field data can be queried on a 1 minute-basis, 15 minutes basis or 1 hour basis. With this aim, three tables of historic data are kept continuously updated in the SCA-Red database. The 1 minute table is cyclic, sized to allocate up to 100,000 registers (about 2 months), and save raw data. EPANET simulations can't be carried out with this data, for the sake of the reliability. The other two tables are derived from the first one every 15 minutes or 1 hour after a filtering process and are unlimited. The time step of the navigator bar, as well as the pattern and reporting time steps of the EPANET file, will be fixed according to the time basis chosen;
- ❖ Customize the values to be shown on the synoptic, graphs and remote stations windows. Choices are SCADA data, simulated data (except for 1 minute time basis), non-telemetered data (idem) and station names;
- ❖ Customize the magnitudes and units to show in the synoptic and other windows. Choices are pressures, heads, elevations or none for pressure gauges; m^3/h , l/s or none for flow-meters; levels, heads, bottom elevation or none for tanks;
- ❖ Modify colors assigned to different variables: by default flows are in blue, pressures and levels in green, heads in white and elevations in purple;
- ❖ Manage the list of models available. Different models can be added or deleted from a list of

available models, but just one of them must be selected as the active. Those models can be built externally or rebuild from previously exported model (for instance, closing a pipe). Some constraints must be fulfilled by models to be accepted, in order to match the EPANET names with field signals (tags) and other questions.

4.4 Connecting SCA-Red with EPANET

Challenge to be overcome concerns the correct imposition of the field data to reproduce the real behaviour of the system, the way to connect the real data with the simulating tools and about the reliability of the results will be explained in the following paragraphs.

4.4.1 Imposing the field data

The correct definition of the hydraulic parameters is an important question to be dealt. Defining a typical hydraulic scenario for an EPS simulation under EPANET standards requires to declare: the network connectivity, the physical characteristics of all components, the nodal demands and its pattern curves, the initial tank levels and the control rules, both time or pressure dependent, as well as other options for units, head-loss formula, accuracy, time steps, etc. Usually values for demands, tank levels or control rules are taken from a typical day, while other data such as connectivity of physical properties are considered unchangeable, except for planning tasks. EPANET allows other options such as declaring pattern curves for reservoirs in order to adjust its level paths or declaring pattern curves for pumps in order to define its operation mode.

To match a pre-defined hydraulic model of a Water Distribution Systems (WDS) to its real behaviour some of the previous data must be considered fixed and other varying according to the real data. SCA-Red assumes that networks connectivity, physical properties of components, base demands at nodes and control rules driven by pressures are fixed data, while tank levels, demand patterns and those control rules driven by time must be adjusted for each simulation period.

In particular, to load the Valencia model with real demands up to 11 demand zones (DMA) have been declared, which injected flow series at one hour-basis or 15 minutes-basis can be derived from the SCADA measurements. Not all flow measurements are used to determine injected flows to DMAs. A preliminary analysis will help to differentiate those signals involved in determining the injection flows to DMAs then those used just to check the goodness of the model. Assuming the relevant flow-meters are identified for each demand zone, first the total base demand assigned to its nodes is computed, and next the demand factors calculated at each time by relating the injected flow to the total demand. So the demand factors answer for both time patterns and the un-accounted-for water demand. It must be noticed that the pattern time step will be adjusted depending on the time basis considered.

About tank levels SCA-Red considers two options: forcing just the initial tank to the real data or forcing the tank levels for the whole simulation period by declaring tanks as reservoirs and assigning to them a pattern curve for heads. For current time and instant simulations any option is valid. For future simulations just the initial tank level is forced, but for past simulations tanks are converted into reservoirs and its heads fixed in order to reproduce more accurately the reality. However when new controls are defined for past simulations just the tank initial level is forced and the simulator will determine the level paths according to the hydraulic equations. It must be noticed that if the hydraulic model would be perfectly calibrated, both approaches will yield to the same results for the real controls. So running one or other approaches allows the user checking for the calibration goodness of the model being used.

Finally control rules driven by time are applied directly to the model, trying to reproduce the real behaviour of the most important control devices. Control rules concern to valves and pumps remotely operated and they can be forced on a 1 hour or 15 minutes time-basis.

General control valves are often modelled as TCV (Throttle Control Valves) being its status

identified by the percentage of closure. Manufacturers can provide curves to relate the k valve coefficient to the closure percentage, but it is difficult to guarantee such behaviour for valves after working for a long time. Instead it is more convenient simulate the valve status by forcing the downstream pressure, the upstream pressure or directly the valve flow-rate (depends on the available sensors) by converting the TCV valves in PRV (pressure reducing valve), PSV (pressure sustain valve) or FCV (flow control valve) respectively.

SCA-Red considers the remotely operated valves as PRVs, being the measured downstream pressures forced at each time step as a pressure setting. It is important to notice that all control rules driven by time must be referred to the starting simulation time in order to be successful. Other measured pressures not used to force valve settings are considered by SCA-Red as checking points to compare real values with model results.

4.4.2 Connecting with EPANET files

Second question to be dealt in order to match a pre-defined model the real network behaviour concerns on how forcing the previous data into the model. The EPANET toolkit offers the chance of reading the input file (the pre-defined model), change some parameters, run it, and get the results. In particular the initial tank level and the demand patterns can be redefined in this way. However, in other matters the toolkit becomes limited: tanks can't be turned into reservoirs, valve's type can't be changed, and above all the number of control rules can't be enlarged. For simulations in present time the facilities provided by the toolkit are enough. As the duration is set to 0, doesn't matter the number of time control rules declared in the pre-defined model or the pattern lengths; just the factors and controls for time 0 are updated. However for long period simulations carried out in past or future time, the limitations of the toolkit have been overcome by rewriting the input file; with this aim, first the input file for the pre-defined model is parsed in saved in memory; next a new file is built by pasting to the fixed data the new lines. Finally the new file is read, run and queried using the toolkit.

4.4.3 The treatment of the field data

Last question to be dealt on connecting real data to EPANET relies on the reliability of the results, which in fact depends more on the reliability of data than on the reliability of the model itself. On the other hand the reliability of data depends a lot on the reliability of the real time acquisition system.

Particularly, in order to match the Valencia model with the reality about 500 signals are managed. Often some of these signals fail, being the most critical those concerning flow rates and tank levels (closing a pump or valve mistakenly is not so serious due to the huge number of valves and pumps available in the model). To deal with this problem, field data are previously filtered before being forced into the model. While the table of 1 minute historic data allocates always the raw data, tables of 15 minutes and hour historic data are duplicated. Ones allocate just the average values of the raw data on the corresponding time basis; the second ones allocate the filtered data. Filtering the row data consists of three steps: marking the averaged values and finally smoothing the repaired signal.

Regarding to the first step, the following anomalies are considered:

- Values which have not been registered in the data base, for whatever reason;
- Values which are outside the range of possible values for the corresponding physical measurement;
- Values which shown a sudden change regarding the previously observed values;
- Values which remain unaltered for a considerable number of consecutive samples, which usually indicates a problem with the sensor;
- Values outside of the range given by $m \pm (2*std)$, where m is the signal average at the current time (without taking into account values falling into any of the three categories above), and std is its standard deviation.

In the second step, marked data definitively rejected are substituted by new values, according to the following strategy:

- ❖ If the sequence of invalid data is short (less than 2 hour), linear interpolation is used to join the data preceding and following the anomalous sequence;
- ❖ If the anomalous sequence is greater then 2 hours but less then 24 hours, a time series predictor is used to foreseen the real values of these variable;
- ❖ If the sequence is longer, each invalid value is replaced by the average of the historic values registered at the same time of the day.

Repairing data is carried out in two stages. First a provisional valued for the signal is provided according to the elapsed time: for less than 2 hours previous value is cloned. Up to 24 hours the predicted value is used temporary; finally as predictors usually fails for longer periods, the average historic values for each time is taken instead. Once the signal is recovered and validated, temporary values are corrected using morphing techniques in order to smooth the transition between the last and the first reliable value.

Finally in the third step, when raw data are considered valid, a signal smoothing is carried out by using a low-pass filter in order to eliminate variations due to noise, before apply them to the model.

Through an application called SCADA Data Analysis is possible analyse historical data to be stored from SCADA capture.

When starting the application the main form that we see is the following image:

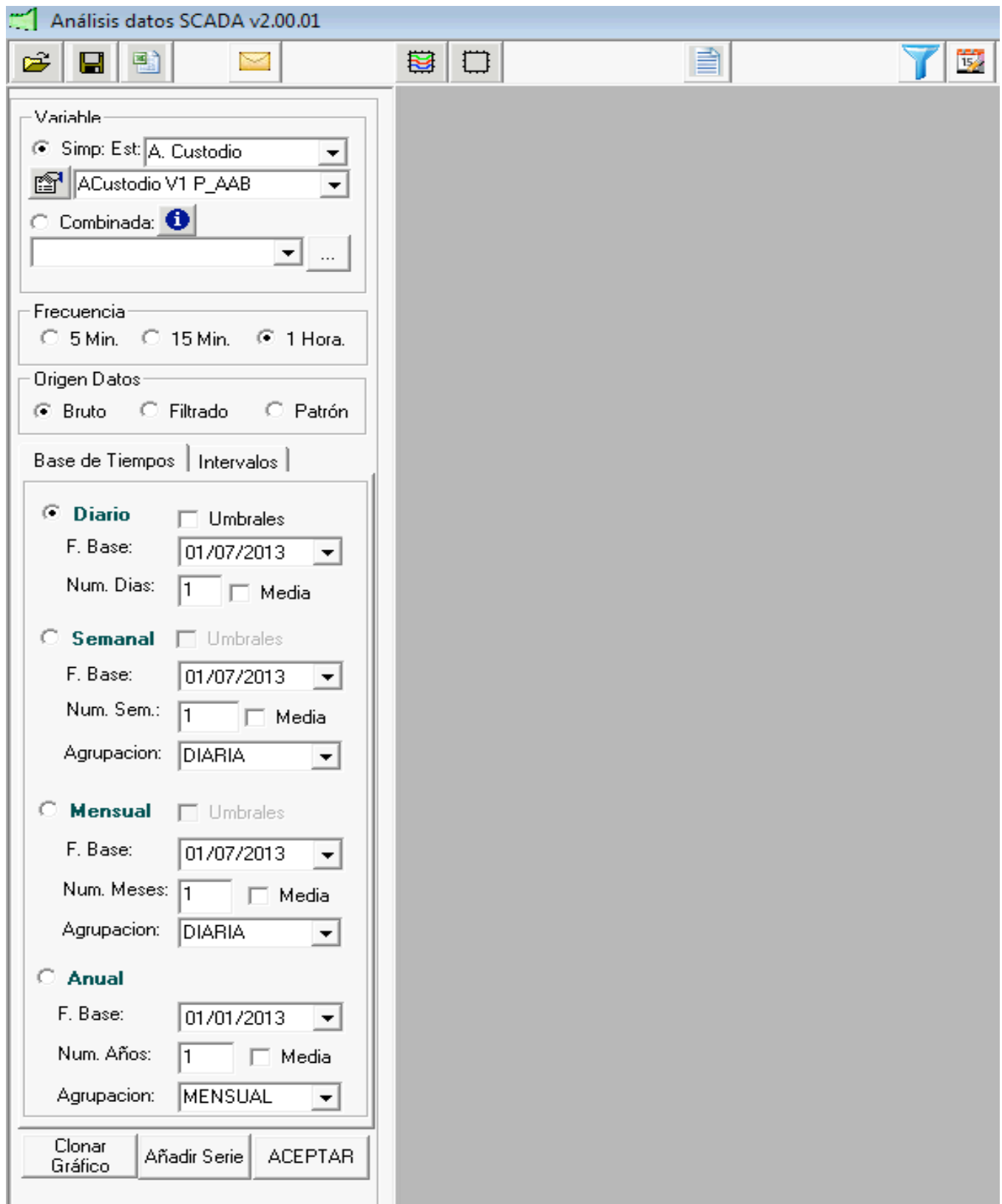


Fig.4.8:Main screen

On the left is placed a panel where the user can configure the parameters necessary to make the graphics.

* First Step: Selection of variables

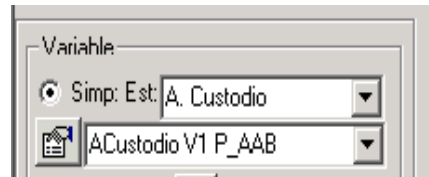


Fig.4.9:Selection of variables

In this context the user can select the SCADA signal for which you want make a graphical representation of the data in the tables; the user can filter by type of variable the signals that he can select (in this example the user has selected the low water pressure of the valve V1 in the station of A.Custodio);

* Second Step: Selection of sampling frequency

Following the selection of variables, there is a panel where you can select the sampling frequency at which historical data is stored either 5 min., 15 min. or 1 hour.

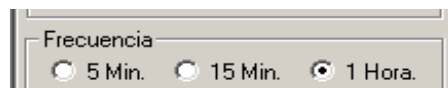


Fig.4.10:Selection of sampling frequency

* Third Step: Selection of data source

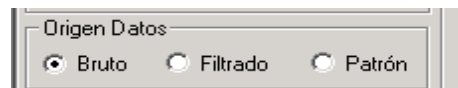


Fig.4.11:Selection of data source

* Fourth Step: Historical data grouping

In this section there are two options when it comes to group data subsequently visualized in graph form.

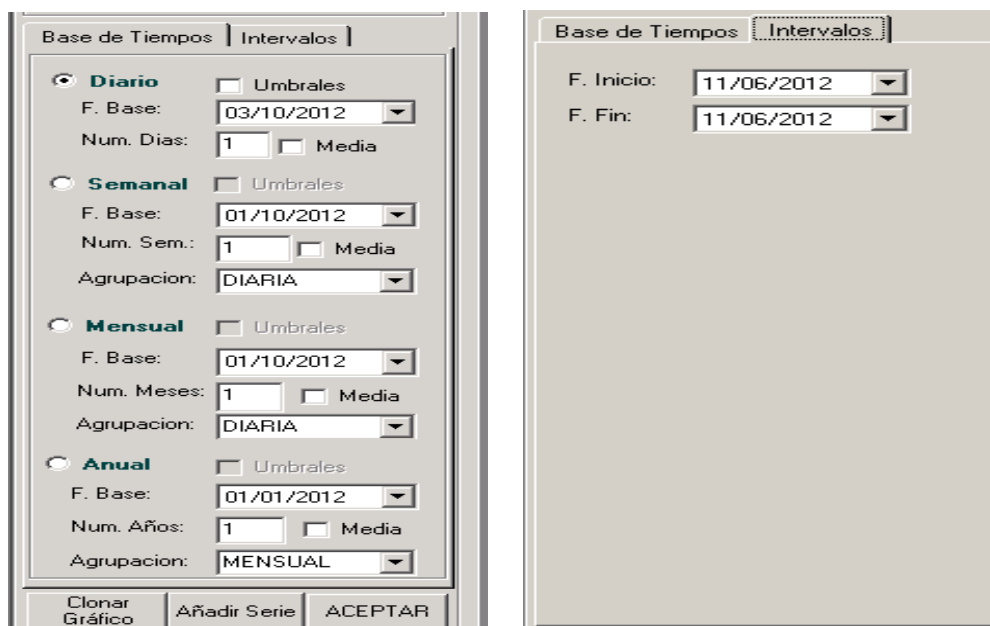


Fig.4.12:Options of grouping historical data

Once defined the parameters that we could seat for given a signal data, with the button ACEPTAR, we can representation the graph.

In the following 4 images we will show the different types of grouping (daily, weekly, monthly and yearly) on an hourly basis frequency of the raw data source for the low water pressure in the station of A.Custodio:

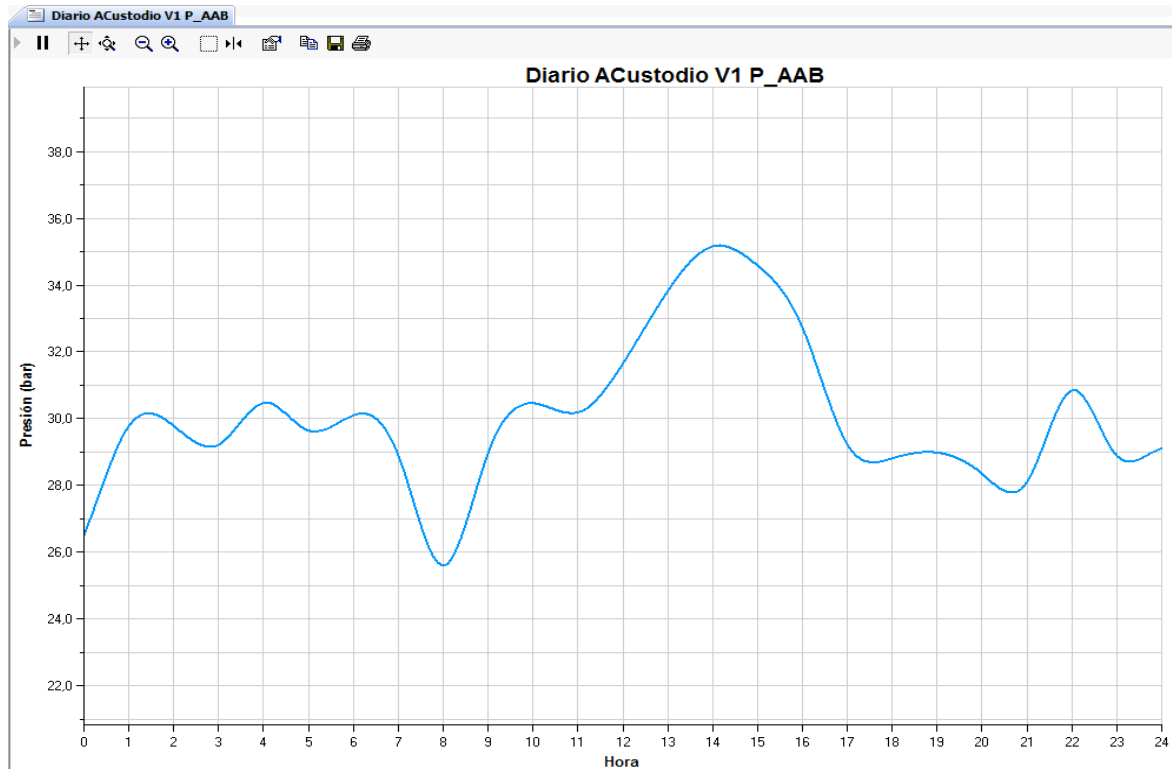


Fig.4.13:Daily representation of low water pressure in the station of A.Custodio

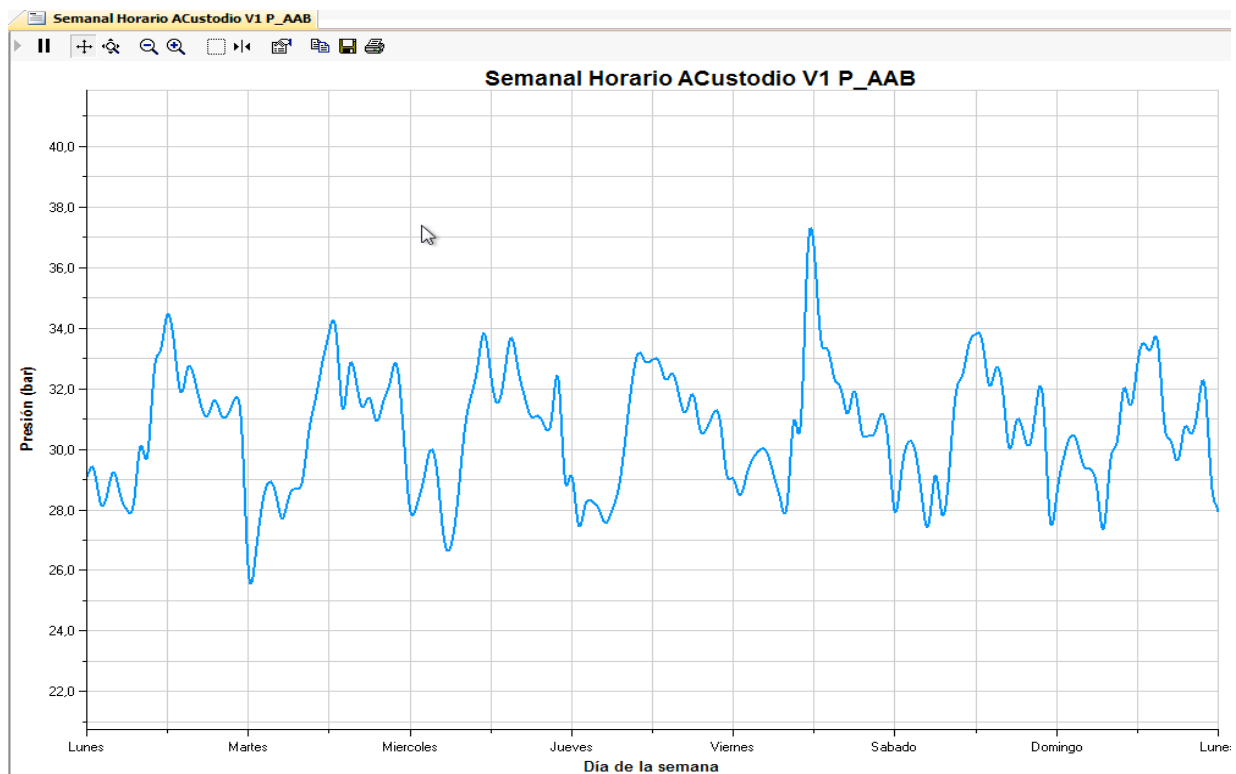


Fig.4.14:Weekly representation of low water pressure in the station of A.Custodio

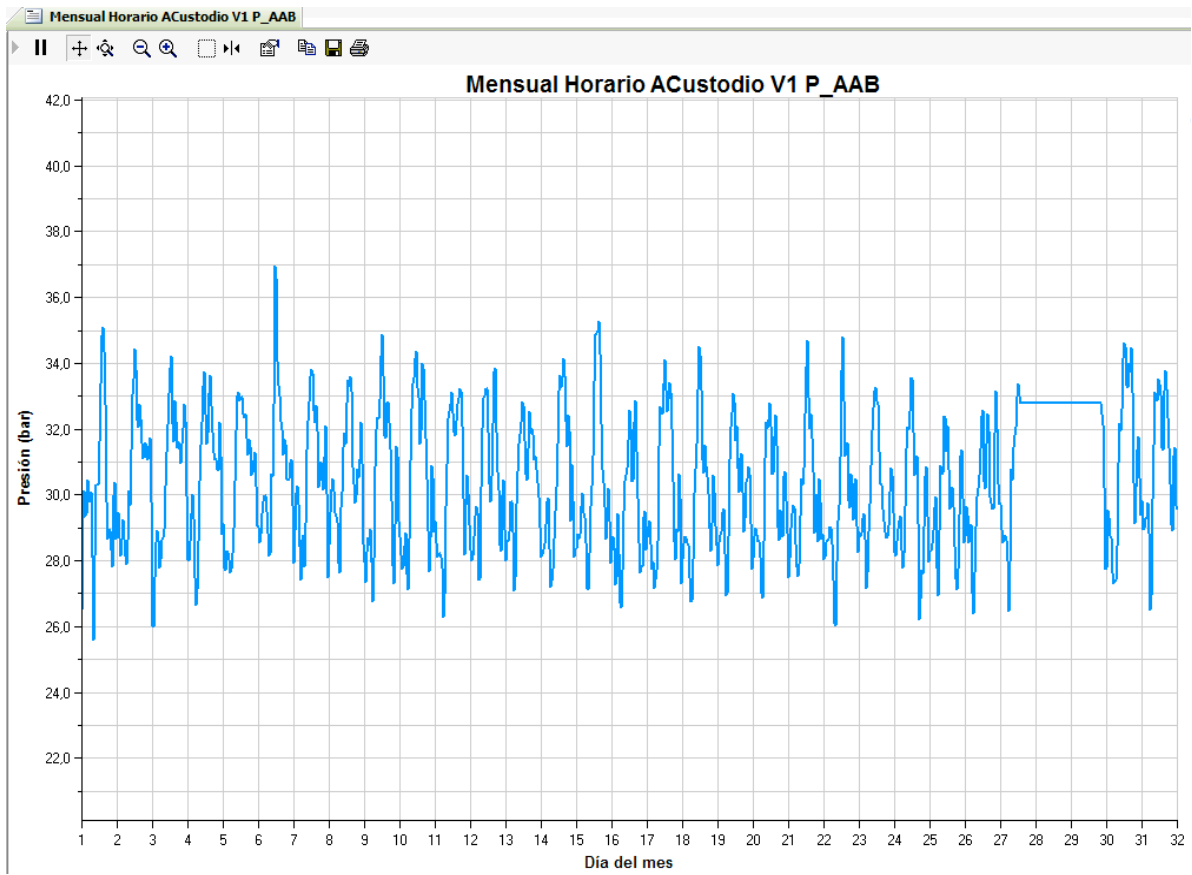


Fig.4.15: Monthly representation of low water pressure in the station of A.Custodio

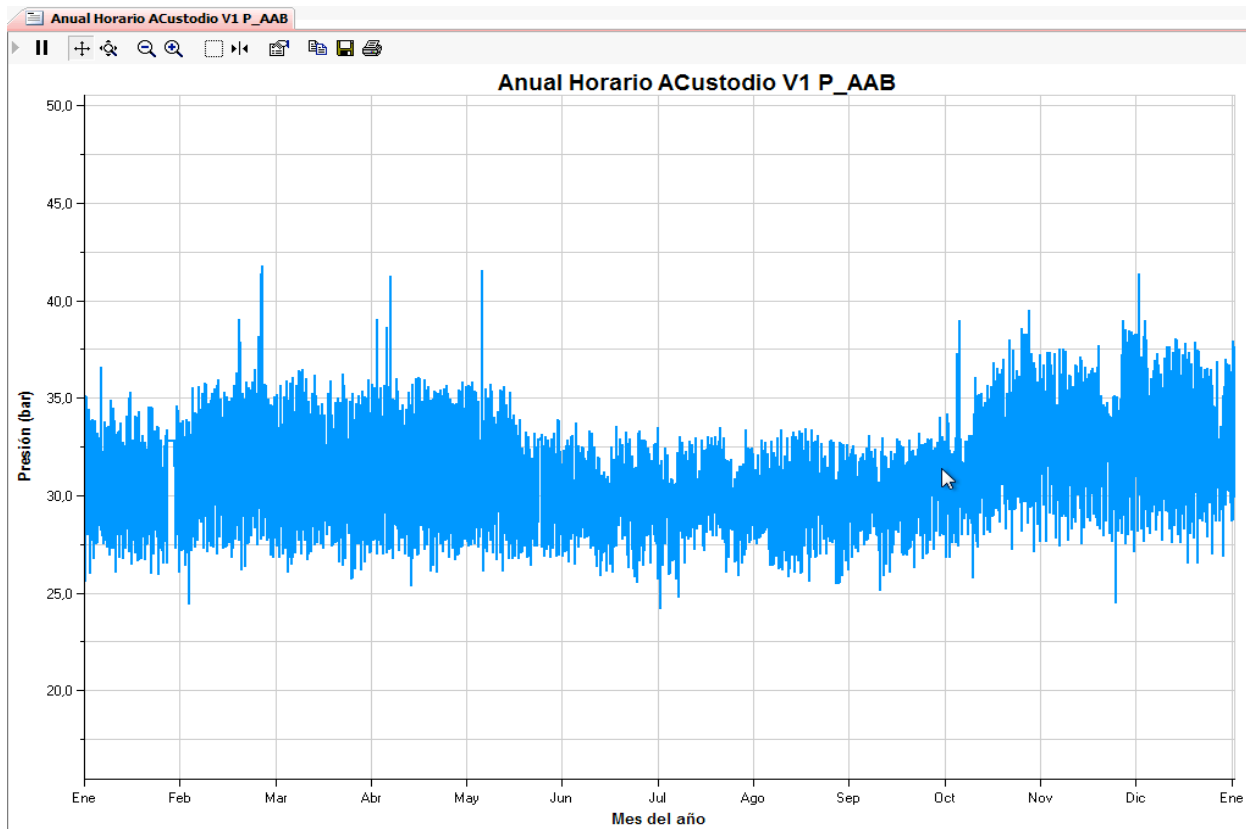


Fig.4.16: Yearly representation of low water pressure in the station of A.Custodio

For each of these representations it is possible to examine the detailed values of the graphs exporting them to Excel. In the toolbar there is a button that will allow us to realize this operation.

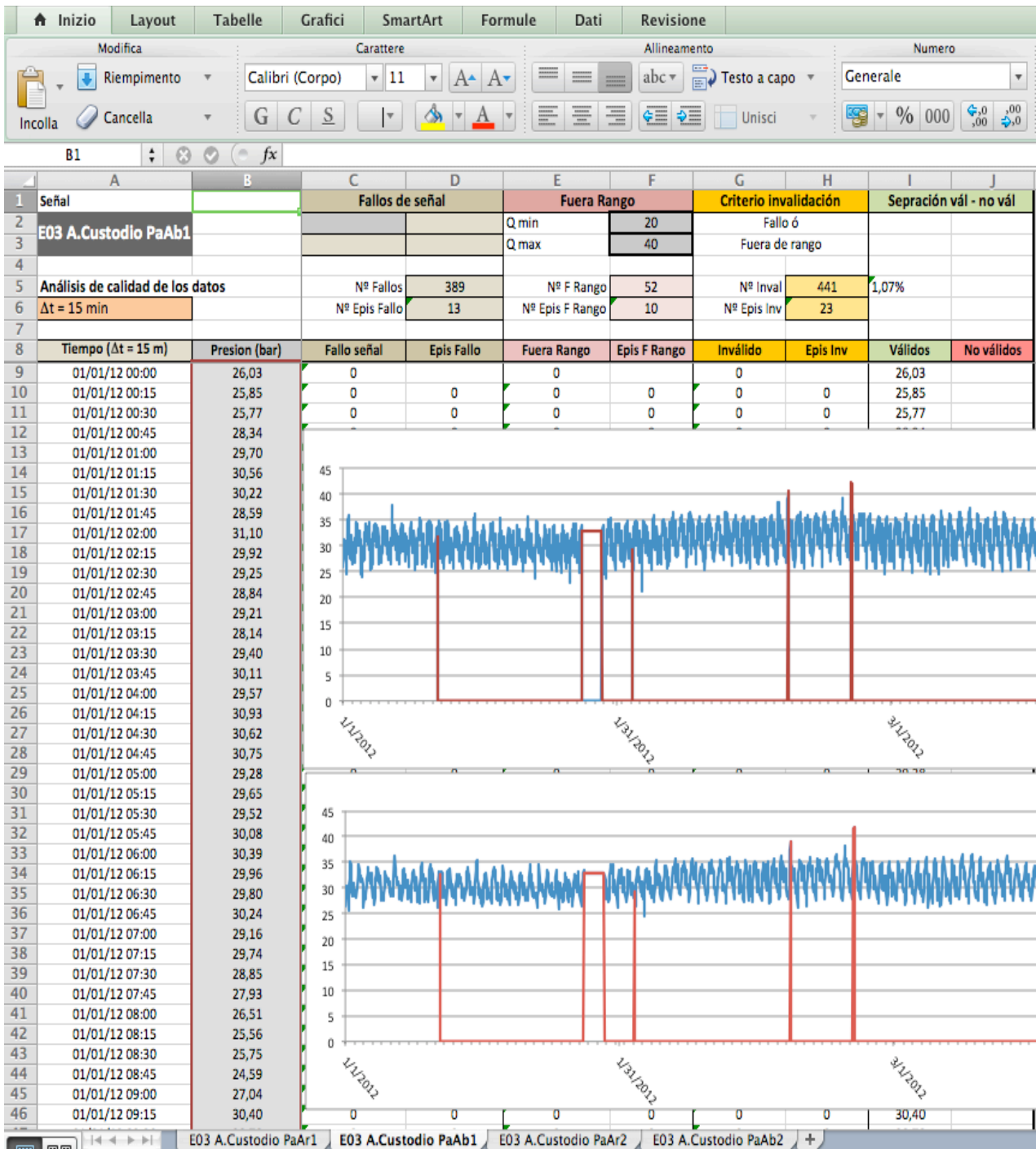


Fig.4.17:Excel file: “Annual analysis of water pressure on 15 min basis frequency in the station of A.Custodio”

4.5 Client-server architecture

From the beginning a professional version was pursued, therefore a client-server architecture was designed. In this way, the server part is in charge to develop the critical tasks, which will be shared by all users. Furthermore, different users can develop different simulations working on the same database.

4.5.1 The server module

The server part of SCA-Red is installed in a dedicated PC, which can connect directly to the master PLC (Programmable Logic Controller) via I/O card or via network cable. In the particular case of Valencia network, this type of connection is done by the operating SCADA (a WinCC 6.0 licence), which is provided with a data server under the OPC protocol (Ole for Process Control). So in this case the SCA-Red server part keeps track of the monitored variables via OPC, modifying its values at the time they change (asynchronous communication).

The main tasks of the server part of SCA-Red are next summarized:

- * Establish the handshake communication protocols with the operating SCADA via OPC;
- * Keep track of any changes in the monitored variables, and save new values in a buffer table, named station-sensors;
- * Update a cyclic synchronous table, by reading the values registered into the station-sensors table every 1 minute;
- * Update the tables of the historic data every 15 minutes of 1 hour, by averaging the registered values in the 1 minute table;
- * Filter the raw data saved in these tables to get more reliable values and update the corresponding back-up tables. As have been commented before this process can be done in several steps, saving firstly temporary values for the anomalous data and correcting them later when valid signals are restored;
- * Compute other variables not directly measured, such as tank flows, pump settings and flow balances for demand zones, which are allocated as well in the historic tables;
- * Manage all questions about units and conversion factors between the registered data and the saved data in the historic tables;
- * Keep updated the pre-defined model to be used as the best mimic of the reality at each time period;
- * Attend for any query formulated by clients.

4.5.2 The client module

The client part of SCA-Red can be replicated in any PC and is in charge of supporting all facilities depicted in section 3. The main tasks of client are next summarized:

- Charge the interface and other initial status at the start;
- Initialize and synchronize the data structures between the EPANET variables, the field database and the SCADA signals (tags);
- Read the pre-defined hydraulic model and prepare it to be used under any type of simulation;
- Attend for the user queries via interface;
- Launch queries to the server and manage the returned data;
- Build the updated hydraulic model for each query and communicate with the EPANET toolkit;
- Show the real and simulated data under any operation mode and view window;

- Export EPANET files on request;
- Manage for the different pre-defined models built by the user in the local environment;
- Apply any other option chosen by the user.

4.5.3 Hardware architecture

Firstly is shown the physical layer where the PLC is located. Next the middleware or logic layer is composed of a server, where the operating SCADA is located, and the server part of SCA-Red. This server communicates with the PLC through the protocol TCP/IP. Finally the presentation layer, also called client, comprises the graphical user interface (GUI) of SCA-Red.

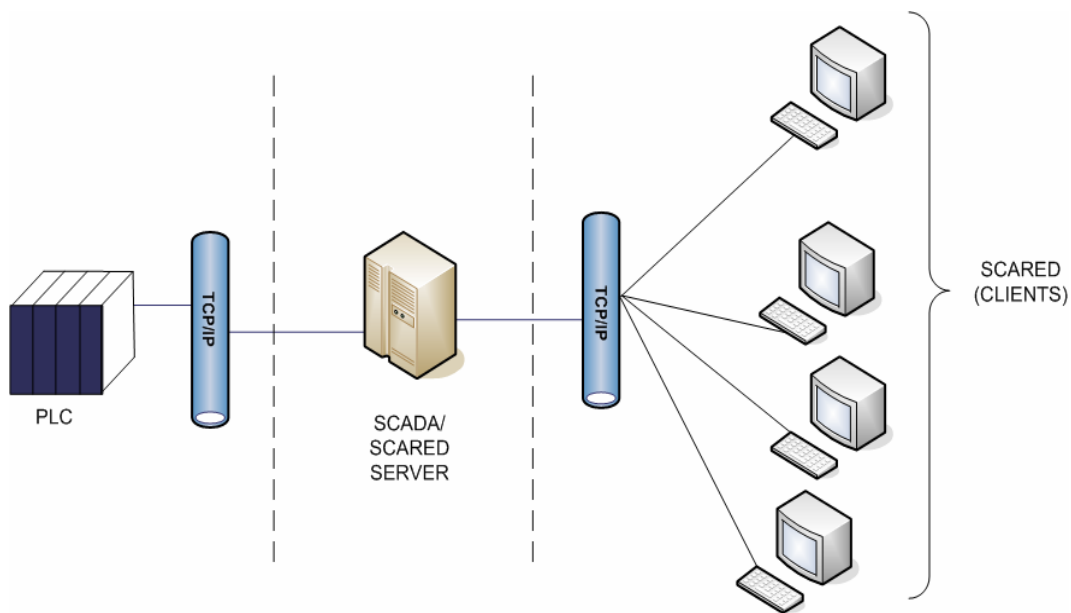


Fig.4.18:SCA-Red hardware architecture

4.5.4 Software architecture

It can be distinguished two big layers or levels in the following diagram:

1. *Server Layer*: in this layer we find the SCADA and the database of historic data, where the values of monitored variables will be stored. Besides, in order to offer an open interface between the SCADA system and the historic data warehouse, there is a component that offers the storage logic between the SCADA variables and the database fields. The actual component uses the OPC technology for the communication level with the SCADA (OPC Foundation, 2001) and the OLEDB drivers for the connection with the database of historic data (Wells, 2001). The component that establishes the synchronism between the SCADA system and the database is the one that constitutes the server part of the application SCA-Red, showed as SCA-Red DB Archiver.
2. *Client Layer*: At this level we can find the components that comprise the client part of SCA-Red.

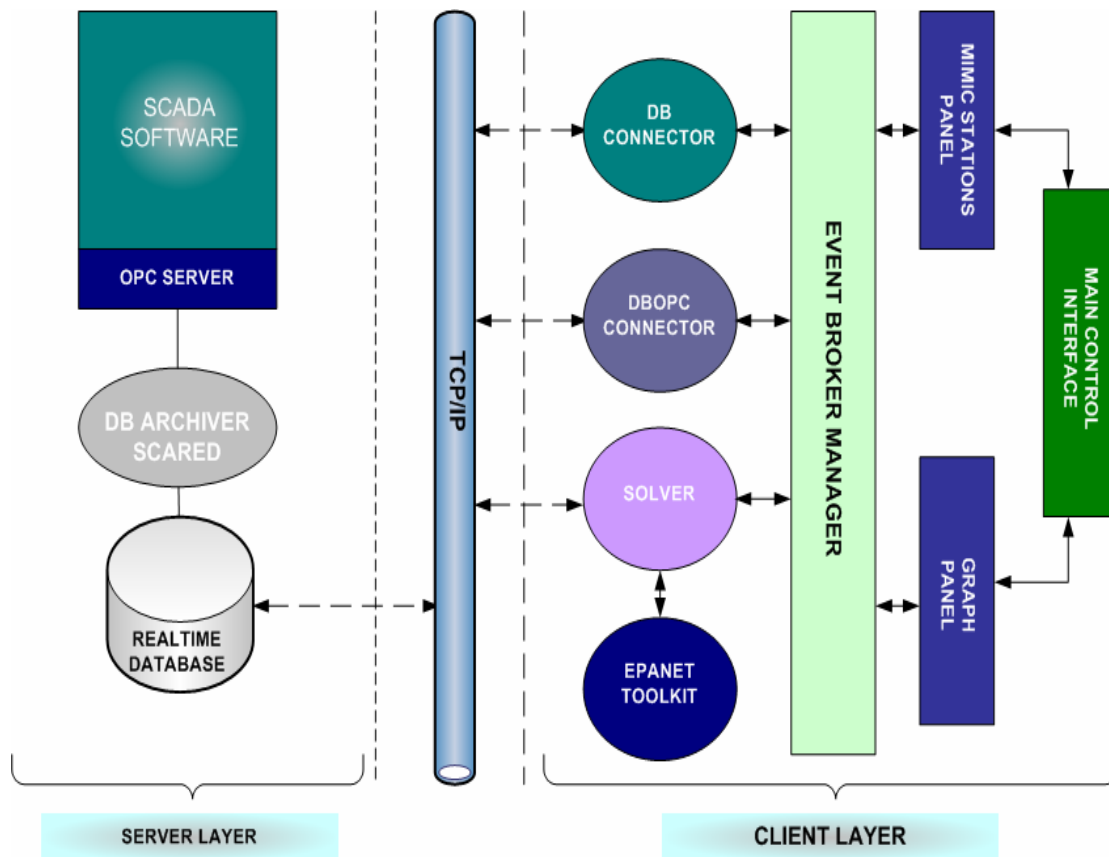


Fig.4.19:Software architecture schema

The communication between the server layer and the client layer is done through the TCP/IP communication protocol.

4.5.5 Conclusions

SCA-Red tries to solve a new challenge on the continuous advance of technologies allowing managers and operators to have a narrow control on the day to day operation of water distributions systems, and helping them to take decisions in real time. SCA-Red can be used also to overview past situations, to optimize the future operation of the network, or to simulate operation maneuvers that might be critical for the normal performance of the network, becoming in this sense into an operator training tool. SCA-Red can still be enlarged in future, to improve the capabilities of comparing different scenarios, to foreseen future demands, to reduce the power consumption by automatically optimizing the network operation in real time, or to become in an alert system against a contamination attack facilitating the early reaction by exporting a real model of the network behaviour at the current time.

Chapter 5: The case study: Water supply system in Valencia

5.1 Introduction

The water distribution networks of large cities form a complex mesh of interconnected pipes, whose mission is to transport water from treatment plants or points of production, to the many subscribers who are supplied by the network.

To face the problems of planning and expansion of the network in order to supply future demands, or as in this case study to learn its current status and simulate emergency situations and propose consequent renewal plan, it is essential today to use mathematical models, computer representations of real physical system, which allow for all kinds of simulations in order to compare the results before carrying out any operation.

Aguas de Valencia S.A., the company that manages the water supply system in Valencia, knowing the utility of mathematical models, in 1993 moved forward to the preparation of the first static model of the arterial network of the city that would serve to characterize network behavior under more unfavourable conditions. That model was made in collaboration with the **University Polytechnic of Valencia**, and served as an excuse for install a series of flowmeters at the entrance of the city, which today allow controlling the distribution of the flow supplied to the city. This model allowed us to know more accurately the different paths that follow the water to cross the arterial network of the city, so as to make an initial diagnosis of network status.

This static model served as a basis for drawing in the following years, in collaboration also with the University Polytechnic of Valencia, a dynamic model that reached up the users from the treatment plants. The model included tanks, pumps and valves for regulation, and for the first time it was possible simulate how the various valves control the pressure level in the city over 24 hours.

The experience gained from previous models and the implantation of new technologies, has allowed Aguas de Valencia SA the preparation of two new models: strategic model and detailed model, which are used in this case study. The most important improvement incorporated in the new models, has been its GIS obtaining from Aguas de Valencia SA, in connection with the database of users, and the SCADA System control network in real time. Indeed, the classical problems in the making of models come not from the potential limitations of the simulator, but more of the difficulties in carrying out the data collection model in three stages most relevant:

1. Obtaining network cartography;
2. Assignment consumption;
3. Field measurements.

All these obstacles have been overcome successfully in recent years thanks to the progressive implantation of new technologies at the company.

The cartography of the new models of distribution network has been captured from GIS of Aguas de Valencia S.A., which details: all pipeline network, its path, connectivity, and most important physical properties. The subsequent elaboration of this information has allowed make a detailed model of 28000 nodes and 30000 pipes.

Moreover, flowmeters allow knowing us the real distributed consumption on the nodes of the city. Using the corresponding databases was carried out model charge, so that each node of the new model is associated users consumption according to the billing data.

Finally, the information from the SCADA, has been used to make calibration of the detailed model, adjusting the pressures and flow rates, besides correctly simulate the variation of the levels in the tanks and the state of start/stop of the pumps all along 24 hours. To carry out all the simulations required during the calibration process we used the program EPANET.

In addition to the efforts made in the preparation of the detailed model of the network of the whole city, Aguas de Valencia S.A. also carried out the preparation of a strategic model like an extract obtained by the previous model. This model will be the subject of our case study. It consists approximately of 4450 nodes, the main arteries and all elements of network regulation.

5.2 Description of network and its main characteristics

The city of *Valencia* and its metropolitan area lay on the eastern seaboard of Spain, this area is densely populated by **1.5 million people**, in approximately **44 towns**.

The network that supplies the city of Valencia population was first established in the early 1900's and has grown in circles and to the east part ever since. The first source of potable water was the treatment plant of "La Presa", which draws water from the "Turia" river.

Nowadays, the Valencia city network is included in a bigger distribution system that comprises all the networks of the 44 mentioned towns. This entity was called *Metropolitan Basic System (MBS)*, and one of its main purposes was to make it possible to supply all the populations with surface water.

In this way, during the 80's, the increase of water consumption, the increase of underground water nitrates, and the need to guarantee the supply to the city and to its metropolitan area (to all the MBS), forced the authorities to project the "Picassent" plant, which takes water from the "Jucar" river by means of a transfer channel. This channel discharge the remaining water to "La Presa" treatment plant, where is blended with the water of the "Turia" river, contributing thus to increase the alternative sources for the global system. As a consequence, the whole metropolitan area is currently supplied with surface water.

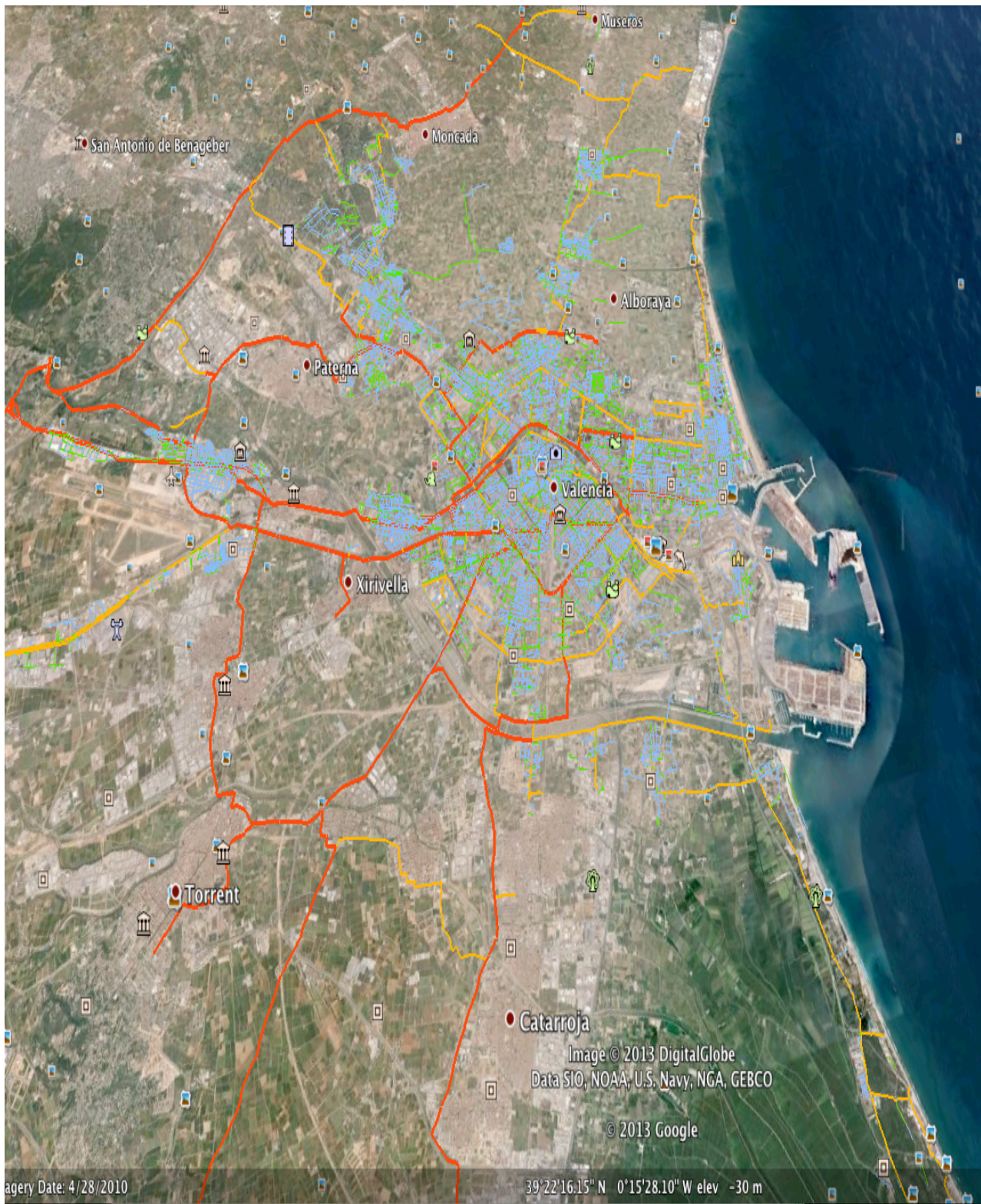


Fig.5.1:Image of network from Google Earth

The distribution network is developed for 1.200 Km of pipe length and provide in addition to the city and its periphery, also much of the suburbs to the North side and to the South side. The consumption diary current is estimated on average for approximately 300.000 cubic meters required for a population of almost 1.5 million inhabitants.

The next figure shows a detail of the Valencia Network corresponding to the city area. The biggest diameters are highlighted in red and with a thicker line. The smallest ones are the blue colored. In this figure it is easy to verify that mains from “La Presa” (at an altitude of 110 m a.s.l., situated in

North-West of the city) are connected to the city network by the west and northwest, and mains from “Picassent” (at an altitude of 92 m a.s.l., situated in South-West of the city) do it by the southwest. Both plants are coordinated to carry out the daily supply, so some of them could hardly supply the city alone; the daily supply is, in an approximate way, divided between the two plants: 60% from “Picassent” and 40 % from “La Presa”.

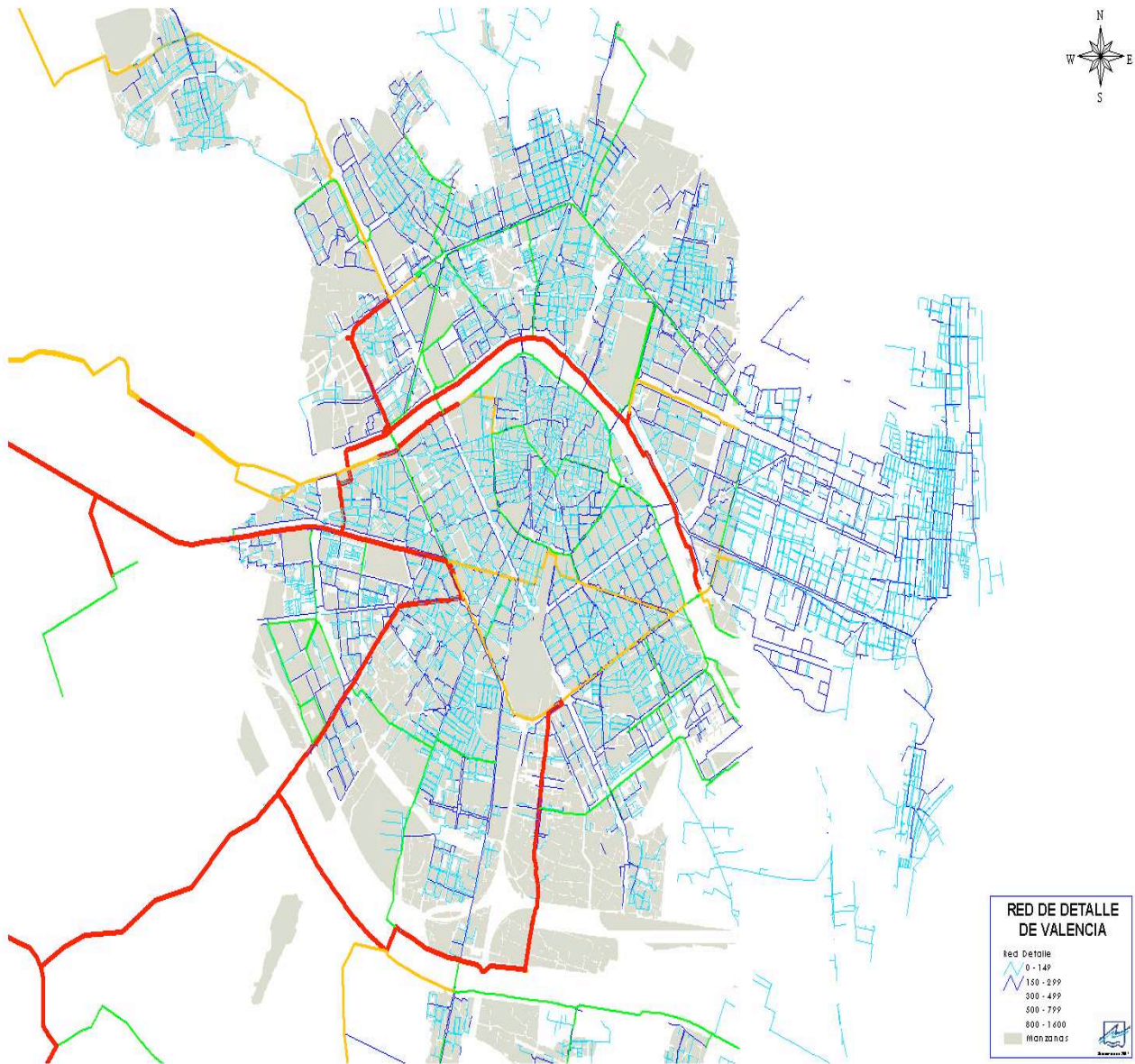


Fig.5.2:City Network Layout

Examining the path that the water takes before reaching the users, try to describe the infrastructure present in the supply network of Valencia.

5.2.1 The treatment plants

After catchment through the large surface water intakes (from rivers and canals) a number of physical-chemical treatments are necessary. These treatments are: roughing processes, coagulation, flocculation, decantation, filtration and chlorination, against which the water flows into one of the galleries of filtered water. The final chlorination will occur later, at the exit of the impulsion and just before the injection to the system.

The water treatment plant of “**La Presa**” is powered by three reservoirs and consists of four tanks: two with a capacity of 15.000 cubic meters, one of 40.000 cubic meters and one of 20.000 cubic meters, for a total of 90.000 cubic meters regulated by 10 pumps:

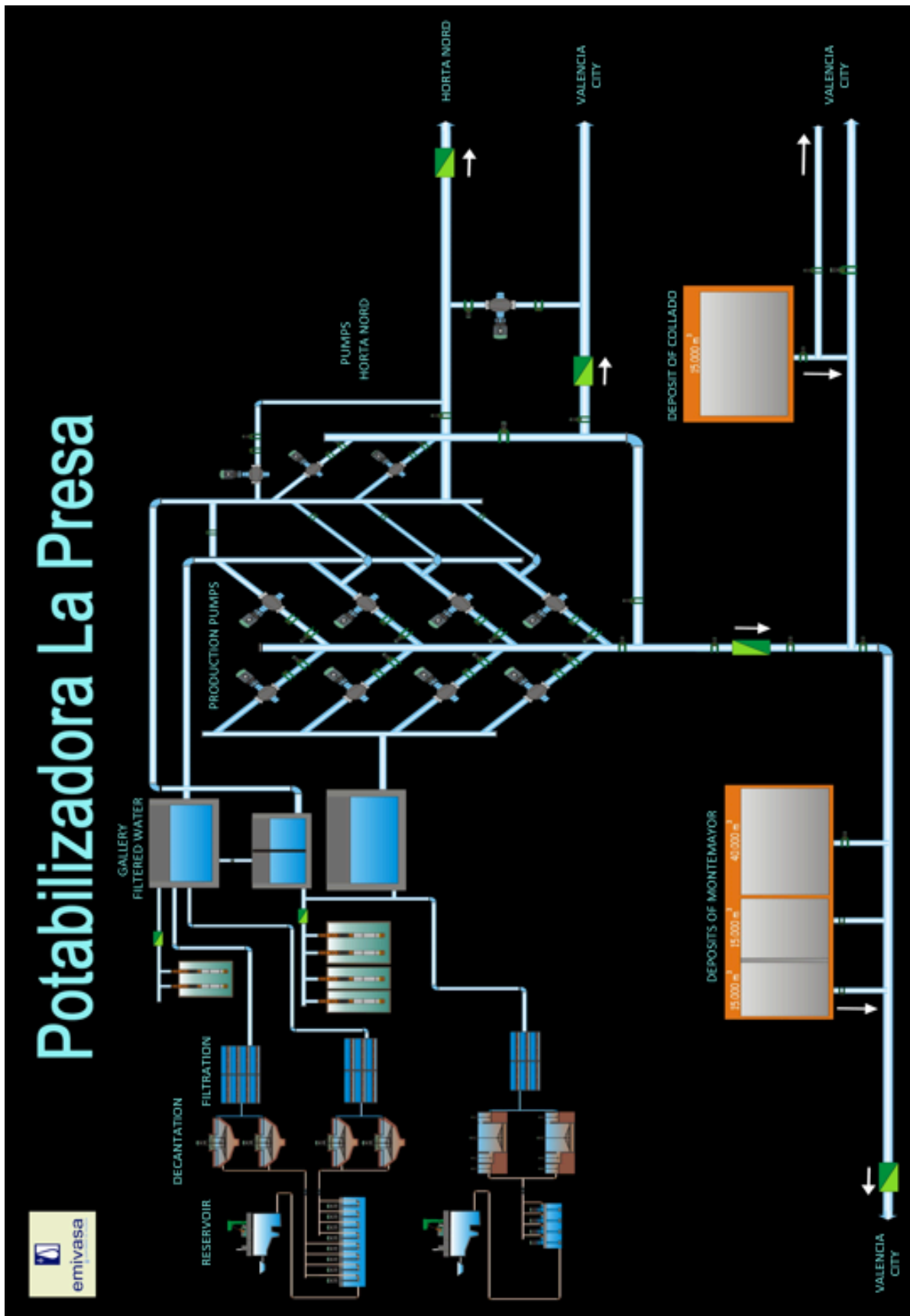


Fig.5.3:Representation of treatment plant of “La Presa” in Sca-Red

The water treatment plant of “**Picassent**” is powered by a reservoir and consists of two tanks with each one a capacity of 50.000 cubic meters, for a total of 100.000 cubic meters regulated by 10 pumps (3 of them are nocturnal):

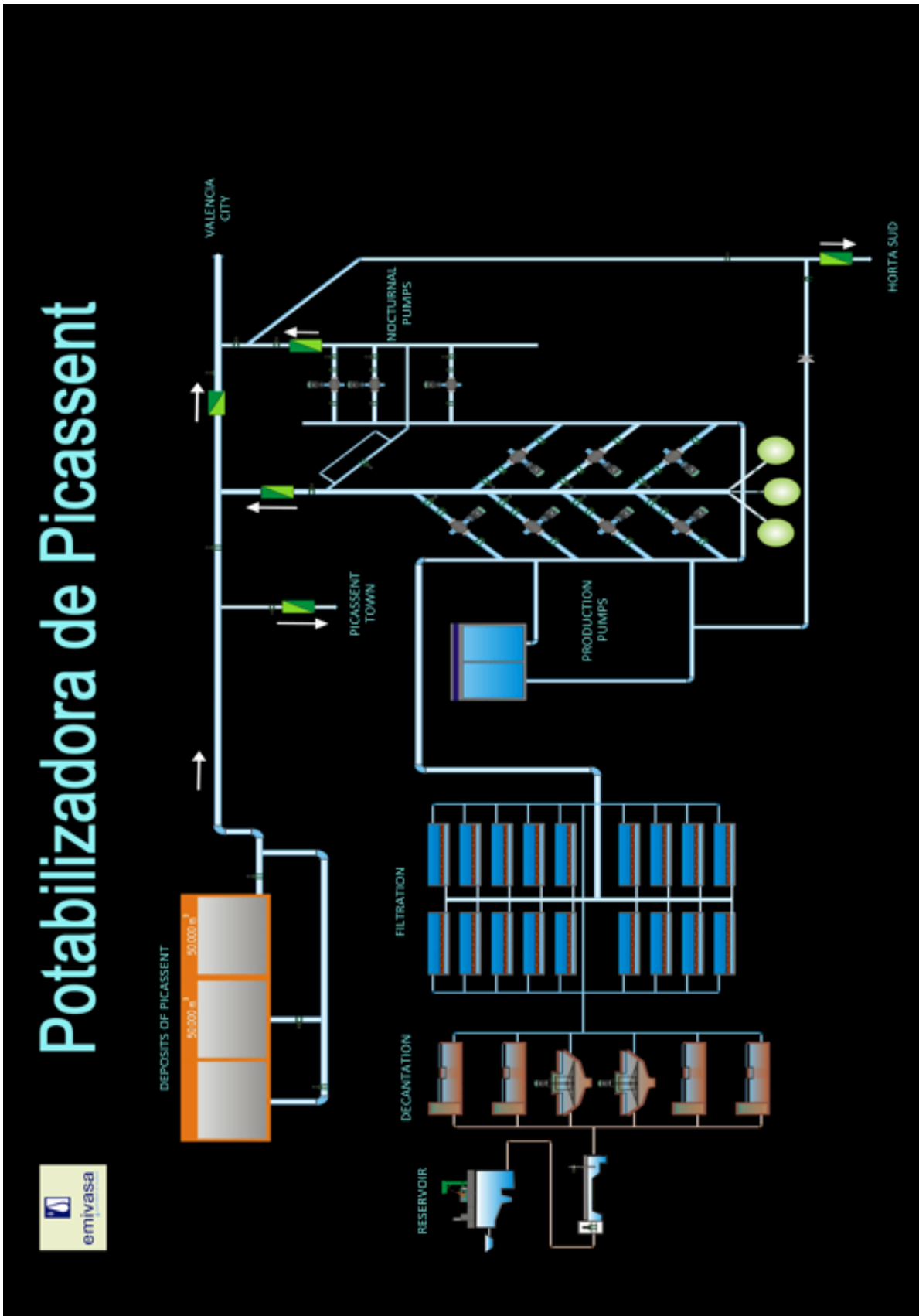


Fig. 5.5: Representation of treatment plant of “Picassent” in Sca-Red

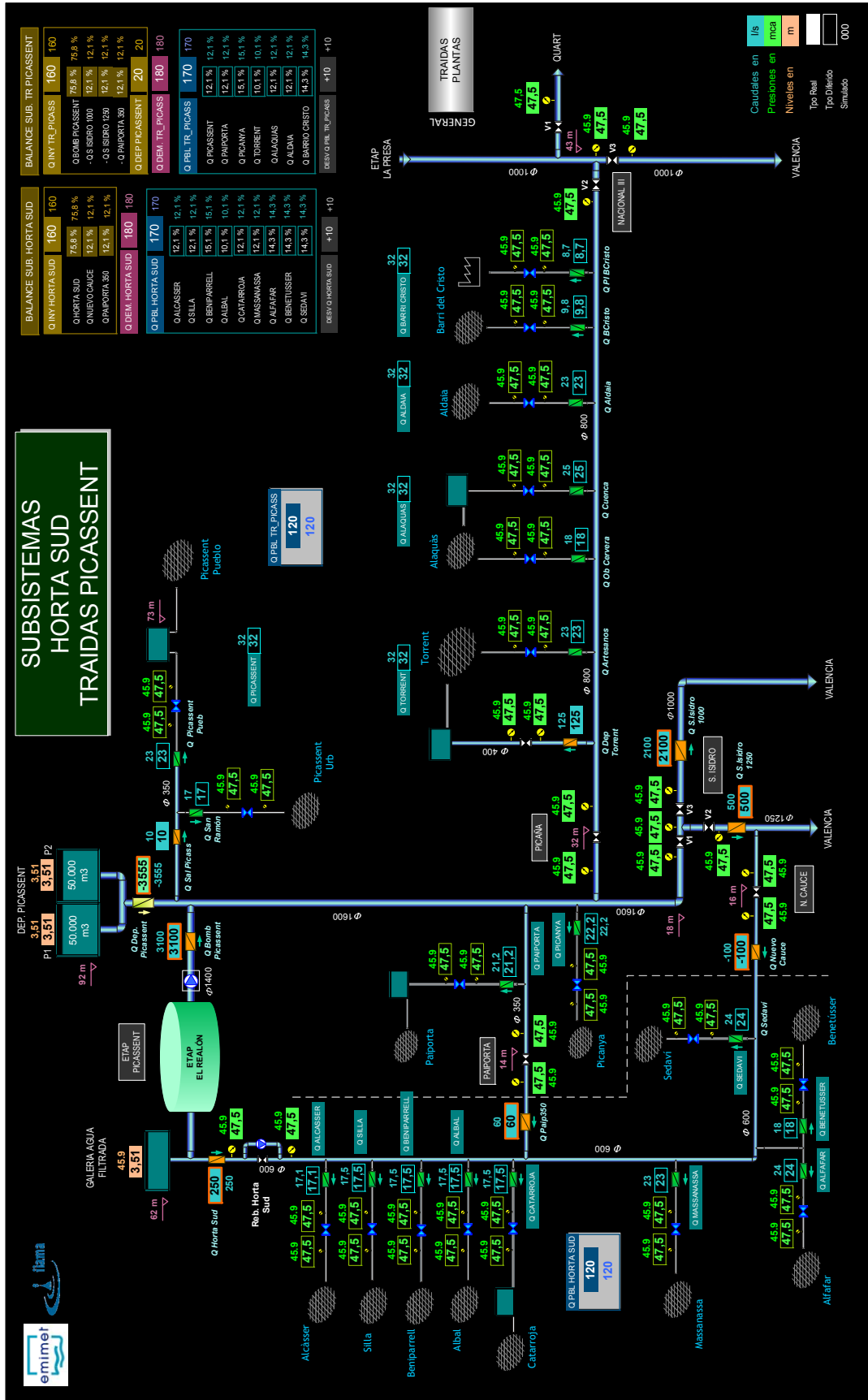


Fig.5.6:Representation of network supplied from the plant of "Picassent" in Sca-Red

5.2.2 The pumping groups

A continuation of the filtered water galleries, we found impulsion or pumping groups: these are big groups of pumps connected in parallel. The mode of operation of the groups is conditioned by the demand for water at all times and the level of water stored in major tanks in the network.

The pumps start in a direct way and the phases of attack-detachment occur in a gradual manner due to the presence of some inverter that act directly on the frequency thus allowing a reduction of the stress on the mechanical, hydraulic and electrical components.

STATION	ID PUMP	FLOW (l/s)	BOOT ORDER
LA PRESA	Production Pump1	275	7
	Production Pump2	347	3
	Production Pump3	330	4
	Production Pump4	330	5
	Production Pump5	290	6
	Production Pump6	275	8
	Production Pump7	275	9
	Production Pump8	240	10
	Pump9 (Horta Nord)	578	1
	Pump10 (Horta Nord)	578	2

Fig.5.7:Description of the pumps in “La Presa”: flow and order start marching

STATION	ID PUMP	FLOW (l/s)	BOOT ORDER
PICASSENT	Production Pump1	420	4
	Production Pump2	420	5
	Production Pump3	490	1
	Production Pump4	490	2
	Production Pump5	490	3
	Production Pump6	420	6
	Production Pump7	420	7
	Nocturnal Pump1	-	8 (not are launched)
	Nocturnal Pump2	-	9 (not are launched)
	Nocturnal Pump3	-	10 (not are launched)

Fig.5.8:Description of the pumps in “Picassent”: flow and order start marching

5.2.3 The tanks

The importance of tanks is due to the multiple functions that are developing:

- gain some security of supply, to enable the storage and supply of water in case of disruptions in the normal functioning of the network;
- laminate the flow supplied to the network, and allow storage of surplus when consumption is lower than the rate provided, as well as the further maximos supplies flows at peak hours demand without changing the flow in the pipe transport or adduction;
- regulate the operation of groups of impulsion;
- maintain regularly at the network pressures.

In almost all tanks transport network measurement devices are connected to a telemetry system (SCADA). This allows remote control and centralize the information on the stored water level from time to time in them.

5.2.4 The pipes network and the control valves

The pipes of the network are closed and pressure conduits, as is usual in networks dedicated to the conduction of potable water. They can be divided into two large families:

1. *Adduction or transport pipes*. This is the most abundant family, consisting of the main pipe network, which carry higher flows and those working at higher pressures. They are responsible for the transport of water from supply points to local distribution networks of each population or consumption point. The diameters are placed above the 200 or 300mm until 1600mm;
2. *Distribution pipes*. Constituted by smaller pipes that carry less volume and operate at lower pressures. They are responsible for distributing water to different users, in particular to the point of attack. The diameter, at most, reaches 200 or 250mm.

The network under study is basically formed by the pipes with a similar function to those of the first group. It is therefore a transmission system or adduction, which constitutes Strategic model or simplified model of the network.

As for the materials used in the manufacture of pipes of the network are the usual: cast iron, concrete, fiber cement and polyethylene.

For the control of the network of water supply to the city of Valencia there were a series of valves, usually remotely operated to facilitate the acting on them. There are also many other additional non-remote controlled valves, which for various reasons of regulation and control of the network can be fully or partially closed. A total of 82 valves, and each of these valves has been modeled according to the information available on the same and different criteria used in the model construction. Usually has chosen to define a valve regulating (Throttle Control Valve or TCV) as the setpoint, assigning them a coefficient (0 or 1) as a function of the degree of their opening. In some cases the valves are modeled as pressure-reducing (Pressure Reducing Valve or PRV) because it only has information about the pressure downstream thereof or for adapting the model results to those measured for the reality.

Once typified each of the valves and determined which ones that are going to be introduced into the model we have proceeded to the information to include them in the database of the model; the characterization of the valves will be completed once to establish the different laws control will be introduced directly into EPANET.

5.3 Simplification of the network. Confection of the strategic model

The elaboration of the strategic model of the network consisted essentially in a simplification or reduction of the detailed model, obtaining a model that contains only the main elements of the network, and which will ultimately determine the overall behavior thereof. Should be noted that in a network, essentially larger diameter pipes carry the majority of flow distributed and ultimately determine the hydraulic behavior of the network, consequently strategic or arterial model is sufficiently representative for realize analysis global of distribution network.

The fundamental objective in getting the strategic model of the network was to obtain a model made exclusively for pipe diameter greater than or equal to 200 mm, as well as by the main elements of regulation, treatment plants, etc...

The detail model simplification was carried out in the following sequence:

- Creation of a new scenario: firstly proceeded to create a new scenario with the corresponding database so that it was possible to make a copy of the database of existing detailed model with all its elements and attributes;
- Importation in the new scenario of detailed model: after creating the new database we proceeded to import on this all the information concerning the detailed model. Clearly the need to make a copy of the database before starting the process of simplification in order to avoid loss of information as a result of elimination of elements. On the other hand, proceeding in this way ensures the relationship between the two databases as the identification of the different elements remain;
- Selection of pipes to be removed: it was decided to extract a network model containing pipes of diameter greater than or equal to 200 mm. Consequently all those pipes were chosen not complying the above condition and proceeded to their elimination;
- Strategic Model Validation: as a final step of that process is necessary to generate an EPANET input file with which to make a simulation whose main use is to check both the connectivity of the model and the properties of the different elements are in principle appropriate.

The model obtained so far is not complete: we should proceed to the definition of a number of additional parameters such as nodal demands, the elements of regulation or control laws thereof.



Fig.5.9:Image of Strategic Model from Google Earth

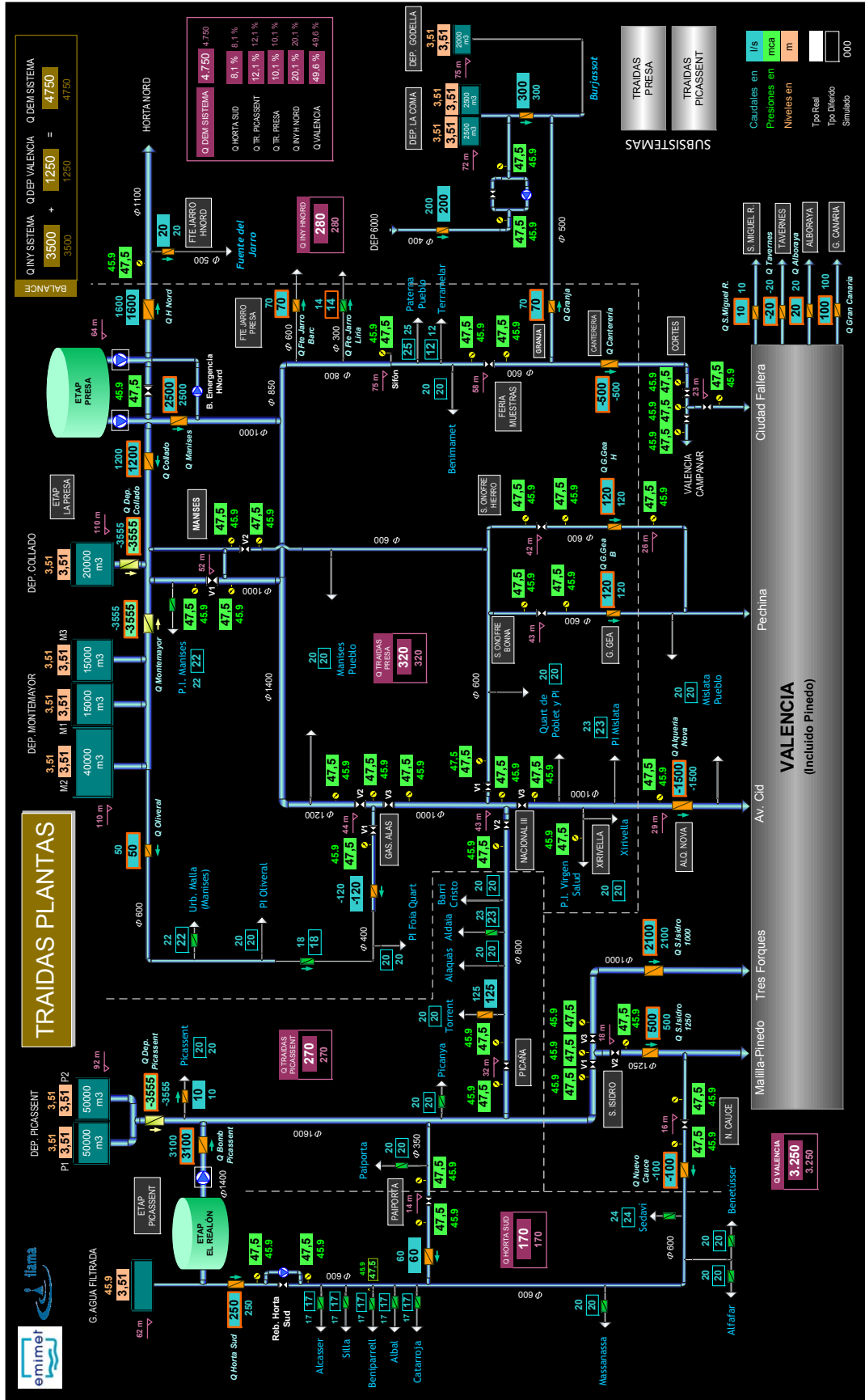


Fig.5.10:Representation of the main scheme network in Sca-Red

5.4 Analysys the study period. Selection of the charging period

The aim of the assignment of consumption at the nodes of the model is to determine the demand that satisfies each of these nodes and as close to reality as much as possible according to the spatial distribution space users. A system of water supply is provided in charge to assure the transport and distribution of water from captacion or production sites to consumption sites in the quantity required (flow) and with sufficient quality (pressure) in a period when was recorded the maximum consumption of the year (you can notice in the following graph).

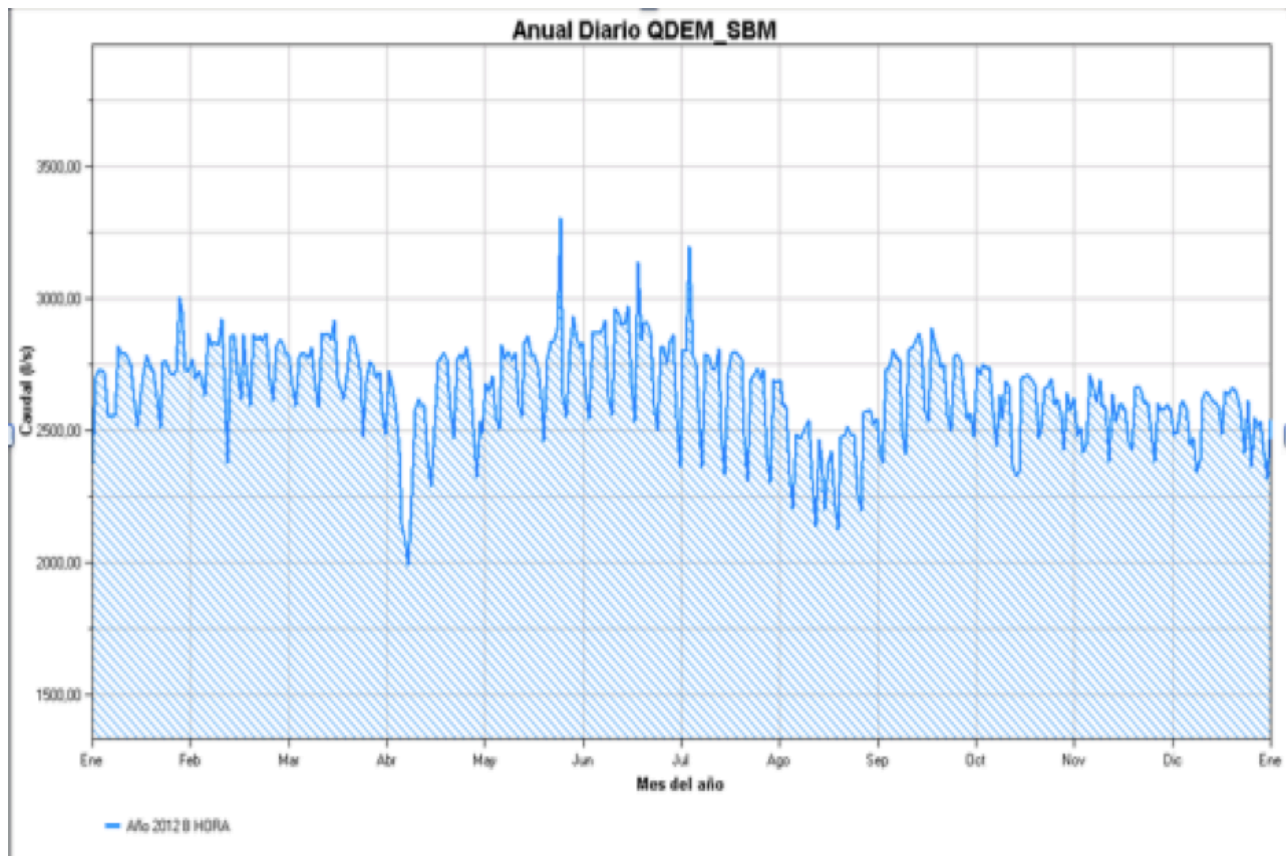


Fig.5.11:Daily flow rate consumed in the whole system during the year 2012

As we have already stated in the previous chapters: the quality of a model is clearly influenced by the quality of the initial data; this is one of the reasons that led us to make a proper and detailed analysis of the data collected in the database of SCADA. For determining so the nodal demands to charge the model, which is as close to reality as possible, we proceed with the analysis of the data of the past year (ie 2012), so as to be able to find that day of the year in which all values of the system are more reliable and less affected by anomalies.

The data coming from the sensors may submit anomalous values, which occur both with the succession of constant values or with the presence of values completely out of the rank such in technical jargon “outliers”, or rather observations that are numerically distant from the rest of the data. The succession of values perfectly constant, which is represented with a straight line parallel to x-axis (ie the one of the times), originates in the synchronization process and is caused by a insufficient data this lack of data may be attributed to several factors such as:

- voltage failure;
- communication failure;
- time zone change.

The “outliers”, instead, presented with the peaks above or below the standard values, in this case are generated for the presence of:

- an environmental magnetic noise.

Through the application “SCADA Data Analysis” (described previously) we have been able analyze historical data stored in the database. With the consultation of these data, we were able to see where, when and for how long the values of pressure, flow and level were affected by errors. The analysis of the signals is processed with an annual representation of historical raw data with a sampling frequency of 15 min with hourly grouping. Subsequently, these values are exported to an Excel file, where they will be processed. First are represented on an hourly basis as the average of four values that constitute the respective hour, and subsequently the same values are recalculated and displayed on daily basis as the mean of 24 values for the day in question.

In the following figures are shown:

1. The analysis of a signal (pressure signal in this case) with a sampling frequency of 15 min show the presence of an anomaly represented with values of pressure out of the rank: outliers;
2. Processing of the signal: its representation on hourly basis and daily basis on Excel file;
3. Summary file: the quality of all signals of the year 2012 on daily basis.

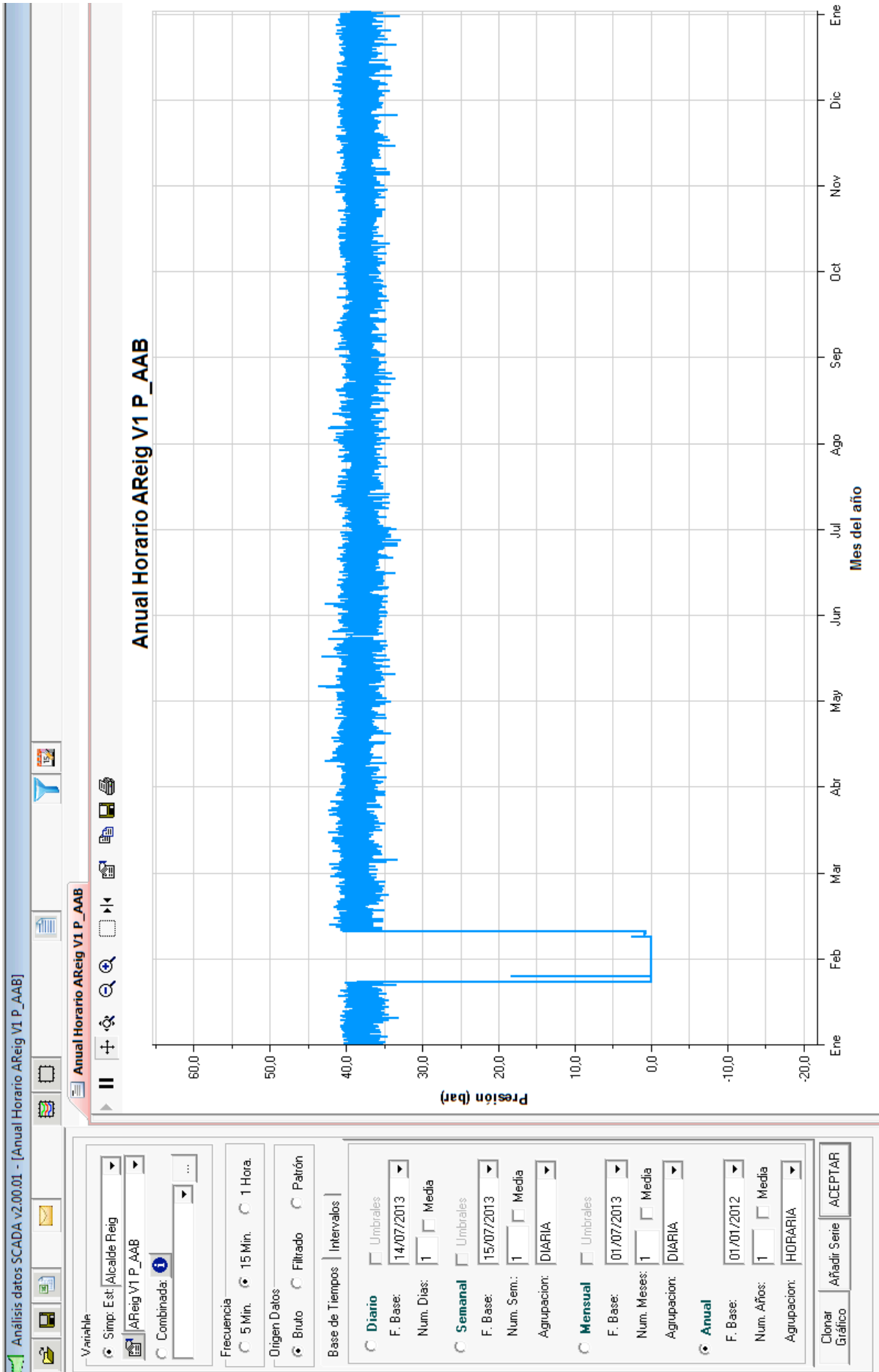


Fig.5.12:Annual analysis of a particular pressure with the presence of abnormal values

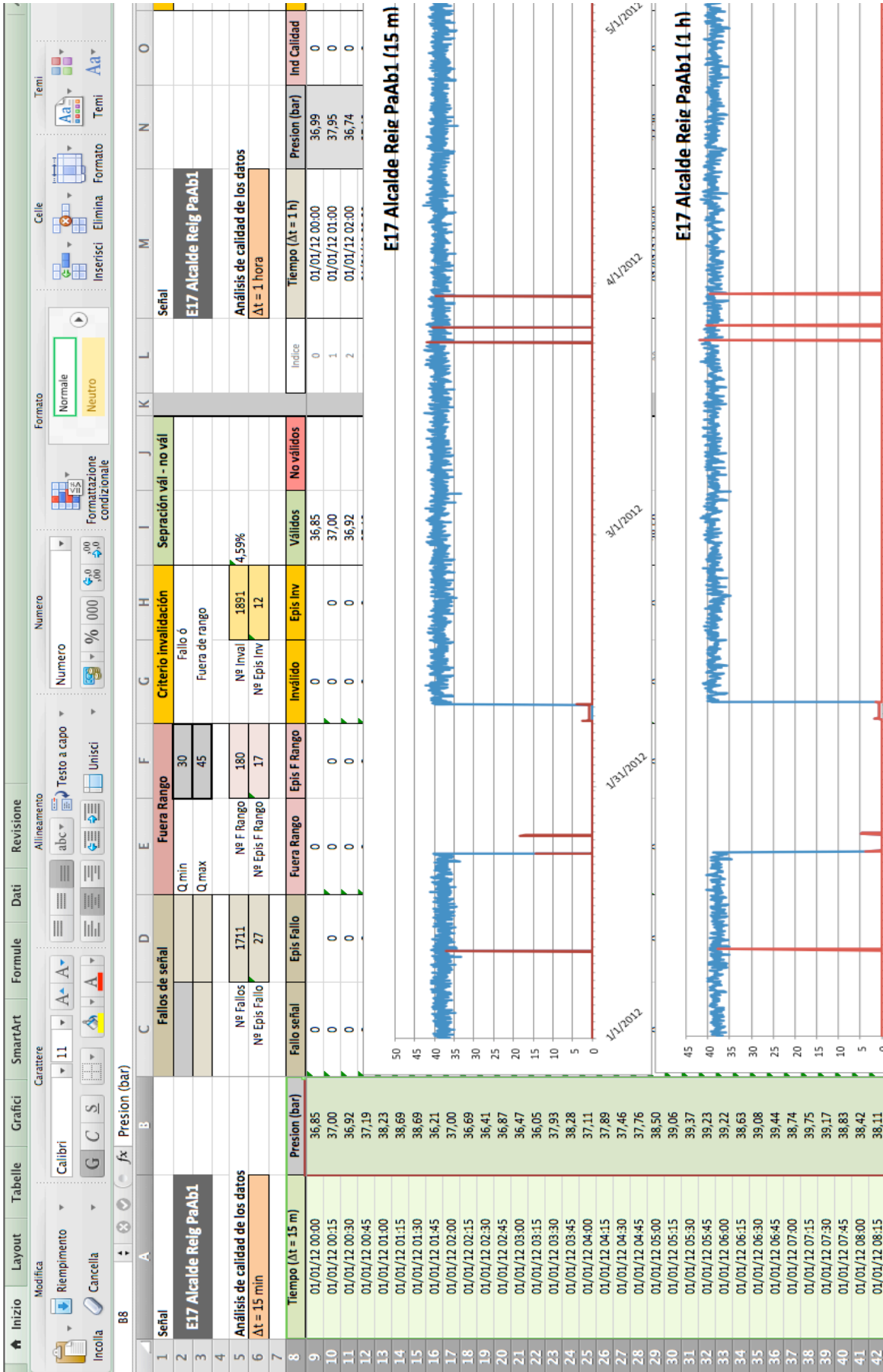


Fig.5.13:Processing of signal: Exportation of annual analysis of the previous pressure signal on Excel file

	A	B	C	D	FL	FM	FN	FO	FP	FQ	FR	FS	FT	FU	FV	FW	FX	FY	FZ	GA	GB	GC	GD	
1																								
2																								
3	IDESTACION	ESTACION	IDSCARED	IDABREV	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
40			RT_E08_V3893	PaseoPechina V1 P_AAR	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
41			RT_E08_V3894	PaseoPechina V1 P_AAB	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
42			RT_E08_V3895	PaseoPechina V1 Pos	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
43	E08	Paseo Pechina	RT_E08_V3945	PaseoPechina V2 P_AAR	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
44			RT_E08_V3946	PaseoPechina V2 P_AAB	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
45			RT_E08_V3947	PaseoPechina V2 Pos	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
46			RT_E08_V3974	PaseoPechina Q1	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1	0,2	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0
47			RT_E09_V1930	P.Campanar V1 P_AAR	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
48			RT_E09_V1931	P.Campanar V1 P_AAB	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
49			RT_E09_V1932	P.Campanar V1 Pos.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
50	E09	P. Campanar	RT_E09_V1988	P.Campanar V2 P_AAR	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
51			RT_E09_V1989	P.Campanar V2 P_AAB	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
52			RT_E09_V1990	P.Campanar V2 Pos	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
53			RT_E09_V2017	P.Campanar Q1	0,1	0,1	0,1	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,2	0,1	0,1	0,1	0,1	0,1	0,1	0,0
54			RT_E10_V3625	GAViles V1 P_AAR	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
55	E10	Gral. Aviles	RT_E10_V3626	GAViles V1 P_AAB	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
56			RT_E10_V3627	GAViles V1 Pos	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
57			RT_E11_V1509	Pinedo V1 P_AAR	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
58	E11	Pinedo	RT_E11_V1510	Pinedo V1 P_AAB	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
59			RT_E11_V1511	Pinedo V1 Pos	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
60			RT_E11_V1538	Pinedo Q1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
61	E12	Gran Via	RT_E12_V2499	GVia PresAlta	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
62			RT_E12_V2467	GVia PresBaja	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
63			RT_E13_V2363	Presa Q Collado	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
64			RT_E13_V2366	Presa Montemayor Nivel1	0,4	0,2	0,2	0,4	0,2	0,1	0,0	0,4	0,1	0,1	0,1	0,2	0,4	0,2	0,4	0,3	0,1	0,1	0,8	
65			RT_E13_V2367	Presa Montemayor Nivel3	4,0	4,0	4,0	2,5	0,1	0,0	0,0	0,2	0,3	0,2	0,1	0,1	0,2	0,1	0,3	0,1	0,0	0,3	0,7	
66			RT_E13_V2368	Presa Collado Nivel	0,3	0,2	0,3	0,3	0,3	0,8	0,0	0,2	0,1	0,0	0,1	0,3	0,3	0,3	0,3	0,3	0,1	0,2	0,0	0,0
67			RT_E13_V2374	Presa Q Oliveral	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
68	E13	La Presa	RT_E13_V2386	Presa Montemayor Nivel2	0,2	0,1	0,2	0,1	0,0	0,0	0,8	0,8	0,2	0,2	0,0	0,1	0,3	0,3	0,3	0,4	0,3	0,0	0,0	0,7
69			RT_E13_V2385	Q Horta Nord	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
70			RT_E13_V2362	Presa QManises1000	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
71			RT_E13_V2379	Caudal Calcu. Montemayor	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
72			RT_E13_V2380	Caudal Calcu. Collado	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	

Fig. 5.14: Choice of the better day: Summary file of the annual analysis on daily basis of all the signals

In the processing signal file, represented in the second figure, for each signal is provided a quality index based on the criterion that we consider most appropriate. This criterion has been applied to the signal with a sampling frequency of 15 min obtained from SCADA Data Analysis, considering anomalous all those values taking the same value in the sequence (constant value) or those considered outliers.

For each value considered abnormal has been assigned a value equal to 1, regardless of the good ones to whom was assigned a value of 0. Consequently, the signal with a sampling frequency of 15 min (4 values for each hour) assumed a quality index with:

- 0 (no abnormal value);
- 1 (1 abnormal value);
- 2 (2 abnormal values);
- 3 (3 abnormal values);
- 4 (all abnormal values).

Subsequently, the signal values (flows, pressures and levels) and their quality indexes were grouped for hour, simply making an average of 4 values relative to hour in question. Similarly, in the same file, the values grouped by hour have been processed through an average of 24 values, so as to obtain the daily values with the respective quality indices.

Following these values will be used to determine the day that has fewer anomalies. In the last figure, indeed, all signals are grouped by station, for recognition code, and for quality daily index for all the year 2012. Each box represents the daily quality of the signal: each one of them is represented by a number which indicates the value of the quality index, and for each value a color ranging from a lighter shade (value 0 ---> bluish, very good signal) to darker (value 4 ---> red, very bad signal).

The complete analysis of all the signals present in the model and the grouping of the same quality daily (quality value by day per signal) allowed us to find the day less afflicted by errors with which we can load a model who comes closer as possible to the reality. The better day in the whole year 2012 that it is: **June 27th**. This will be the day that we are going to consider for our simulation.

In the case of dynamic models in addition to an average value for the demand (basic demand) requires the collection of a series of modulation curves that allow knowing the temporal variation of demand.

5.4.1 Modulation of the demand

The mathematical models of supply network extended period, allow the simulation of the same including the time variable. The demand nodes need not be constant along the simulation period; this variation can be modeled generally as a series of fluctuations around an average value of demand. The way of representing these fluctuating demands is through modulation curves. These curves have a variable modulation factors over time, which multiplied by the mean value of the demand, provide instant node consumption for each time interval. Modulation curves represent the variation, hour by hour, of the consumption in a total period of 24 hours, starting at 0 hours and ending at 23 pm the same day. They have an average value unit because have been determined the hours factors of modulation as a result from dividing the value of the hourly demand between the average value of the daily demand.

The information used in the calculation of the modulation curves originated from data recorded by the data acquisition system SCADA of the company: basically, levels in major tanks and flow network through the main pipe. Based on the flowmeters on the existing network, to the senses of circulation of water and closed sections or pipes currently, are considered 13 different modulation curves, one for each sector of the supply network.

To obtain modulation curve demand any of these sectors is necessary to calculate net flow injected hourly to the sector for input and output difference:

Entries are all those pipes through which water contribute to the sector;

Outputs are all those pipes through which water flows out of the sector;

Tanks present in the sector also have a role in a balance of this type because they can act either as inputs or outputs: when empty they behave as inputs and as outputs when filled.

Summarizing, the net flow expression always has a look similar to this:

$$Q_{net} = \sum Q_{ent} - \sum Q_{out} \pm \sum Q_{tan}$$

Known net flow, hour by hour, simply divide each value with the basic demand (DB, estimated during the packaging of the model (described in section 2.5.3)), order to obtain the different hours coefficients or *demand factors* (F_i) that make time modulation curve:

$$F_i = \frac{Q_{net}}{DB}$$

From the above expression is the immediate calculation of the hourly consumption of each point in the network, you can just multiply the demand factors in question for the basic demand to get the change of the flow during the day.

As mentioned earlier, several modulations have been proposed in the model have, which are different for sector or district: one for the urban network (D.M.A. Valencia, or District Meter Area Valencia), the others for the populations of the metropolitan area, and one for each controlled output flowmeter Valencia which time records are available. In the following picture, we represent one of the 13 DMA, which are modulated all flows exiting from each node at different time.

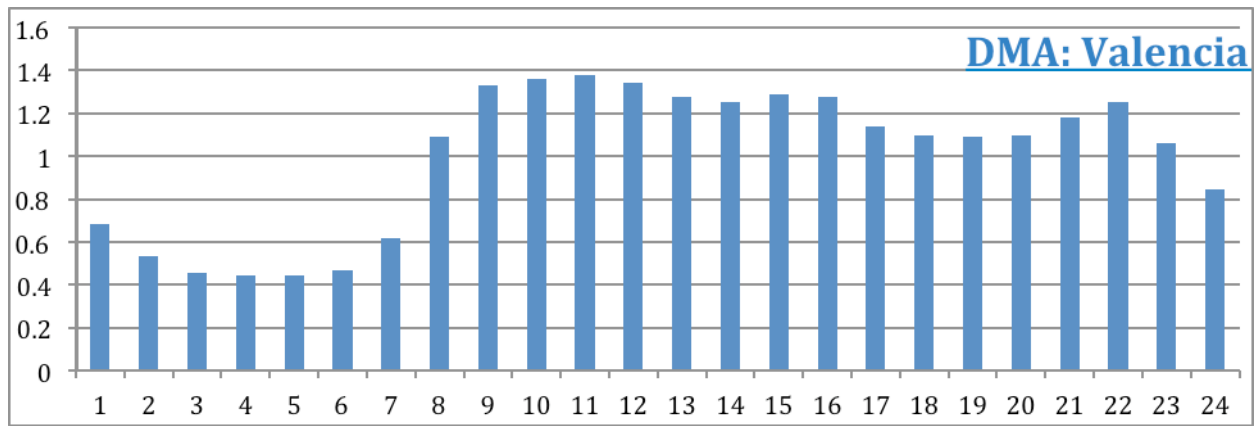


Fig.5.15:Modulation Curve for DMA Valencia

Generally, in modulation curves differ between periods: valley, plain and tip. The first corresponds to the night hours and holds the lowest values of demand. To follow corresponds to consumption maximum hours and holds higher values.

From explanation it follows that it is necessary to select a representative day for calculating modulation curves along the same. The study period of the model is the whole year 2012 and the day, that we have chosen to charge the model, is the “better day” of the year, previously found, in which all values of the system are more reliable and less affected by anomalies, because the quality of a model is clearly influenced by the quality of the initial data.

5.4.2 Charge of the model: setting the input values

Any hydraulic network is designed to meet the demand for water at the point of consumption. Load a model means assigning a demand at a various nodes of the network. “Charge state” of the system is called the consumer situation that occurs in the network at any given time, and so for each node of the network we allocate the basic demand, previously estimated during the development of the model, and the respective modulation curve of the sector in which belongs. Other input values that we charge in the model like system control laws are:

- the initial level in the tanks;
- the downstream water pressure in PRV (Pressure Reducing Valve);
- the open/close state in TCV (Throttle Control Valve);
- the flow rate in FCV (Flow Control Valve);
- the start/stop state of the pumps.

5.5 Simulation of real scenarios

With the help of the mathematical model we will analyze the most relevant aspects from the hydraulic point of view and its influence on the system behavior. The simulation is done for the day close as possible to reality: **June 27th**, in a period when was recorded the maximum consumption of the year (you can notice in the following graph).

This is an initial diagnosis of the network that allows a deeper knowledge of it, draw some conclusions and propose changes and actions that may be appropriate, with the ultimate aim of improving the exploitation and daily operation of supply. The most relevant aspects from the hydraulic point of view we examine are the following:

- Topography of the area;
- Speeds;
- Diameters;
- Flows;
- Piezometric heights and load losses;
- Pressure analysis;
- System Performance.

In a way, is going to work with the most unfavorable situation (the system is subjected to the highest demands) so it can be deduced that the losses and pressure provided by the model will be worse than those corresponding to other states load where demand is lower and therefore also circulating flows.

Besides loading the model with the demands for the month of increased consumption, the most unfavorable situation corresponds to the time of day during which major circulating flow through the network. This does not coincide the total flow time produced or injected into the flow system with the total consumed by it. The difference is the volume stored: when production is higher than consumption, the global volume stored increases, this happens mainly at night. When production falls short of consumption, the overall volume stored deteriorates, which occurs in human most active hours during the day (peak hours).

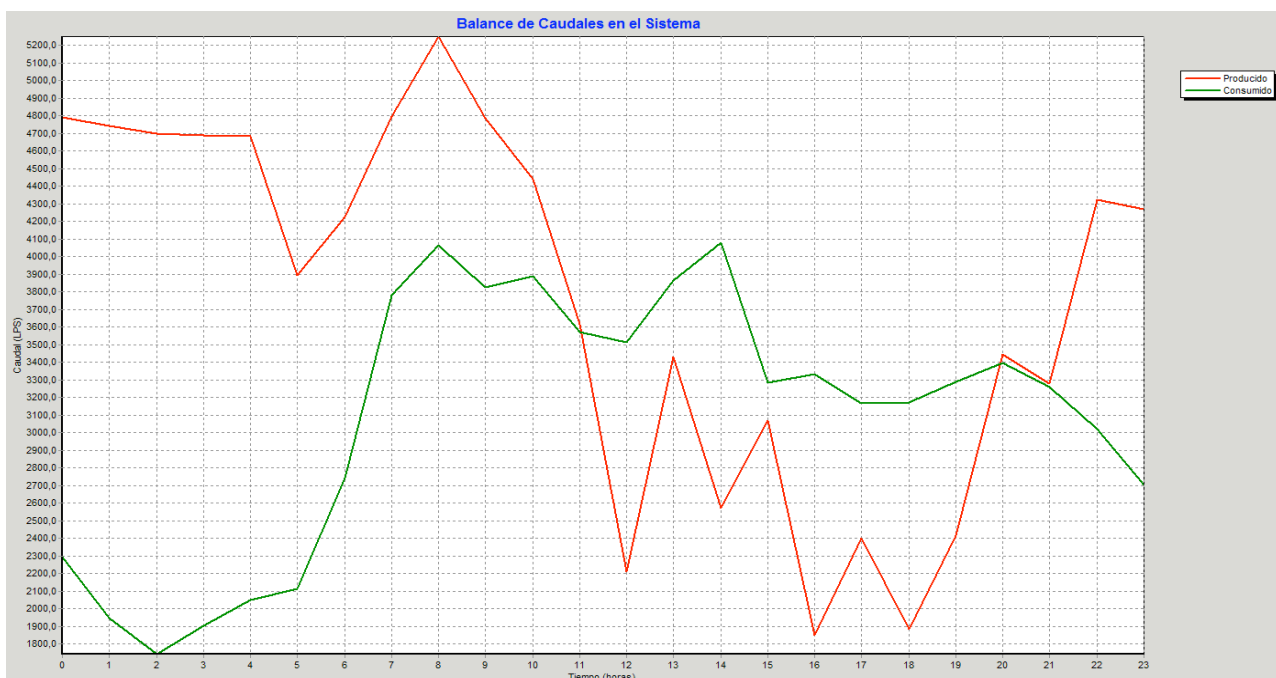


Fig.5.16:Balance flow of the system in 24h: produced(red line)/consumed(green line)

5.5.1 Topography of the area: representation the elevation of the network

In the description of the network, made at the beginning of the chapter, we have seen that the distribution network is developed for 1.200 Km of pipe length and provide in addition to the city and its periphery starting from the tanks of “La Presa”, at an altitude of 110 m a.s.l., situated in North-West of the city and “Picassent” at an altitude of 92 m a.s.l., situated in South-West of the city, to get down until the coastline situated in the extreme East side. The coordinates of the points of consumption of the network, as we can see in the picture below, vary greatly between 110 m of the highest point in “La Presa” and sea level 0 m.

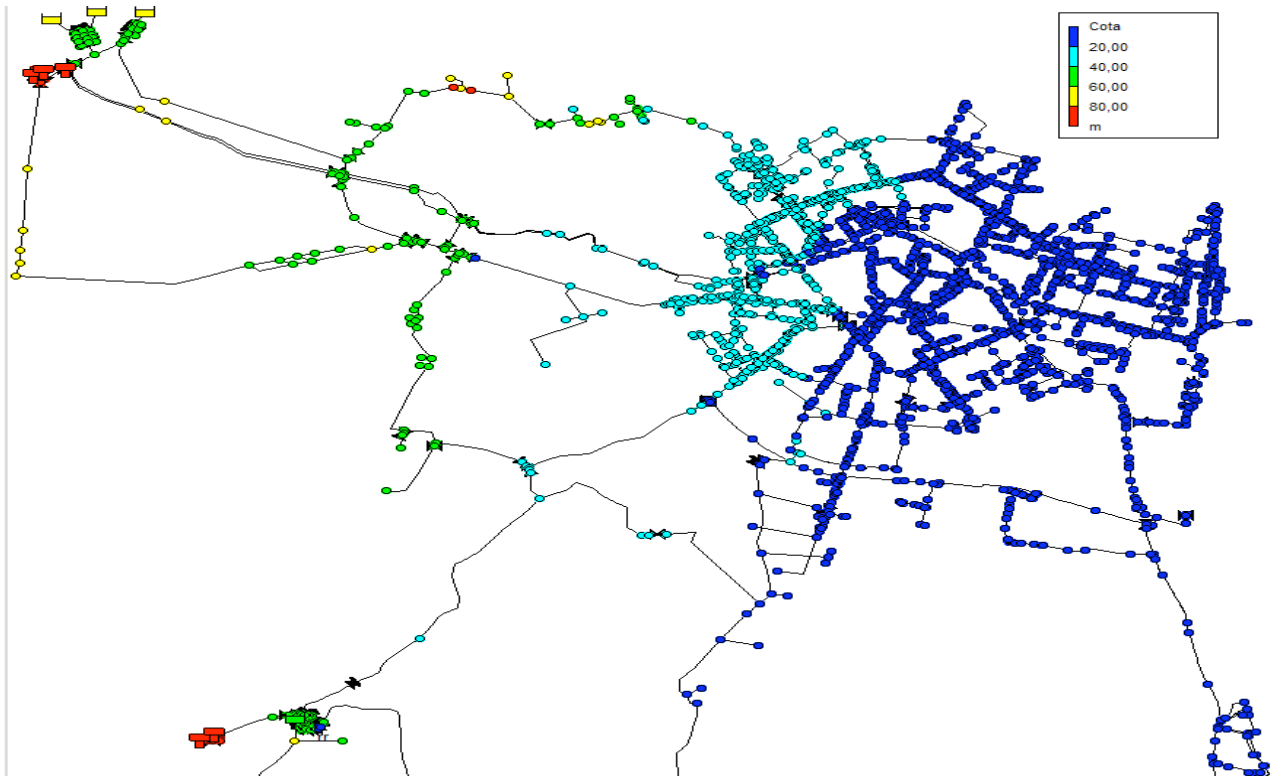


Fig.5.17:Heights of tanks and points of consumption of the network

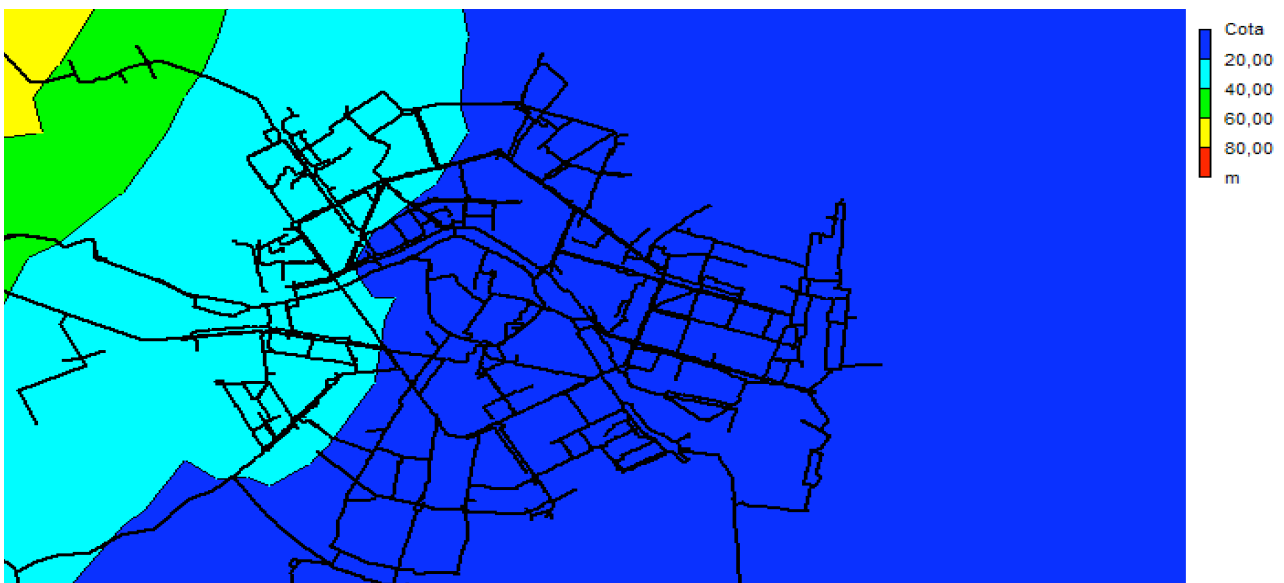


Fig.5.18:Map of isolines heights of the network

5.5.2 Representation of diameters, speeds and flows in pipes

In the following figure where are displayed the diameters of all pipes network: the lines in red and yellow represent all the main abstraction pipes.

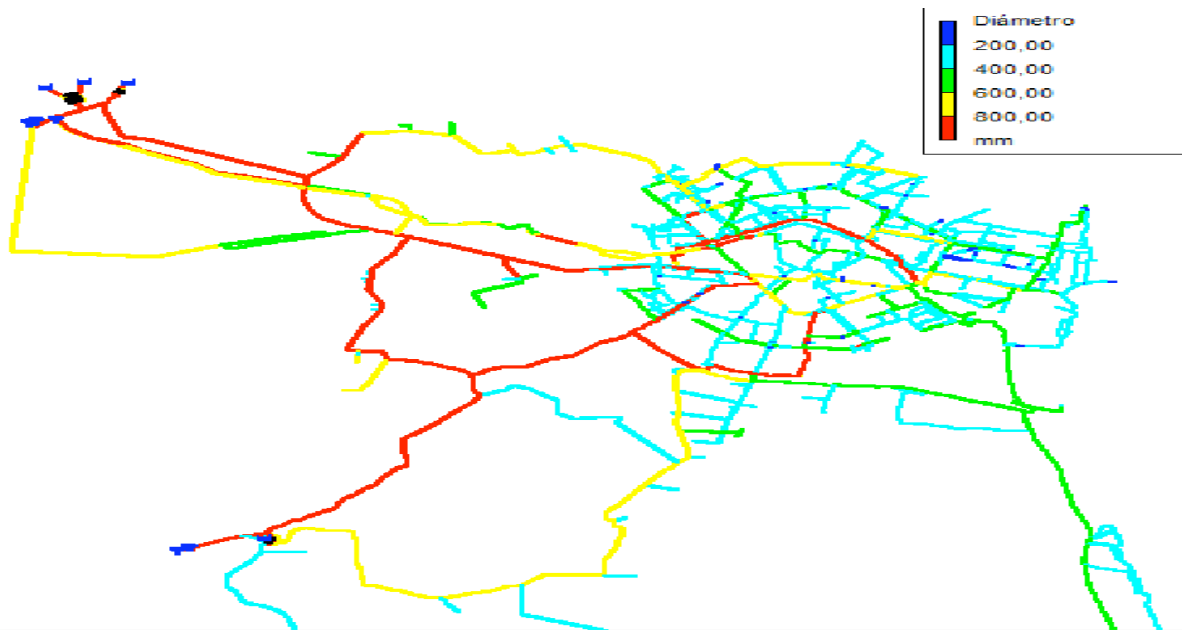


Fig.5.19:Representation of the diameters of pipes network

The velocity of circulation of water in a pipe depends of the flow and its diameter. Excessive speed is inadvisable because carries with it high frictional energy losses, which results in a higher energetic cost when having to increase header height to satisfy the required minimum pressures. In contrast, a speed too low is not advisable because, on one hand assumes some degree of underutilization of the pipe, thus associated cost and, on the other hand, makes the tanks of materials in suspension, causing blockages in the pipes or right incrustations, reducing utile section, not forgetting that also could adversely affect water quality.

Below shows the velocities in the pipes of the network in the most unfavorable situation: at peak time (12:00 hours):



Fig.5.20: Circulation speeds in the pipes at 12:00 pm in the day of the charging state

It is verified that the velocity of circulation of the water is less than 1 m/s in most of the pipes. In fact, the distribution curve, in the following figure, indicates that for 95% of pipes circulating water at a speed below 1 m/s at peak time of day for the month of increased consumption, which is the charging state chosen to analyze the current network situation.

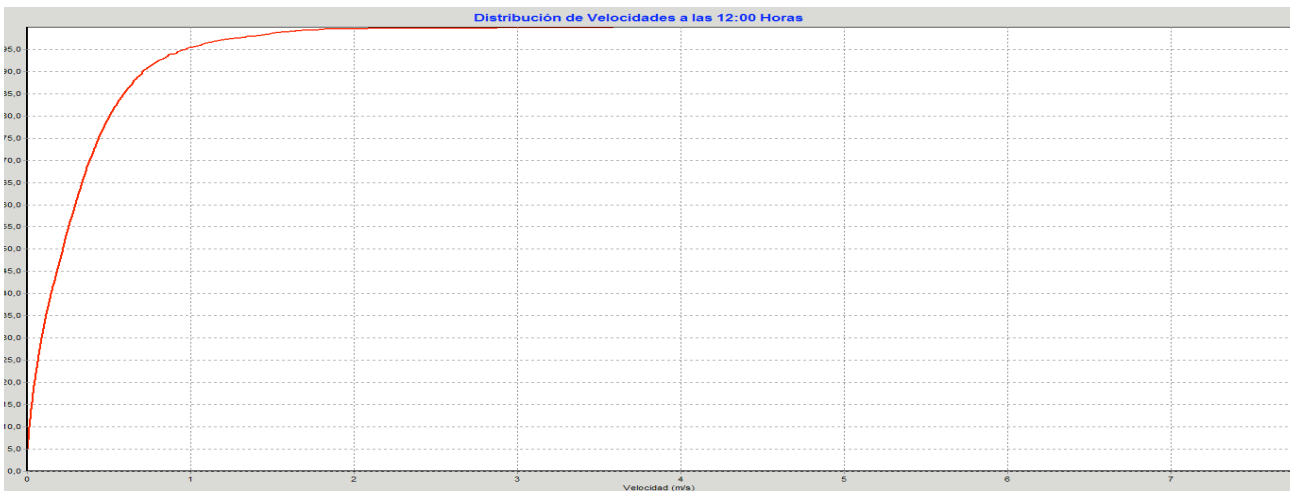


Fig.5.21:Speed distribution curve at 12:00 pm in the day of the charging state

From the map of circulation speeds, is evident that the pipes, in peak hour, have a speed higher than 1 m/s are external ones or abstraction pipes, which serve as junction between the tank and other input nodes in the entry of the city; afterwards the flow is divided into different pipes of smaller diameter.

It comes to abstraction pipes with a diameter greater than or equal to 600 mm, as shown from the graph of speed distribution, are part of that remaining 5%.

For the complete analysis of critical speeds in these abstraction pipes, again thanks to EPANET software, it will be possible to bring in a graph like the speed varies in the course of the day, and to evaluate the maximum value that will assume and in that moment of the day occur.

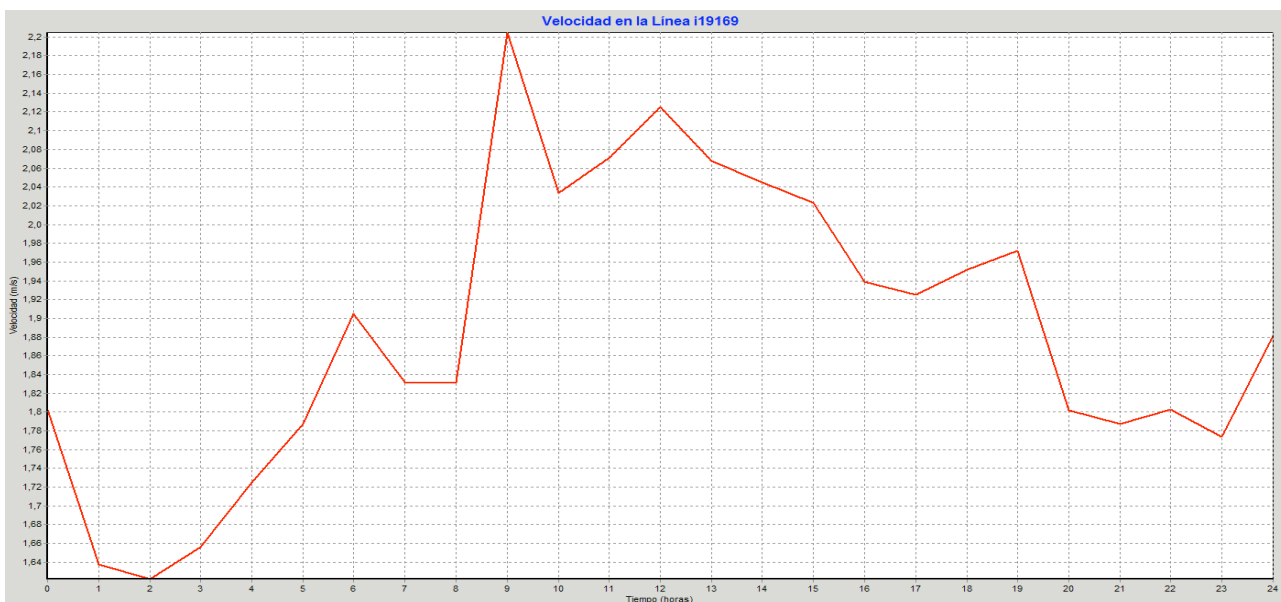


Fig 5.22:Speed in the abstraction pipe (DN600 mm) during the day of the charging state

Another of the fluid variables to be analyzed to further the knowledge of the network are circulating flows through the various pipes, its distribution and trajectory. This manifest which are the pipes that carry more water.

In the figures below, in relation to the figure representing the diameters, and compared to the hour of the day, it appears that larger diameter pipes are carrying higher flow rates and, the closer is the pipe to flow injection sites, the greater the flow circulating.

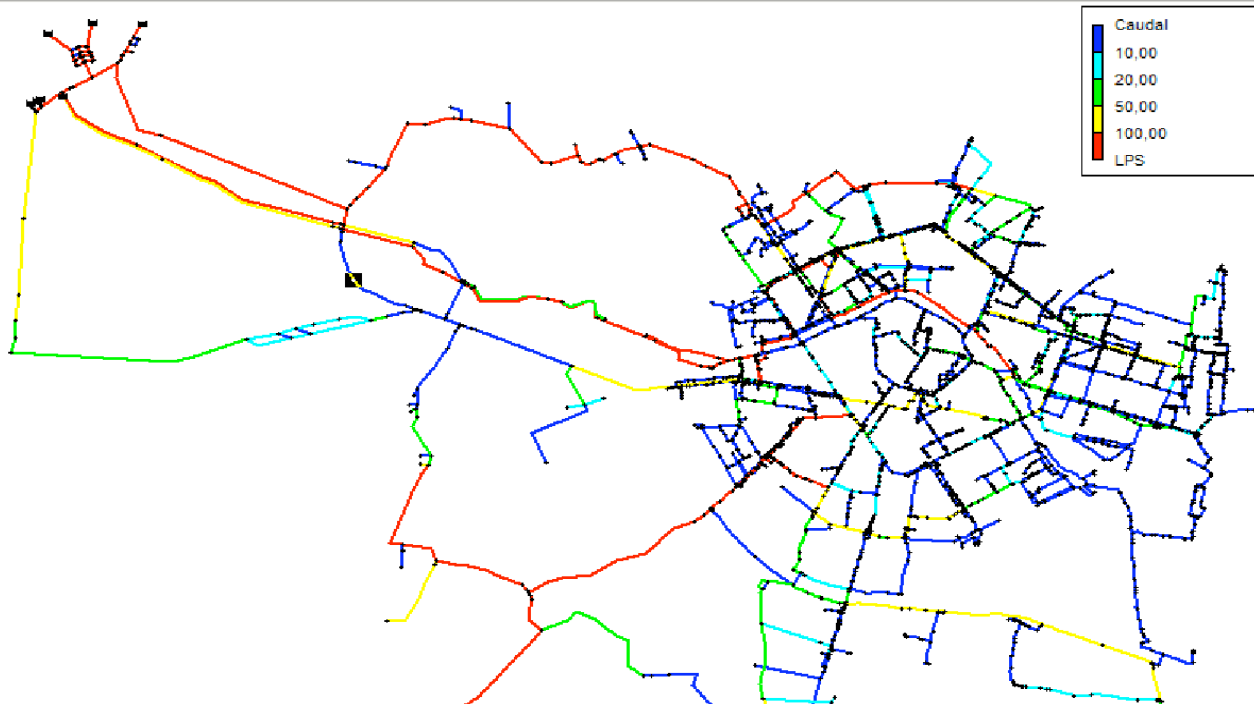


Fig.5.23:Flows in pipes at 04:00 am in the day of the charging state

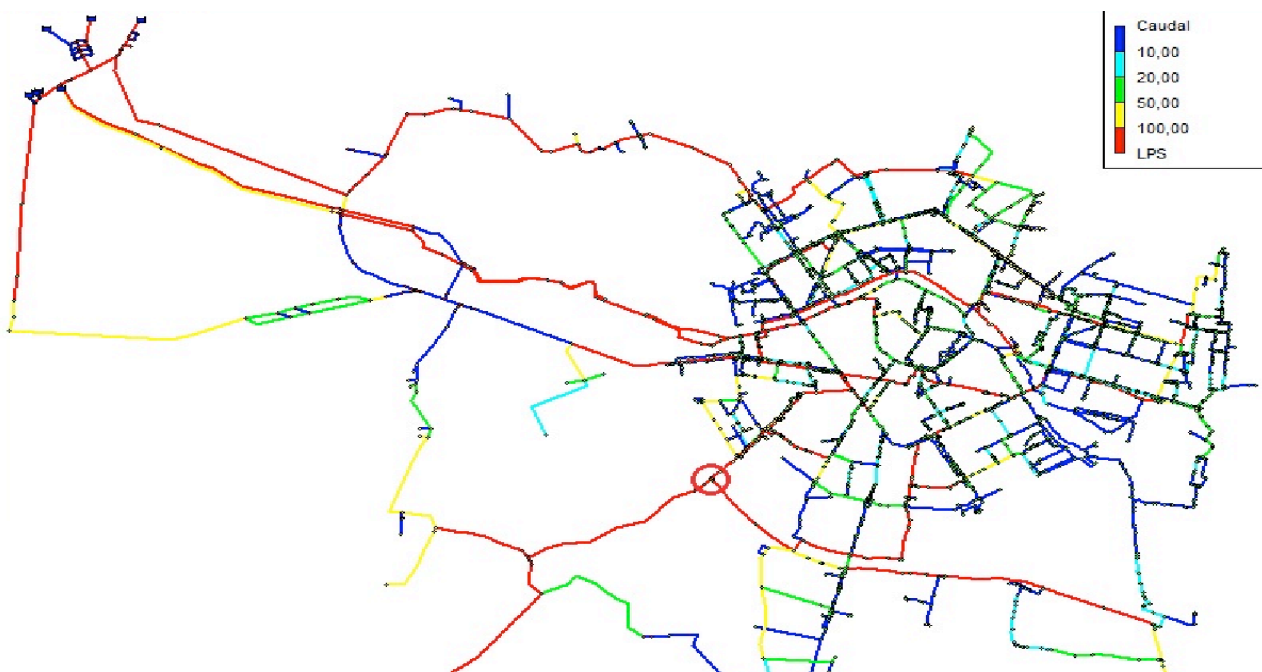


Fig.5.24:Flows in pipes at 12:00 pm in the day of the charging state

Another graph lets you know how varied the flow in any point of the network during the course of the day. We will be able to assess which flow will spend one pipe: for example, the main abstraction from the tanks of “Picassent”. This pipe branches off into two lines (node circled in red, situated in the locality of “San Isidro”, in the outskirts at southwest of the city): one pipe keep on to the South side of the city, and a second pipe continues to provide water to some small towns of the Metropolitan Basic System.

As we shall see, this node represents a critical point in the network, because it supplies water to a large part of the city in the south of Valencia and its suburbs next: reason why will be crossed by high flow rates and a possible problem will not ensure the regular service.

Additionally, we can see, in the following graphs, as the flow rate varies during the day in the main abstraction pipe from the tanks of “Picassent”, and make a comparison with the corresponding speed and pressure.

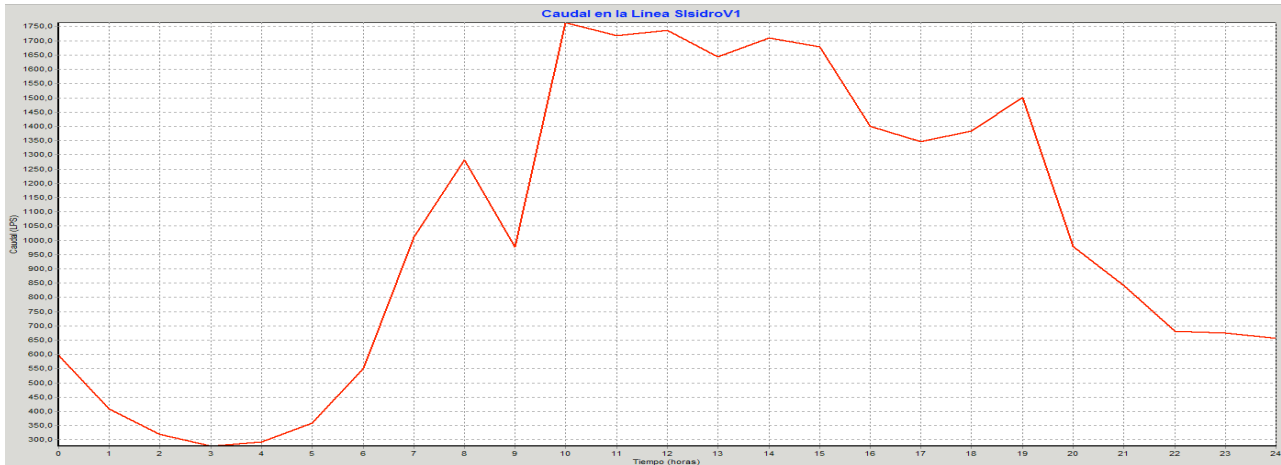


Fig.5.25:Flow in the abstraction pipe of “S.Isidro” (DN1600 mm) during the day of the charging state

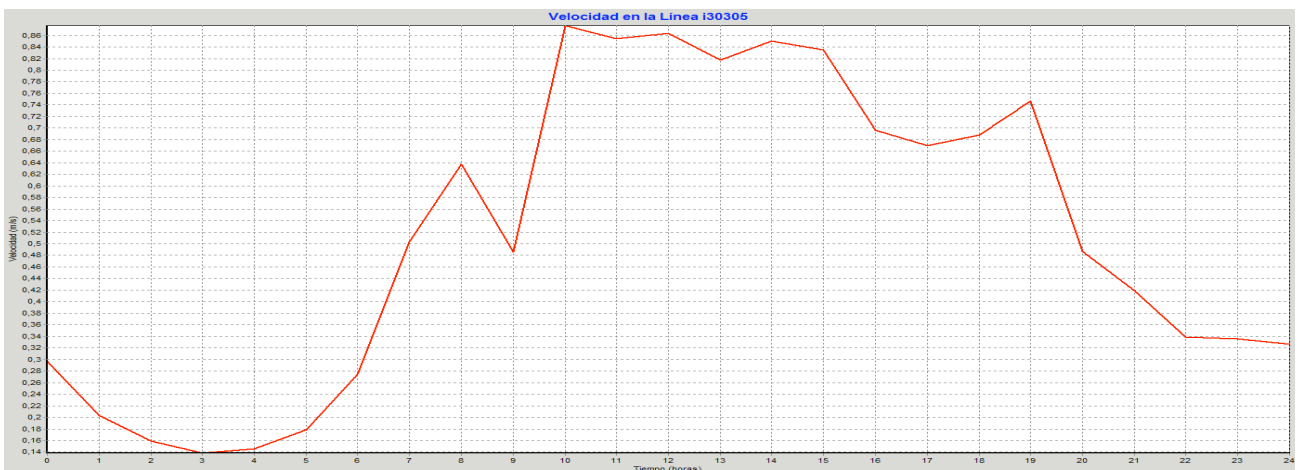


Fig.5.26:Speed in the abstraction pipe of “S.Isidro” (DN1600 mm) during the day of the charging state

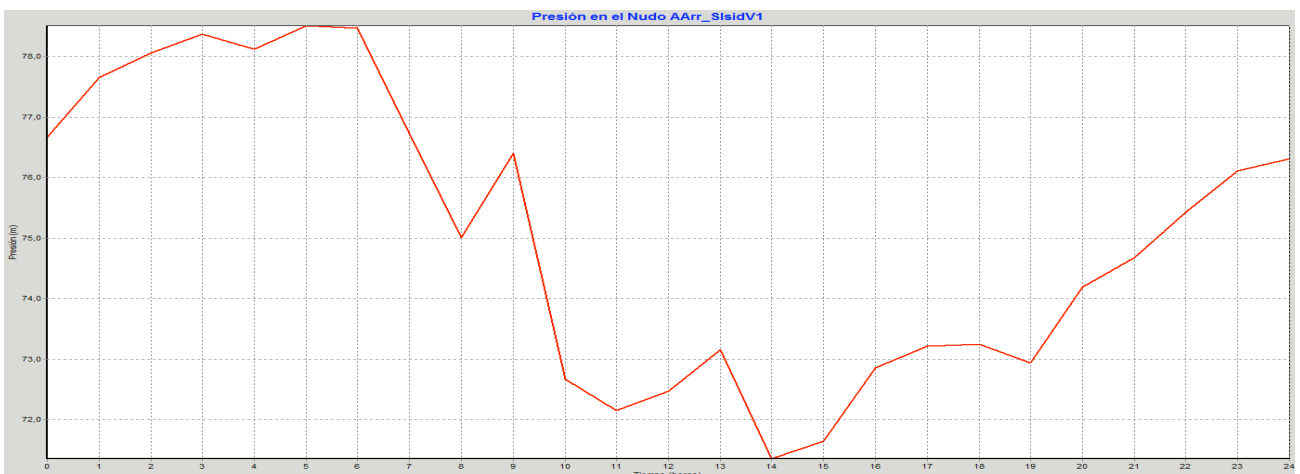


Fig.5.27:Pressure in the valve of “S.Isidro” during the day of the charging state

5.5.3 The treatment plant: levels in tanks and flows in pumps

In relation to the hours of maximum (12.00 pm) and minimum (4:00 am) consumption, the network will carry a higher flow depending of hour of the day; all of which is controlled by regulating tanks placed immediately downstream of the intake works with the tank function of the flow in use in the system.

From the economic point of view, having regard to the different cost of electricity during the day, it is extremely convenient to be able to refill the tank of compensation during the nighttime hours in order to satisfy the required flow during the peak hours.

In the following figures we can see the variation of the levels of the tanks during the course of the day: in the night almost all pumps start marching and the level rises up to the maximum height, reached this level some pumps begin to stop; from the early hours in the morning the tank begins to empty as the network needs high flows required for all users.

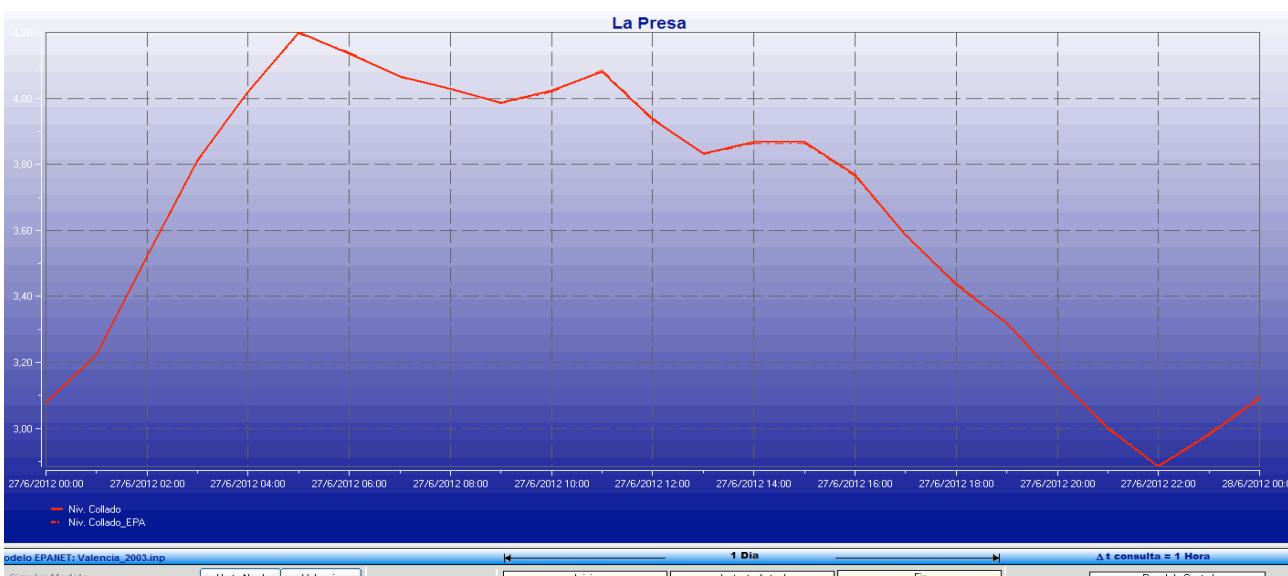


Fig.5.28:Level of the tank of “Collado” in “La Presa” during the day of the charging state

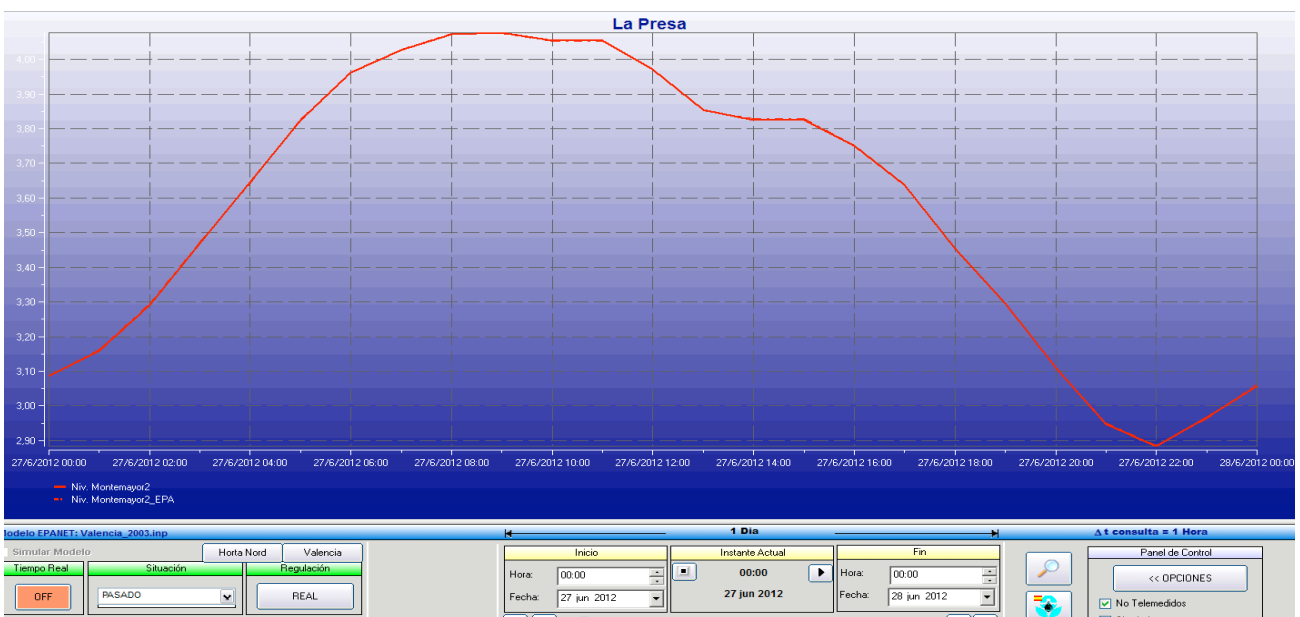


Fig.5.29:Level of the tank of “Montemayor” in “La Presa” during the day of the charging state

In the following images we can see two examples of how the pumping groups work at different time of the day:

- At 4:00 am: 7 pumps (colored in red) are working to fill the tank;
- At 12:00 pm: only 2 pumps (colored in red) are working because the network takes advantage of the accumulated flow in the tank during the night.

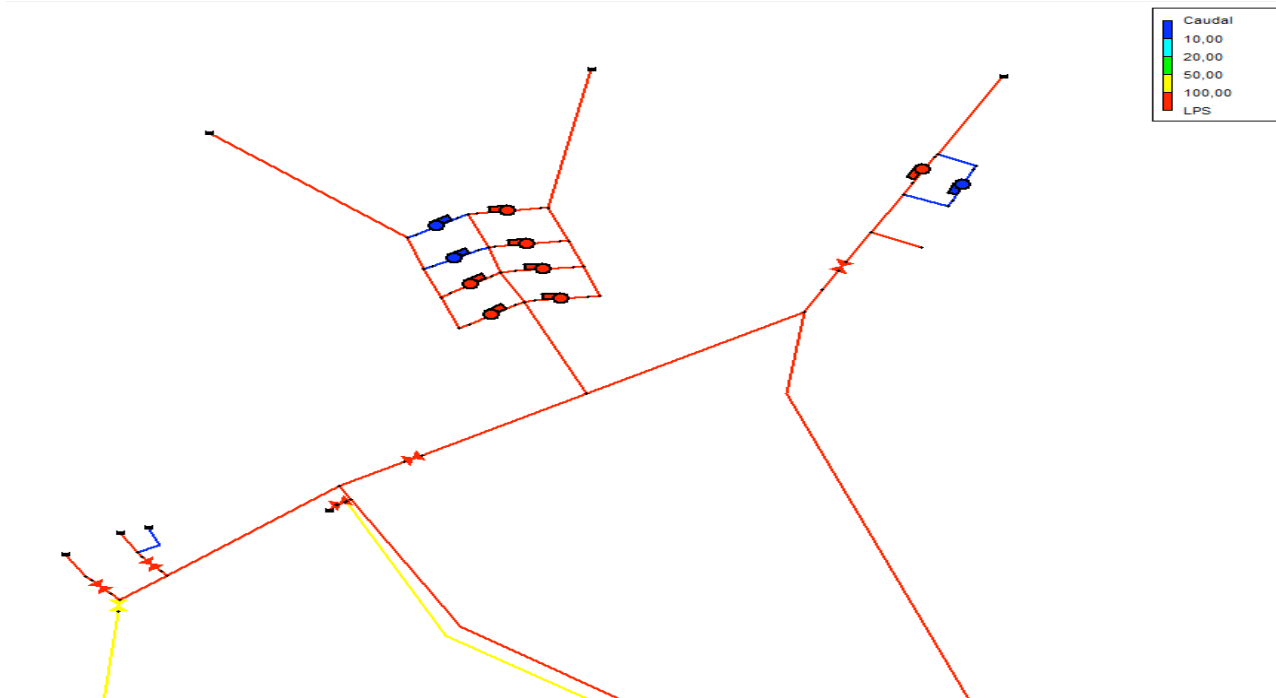


Fig.5.30:Treatment plant of “La Presa” at 4:00 am in the day of the charging state

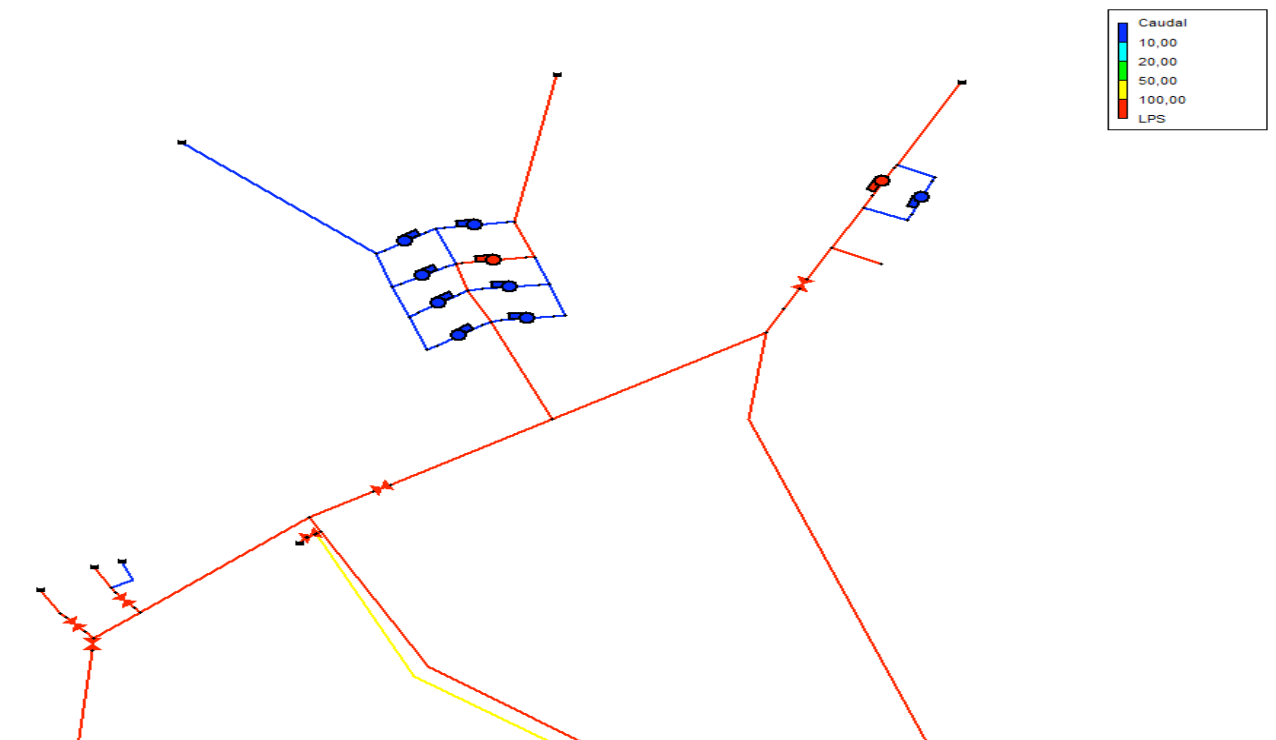


Fig.5.31:Treatment plant of “La Presa” at 12:00 pm in the day of the charging state

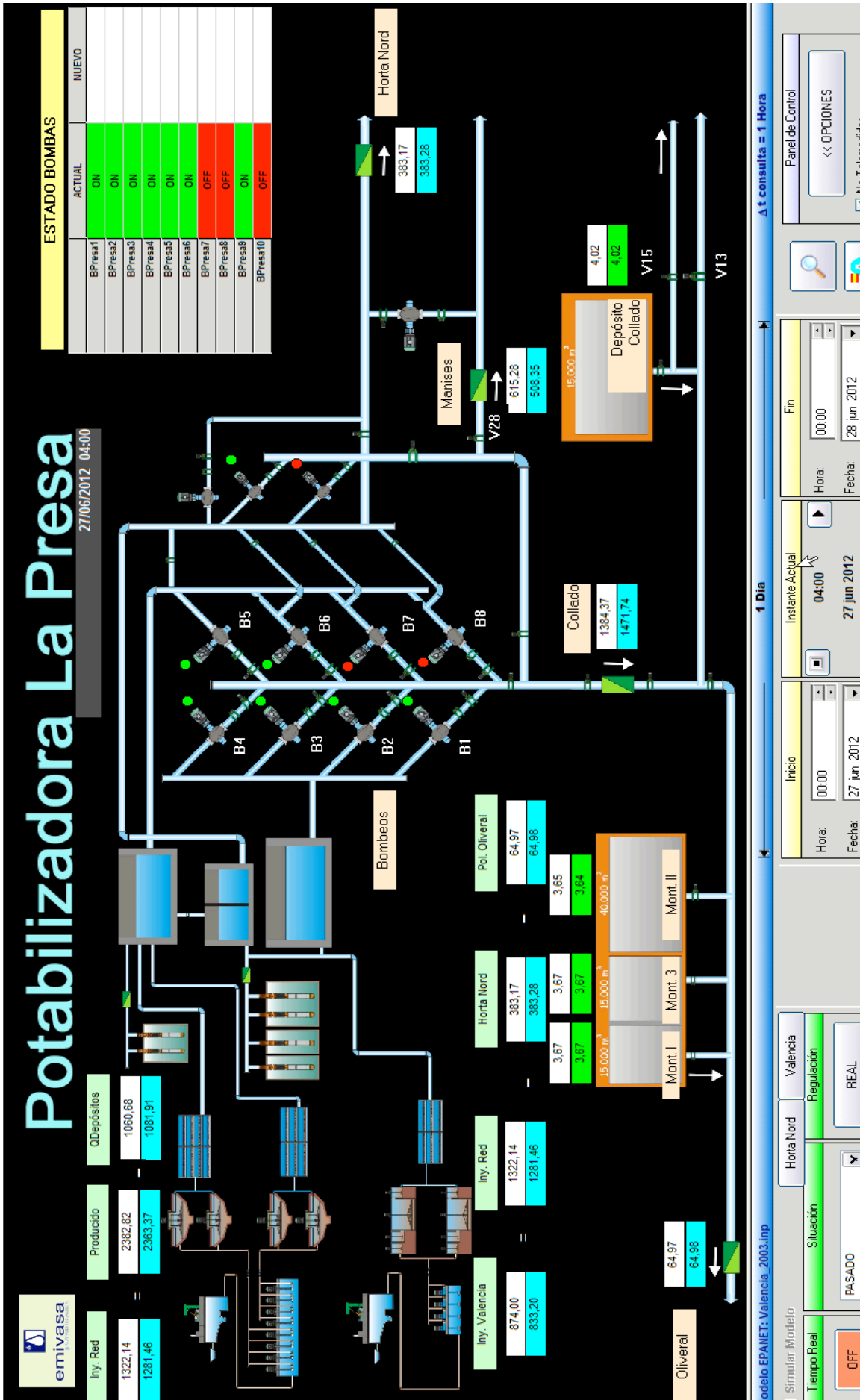


Fig. 5.32: Treatment plant of “La Presa” at 4:00 am in Sca-Red

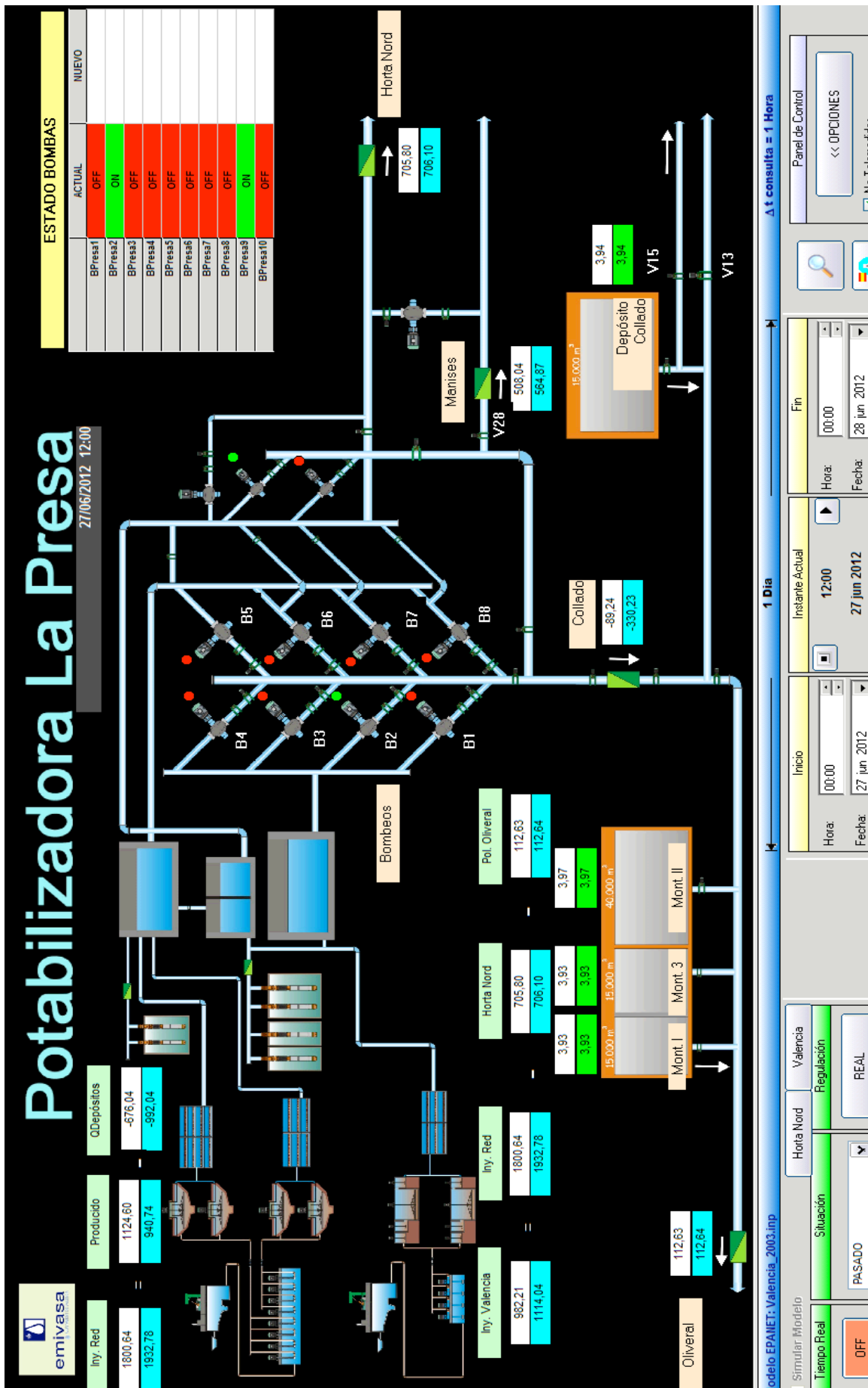


Fig.5.33: Treatment plant of "La Presa" at 12:00 am in Sca-Red

5.5.4 Pressure analysis

Pressure is a term used in fluid mechanics to represent the internal energy of a fluid due to the pressure exerted on its container. It may also be called static pressure or simply static head. It is mathematically expressed as: $\frac{P}{\gamma}$ expressed in m units, where:

P is fluid pressure (force per unit area, often as N/m^2 units); γ is the specific weight (force per unit volume, typically N/m^3 units).

Before proceeding to analyze the situation of the network from the point view of the pressures in consumption points, is important to recall that the modeled network is a network of transportation, responsible for supplying water to the various local distribution networks. A transport network should respect conditions of service related to situations max and minimum consumption:

- The minimum pressure normally required in situation of max consumption to ensure the service (at 12:00 pm) is about 30m from ground level;
- In the situation of the minimum consumption (at 4:00 am) the pressure must not exceed 70m above ground level at any point on the network to reduce the risk of the occurrence of water losses.

In the following figures are represented as maps of isolines the pressures in the network at 12:00 pm (maximum time consumption) and 4:00 am (minimum time consumption) for the charge state considered.



Fig.5.34:Map of isolines of pressure at 12:00 pm in the day of the charging state



Fig.5.35:Map of isolines of pressure at 4:00 am in the day of the charging state

Accordance with the conditions of service related to situations max and minimum consumption, according to the distribution curves are shown:

- at 12:00 pm almost 90% of the nodes have a pressure exceeding 30m, so the service will be assured all over the network;
- at 4:00 am almost 98% of the nodes have a pressure below 70m, reducing the risk of going to against excessive water losses.

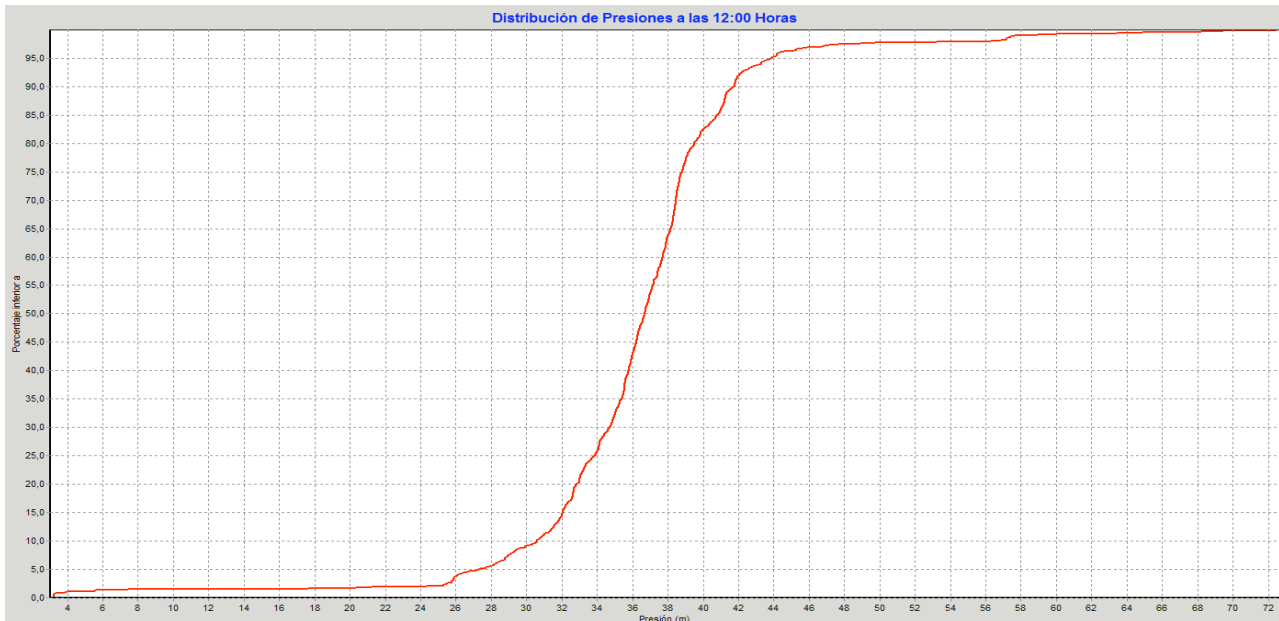


Fig.5.36:Pressure distribution curve at 12:00 pm in the day of the charging state

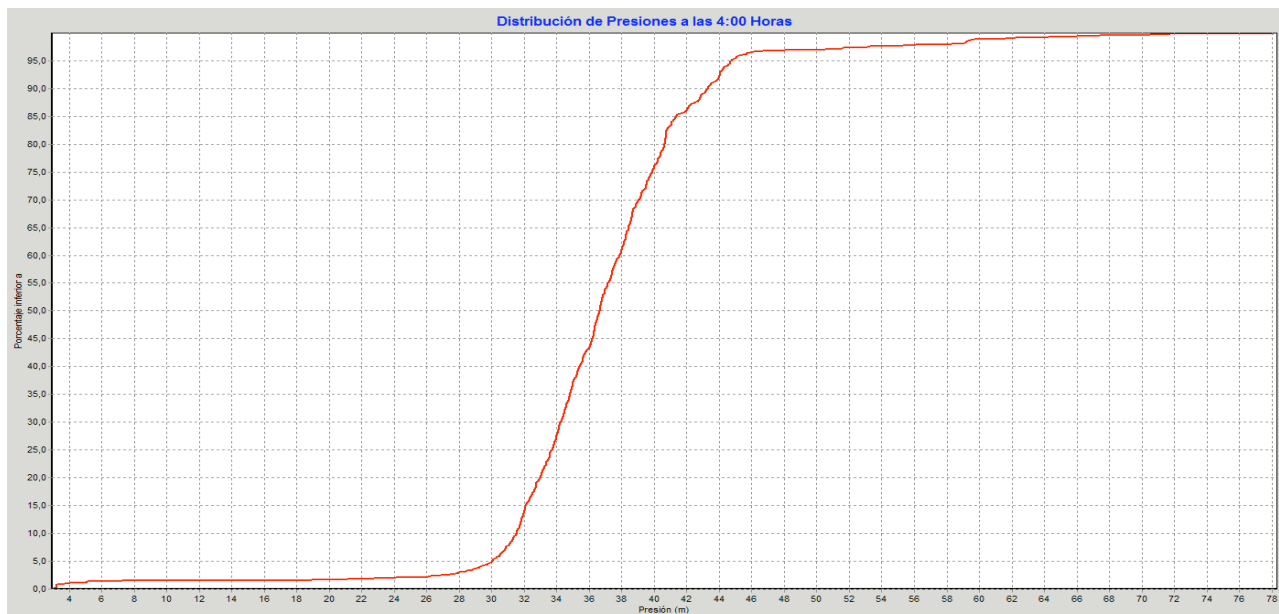


Fig.5.37:Pressure distribution curve at 4:00 am in the day of the charging state

5.5.5 Piezometric head and load loss

The analysis of piezometric heads at the nodes of the network is extremely important in order to know which the load losses are and which branches are the most important. The total hydraulic head, also known as the piezometric head of a fluid, is composed of pressure and elevation:

$\frac{P}{\gamma} + z$ expressed in m units, where:

$\frac{P}{\gamma}$, expressed in m units, represents the pressure; z , expressed in m units, represents the elevation.

The pressure is the equivalent gauge pressure of a column of water at the base of the piezometer, and the elevation is the elevation of the point respect to sea level.

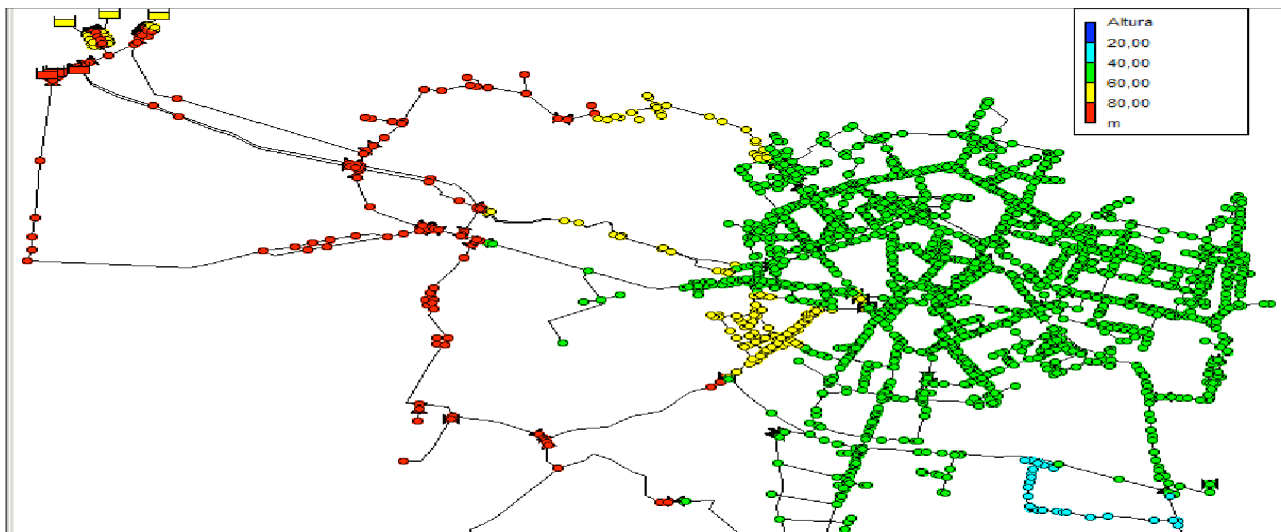


Fig.5.38:Piezometric heads in the nodes of the network at 12:00 pm in the day of the charging state

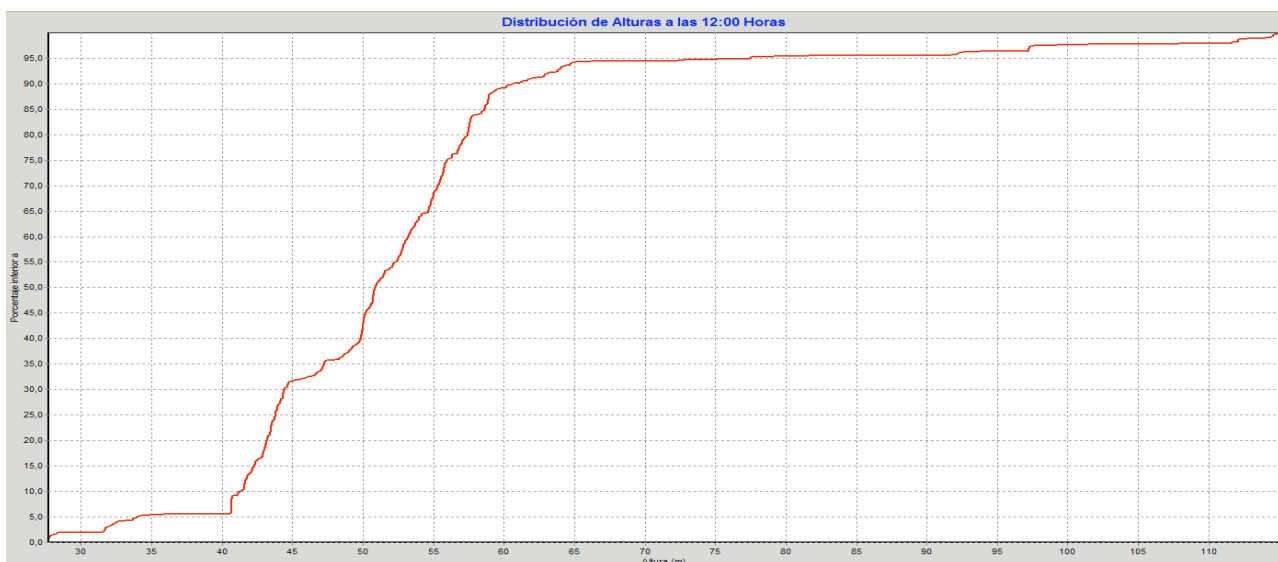


Fig.5.39:Piezometric heads distribution curve at 12:00 pm in the day of the charging state

The map of piezometric heads in the network at peak hour (12:00 hours), is a clear indication of which are the directions of flow:



Fig.5.40:Map of isolines of piezometric heads at 12:00 pm in the day of the charging state

Once known the piezometric heads at various points in the network, you can study the importance of the unitary load loss.

According distribution curve unitary load losses (m/km) at peak time shown below, in most of the pipes are low or very low.

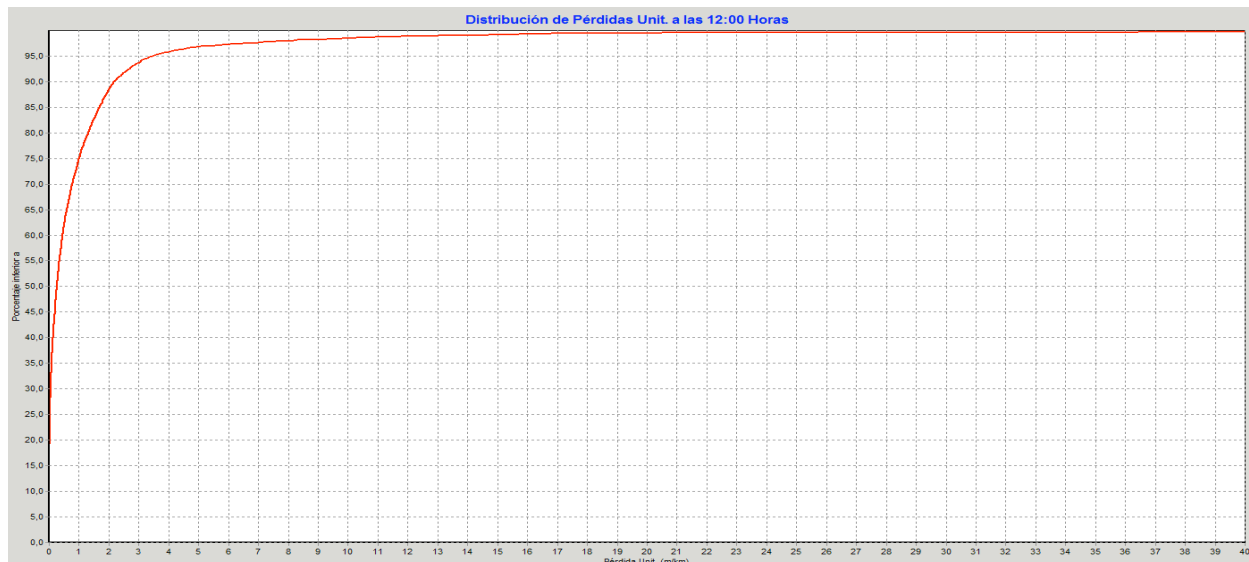


Fig.5.41:Unitary load losses distribution curve m/km in the pipes at 12:00 pm in the day of the charging state

From the distribution curve shown: 90% of the pipes have losses less than 2 m/km, 7% is lost between 2 and 6 m/km and 3% is lost from 6 m/km or more. Once the elevated load losses unitary are localized, it will be possible to draw the longitudinal profile of the pipe concerned, tracing the piezometric heads of the nodes extremities of the same.

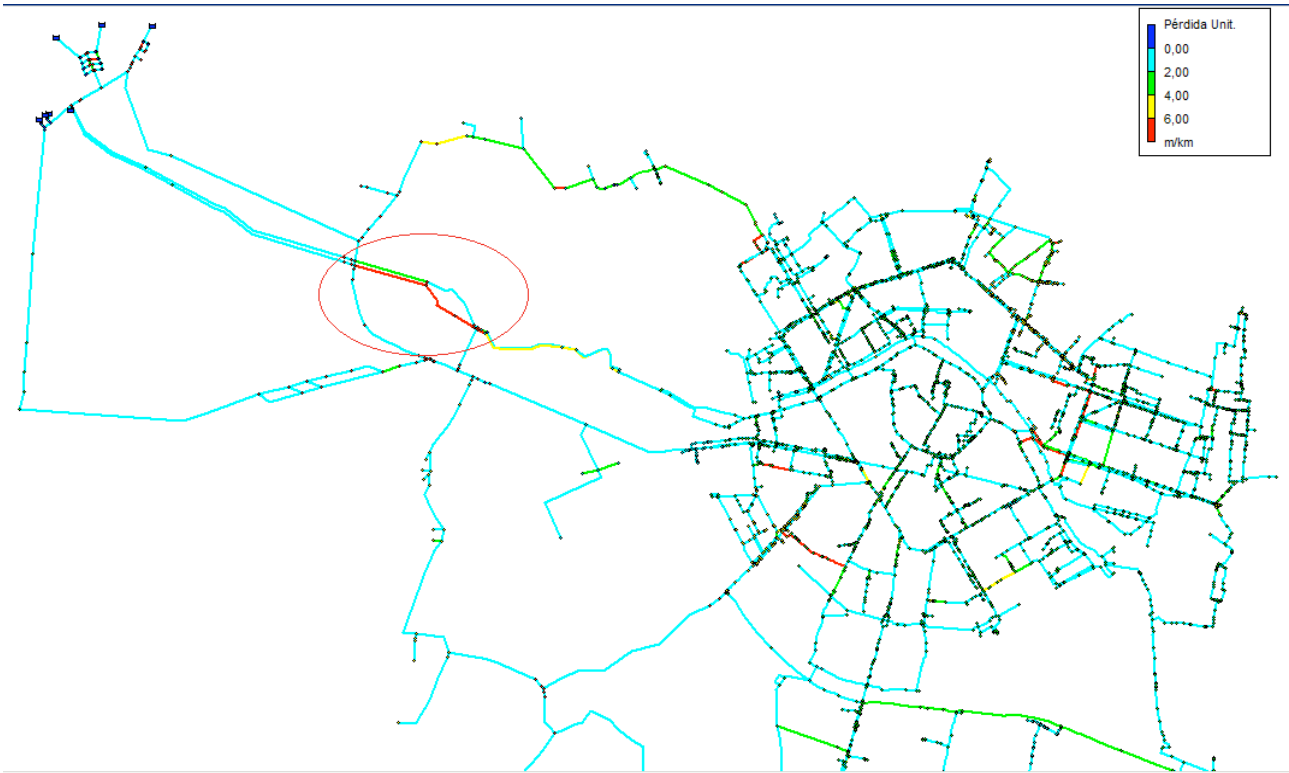


Fig.5.42:Unitary load losses in the pipes at 12:00 pm in the day of the charging state

Let us now analyze the longitudinal profile of two consecutive pipes (circled in red); in the previous map these abstractors appear to have a load loss of more than 6 m/km.

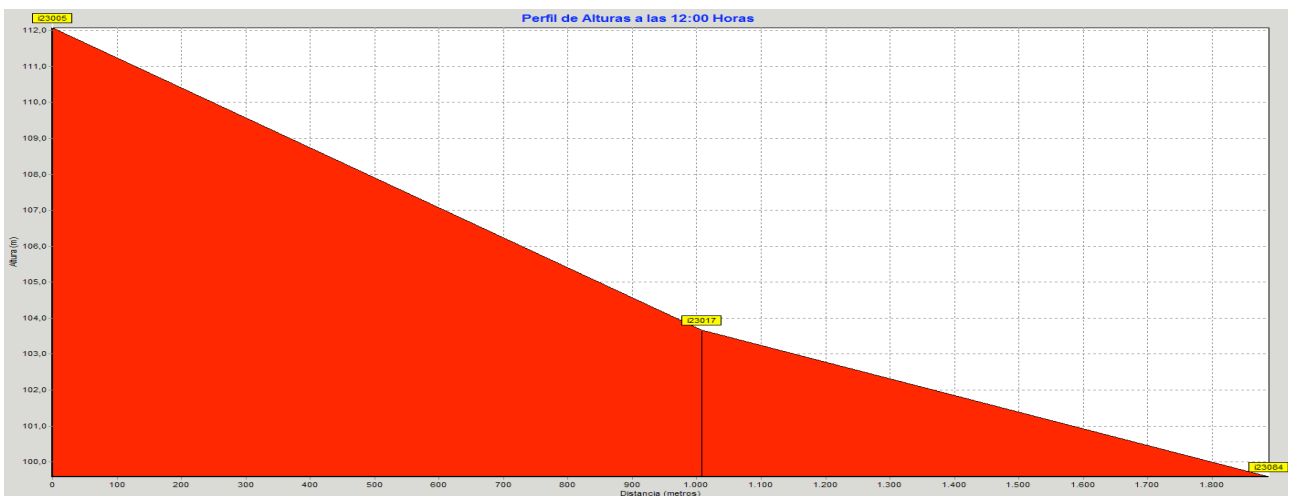


Fig.5.43:Longitudinal profile of piezometric heads of two pipes at 12:00 pm in the day of the charging state

In the first pipe, we notice a load loss of the order of 8 m/Km, while in the second one is less steep and reaches 6 m/km.

Finally we analyze the piezometric heads profiles in most important paths, originating from the injection points and destination the farthest supply points, always considering the flow direction at peak hour. The paths considered are the following:

1. Treatment plant “La Presa” – “Avd.Cardinal Benlloch”;
2. Treatment plant “La Presa” – “Avd.Les Corts Valencianes”;
3. Treatment plant “Picassent” – “Malvarrosa”.

Track: "La Presa" – "Avd. Cardinal Benlloch"

This is the path followed from the treatment plant of "La Presa" to city center, covering a distance of just over 15 Km, moving from a height of 110m to 10m.



Fig.5.44:Path: "La Presa" – "Avd.Cardinal Benlloch"

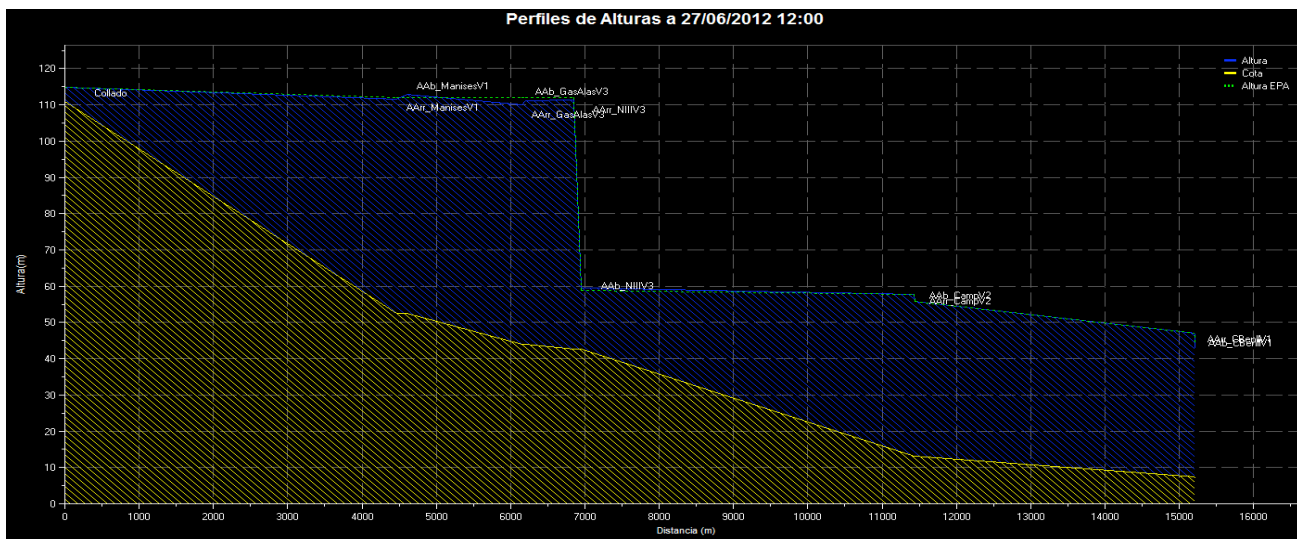


Fig.5.45:Longitudinal profile of heights (yellow) and pressures (blue) at 12:00 pm in Sca-Red

Upon leaving the tanks in "La Presa" at a height of 110m (point 1 in the map), the piezometric head is maintained more or less horizontal until "Nacional III" (point 3 in the map); here at a height of 45m, the piezometric head undergoes a sudden drop caused by the valve of the same name and reaches the altitude of 60m, after which is maintained again horizontal until "Campanar" (point 4 in the map) at height of 15 m there is a pressure of 40m; in the final part the flow arrive in "Cardinal Benlloch" (point 5 in the map) at a height of 10m with the piezometric parallel to the level ground and then with the same pressure.

Track: "La Presa" – "Avd.Les Corts Valencianes"

This is the path followed from the treatment plant of "La Presa" to the outskirts to the North-West of the city, covering a distance of just over 11 Km, moving from a height of 110m to 25m.



Fig.5.46:Path: "La Presa" – "Avd.Les Corts Valencianes"

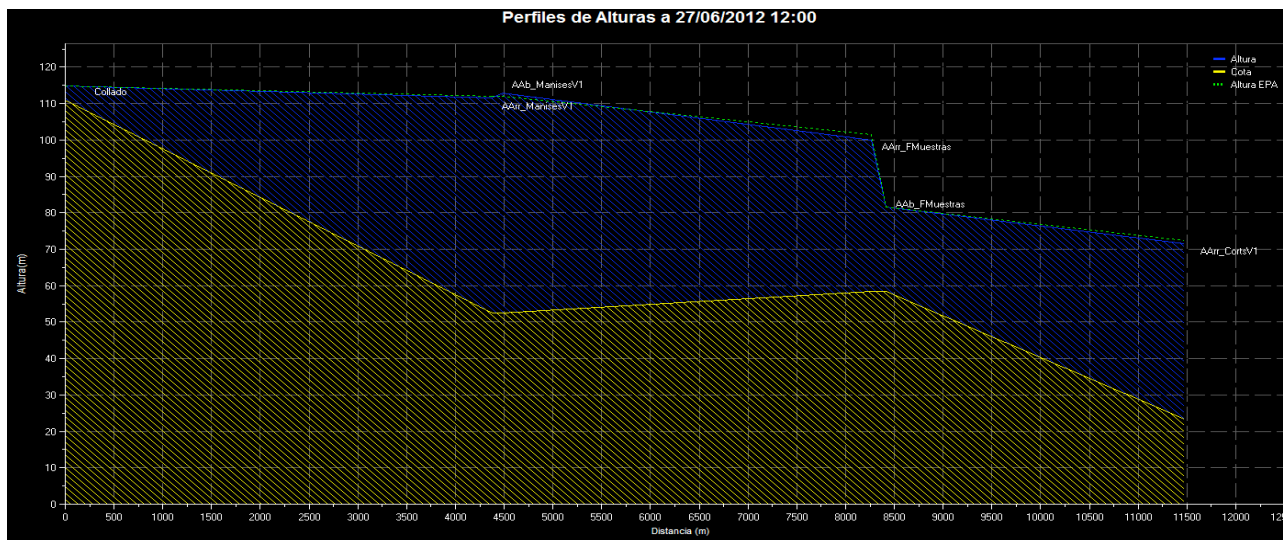


Fig.5.47:Longitudinal profile of heights (yellow) and pressures (blue) at 12:00 pm in Sca-Red

Upon leaving the tanks in "La Presa" at a height of 110m (point 1 in the map), the piezometric head is maintained more or less horizontal until "Manises" (point 2 in the map); here at a height of 55m, the piezometric head hear a slight increase in slope until "F.Muestras" (point 3 in the map) where undergoes a sudden trop caused by the valve of the same name and reaches the altitude of 80m at a height of 60m, after which is maintained with the same slope until "Corts Valencianes" (point 4 in the map) at a height of 25m there is a pressure of 45m.

Track: "Picassent" – "Malvarrosa"

This is the path followed from the treatment plant of "Picassent", the flow crosses the whole city and reaches the farthest point of the tanks, along the coast of "Malvarrosa", covering a distance of just over 17 Km, moving from a height of 92m to above the sea level.

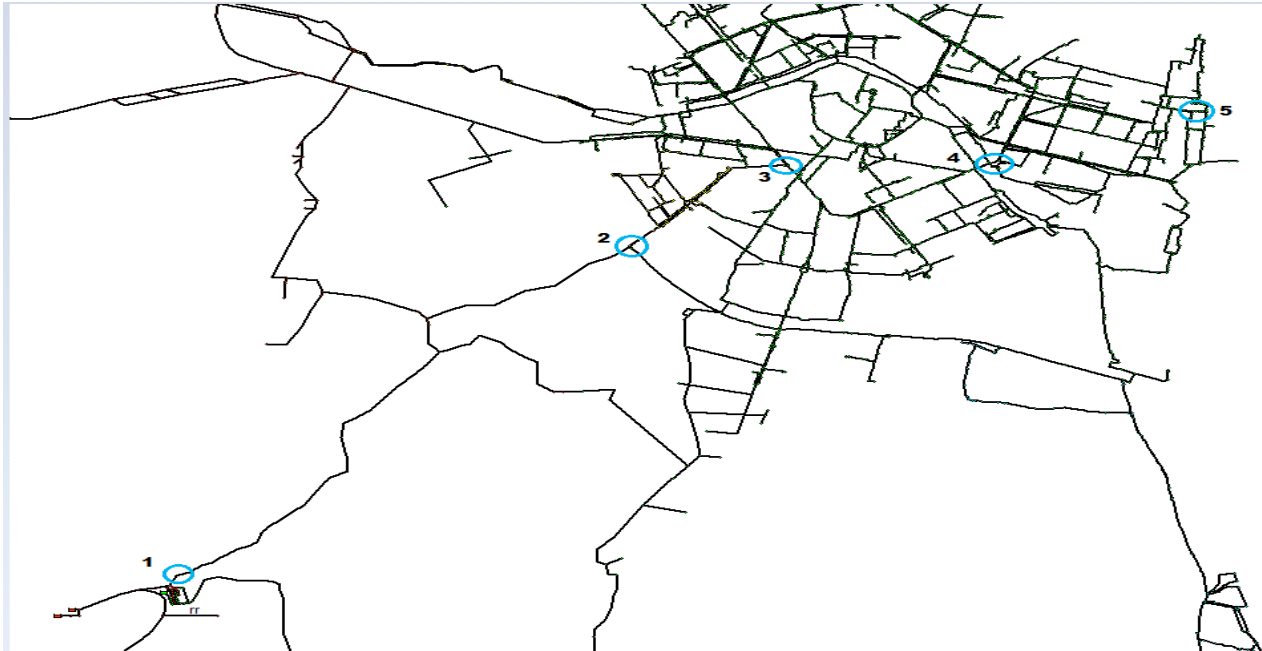


Fig.5.48:Path: "Picassent"– "Malvarrosa"

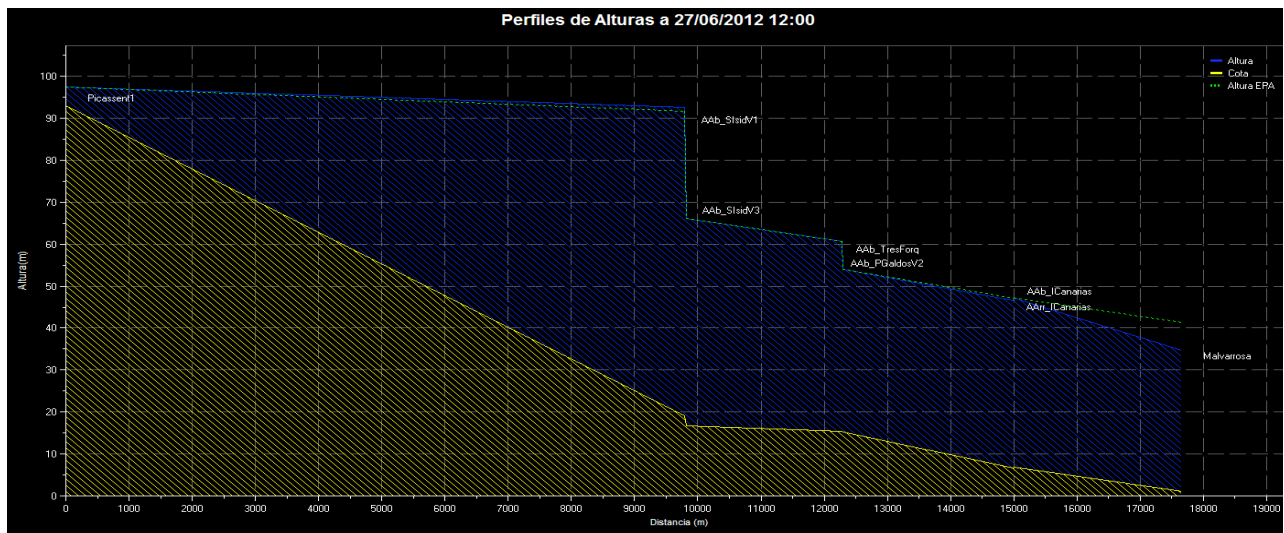


Fig.5.49:Longitudinal profile of heights (yellow) and pressures (blue) at 12:00 pm in Sca-Red

Upon leaving the tanks in "Picassent" at a height of 92m (point 1 in the map), the piezometric head is maintained more or less horizontal until "San Isidro" (point 2 in the map); here at a height of less 20m the piezometric head undergoes a sudden drop caused by the valve of the same name and reaches the altitude of 65m, after which is maintained with the same slope until "Tres Forques" (point 3 in the map) at a height of 15m there is a pressure of 45m; here there is a slight pressure decrease and reaches little more forward "P.Galdos"; subsequently the flow continues with the same piezometric head slope, parallel to the level ground, by way of "I.Canarias" (point 4 in the map) until to "Malvarrosa" (point 5 in the map) with at a height just above the sea level there is the same pressure of 35m.

5.5.6 System Performance

As is known, a system of water supply is charged to assure the transport and distribution of water from the catchment or production sites to consumption sites in the required amount (flow) and with sufficient quality (pressure). In this sense, any analysis of the situation of a system must include both the study of the efficacy and the degree of efficiency. In this aspect come into play a series of ratios technical and/or economic, indicators of the goodness of the state of a network and its management efficiency. The volumetric efficiency of a network is one of the quality indicators more extended system. Is defined as the ratio between the volume recorded, and the volume provided in a time period established by reference. Although being an indicator irreplaceable volumetric efficiency of a water supply system, the volumetric efficiency is not sufficient to a proper diagnosis. However, the volumetric efficiency is valid if it is to make an initial diagnosis of the overall system.

Volumetric Efficiency: $\eta = \frac{V_{recorded}}{V_{provided}}$ expressed in % units.

Through the reading of the data of flow rate of all system, recorded by the sensors (flowmeters) and subsequently stored in SCADA: as regards the Volume provided, consider the volume entering to the system, while the Volume recorded consider that has occurred in points of consumption of each town.

FLOW BALANCE IN THE SYSTEM					
Flowmeters:					
Q Bomb Picassent	Q Horta Sud	Q Manises	Q Collado	Q Oliveral	Q H Nord
Q Dep Picassent	Q Dep Collado	Q Montemayor	Q Fte Jarro Barc	Q Fte Jarro Liria	Q Granja
Q Cantereria	Q G.Gea H	Q G.Gea B	Q Alq Nova	Q S Isidro 1000	Q S Isidro 1250
Q Nuevo Cauce	Q Paip350	Q S. Miguel R.	Q Tavernes	Q Alboraya	Q Gran Canaria
Sectorals Balance			Global Balance		
Q HORTA SUD =	+ Q Horta Sud + Q Nuevo Cauce + Q Paip350		Q INJECTED SYSTEM =		+ Q Horta Sud + Q Bomb Picassent + Q Manises + Q Collado + Q H Nord
Q TRAIAS PICASSENT =	+ Q Bomb Picassent + Q Dep Picassent - Q S Isidro 1000 - Q S Isidro 1250 - Q Paip350		Q DEPOSITS VALENCIA =		+ Q Dep Picassent + Q Dep Collado + Q Montemayor + Q Oliveral
Q TRAIAS PRESA =	+ Q Manises + Q Collado + Q Montemayor + Q Dep Collado + Q Oliveral - Q Fte Jarro Barc - Q Fte Jarro Liria - Q Granja - Q Cantereria - Q G.Gea H - Q G.Gea B - Q Alq Nova		Q DEM SISTEMA =	+ Q INJ SISTEMA + Q DEP SISTEMA = + Q HORTA SUD + Q TR_PICASSENT + Q TR_PRESA + Q INJ HNORD + Q VALENCIA	+ Q Horta Sud + Q Bomb Picassent + Q Dep Picassent + Q Manises + Q Collado + Q Dep Collado + Q Montemayor + Q Oliveral + Q H Nord
Q INJ HORTA NORD =	+ Q H Nord + Q Fte Jarro Barc + Q Fte Jarro Liria + Q Granja + Q S. Miguel R. + Q Tavernes + Q Alboraya + Q Gran Canaria				
Q VALENCIA =	+ Q Cantereria + Q G.Gea H + Q G.Gea B + Q Alq Nova + Q S Isidro 1000 + Q S Isidro 1250 - Q Nuevo Cauce - Q S. Miguel R. - Q Tavernes - Q Alboraya - Q Gran Canaria				

Fig.5.50:Analysis volume provided:Flow Balance System

From the Flow Balance of the month of **June 2012**, month of the year with the highest consumption, the volume provided and recorded all over the network, we got a volumetric efficiency of the system approximately equal to **90%**. It's a good performance, considering the period with the highest consumption (which corresponds to the maximum leaks), about an adduction system that supplies water to 1.5 million people in approximately 44 towns, covering several kilometers as embrace a high surface area. In spite of what is said is a satisfactory return.

5.6 Modifying control rules: An emergency case study

Using the strategic model, we can proceed to the simulation of possible emergencies in the network and later study of the consequences and actions to be taken before the same.

Analyzing a likely critical situation, such as the break of a valve in one of the points subject to high pressure. From the map of isolines of pressure, we realize that such a point may be located in “San Isidro”. Our critical point.



Fig.5.51:Map of isolines of pressure of the network at 07:00 am

Chosen the critical point, we continue to select a time critical: an apparently dangerous situation may occur in the early hours of the morning when the domestic uses take up the service because people begin to living the day and industries are starting to march. This situation is also confirmed by the high values of the pressure in the graph below, which shows the pressure evolution in the course of the day in “San Isidro”: at 7:00 am. This will be our critical hour.

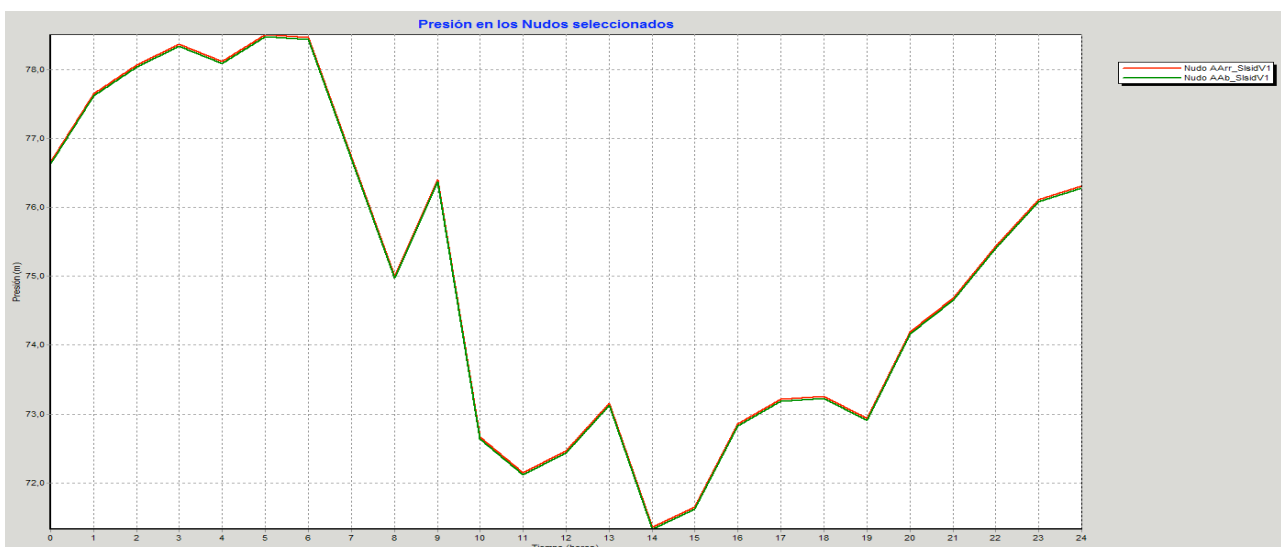


Fig.5.52:Pressure Up/Down in the valve in “S.Isidro” during the day of the charging state

5.6.1 Simulation of break of the valve in “San Isidro”

The first emergency to consider is the break of the valve in “San Isidro”. This is one of the most important places of the network: its supply is made from the tanks “Picassent” to the city center and to the periphery in the South of Valencia. It’s a point where arrive a pipe DN1600 from Picassent and they leave two pipes: one for the center DN1000 and one for the periphery DN1250. The following map shows the location of the break.

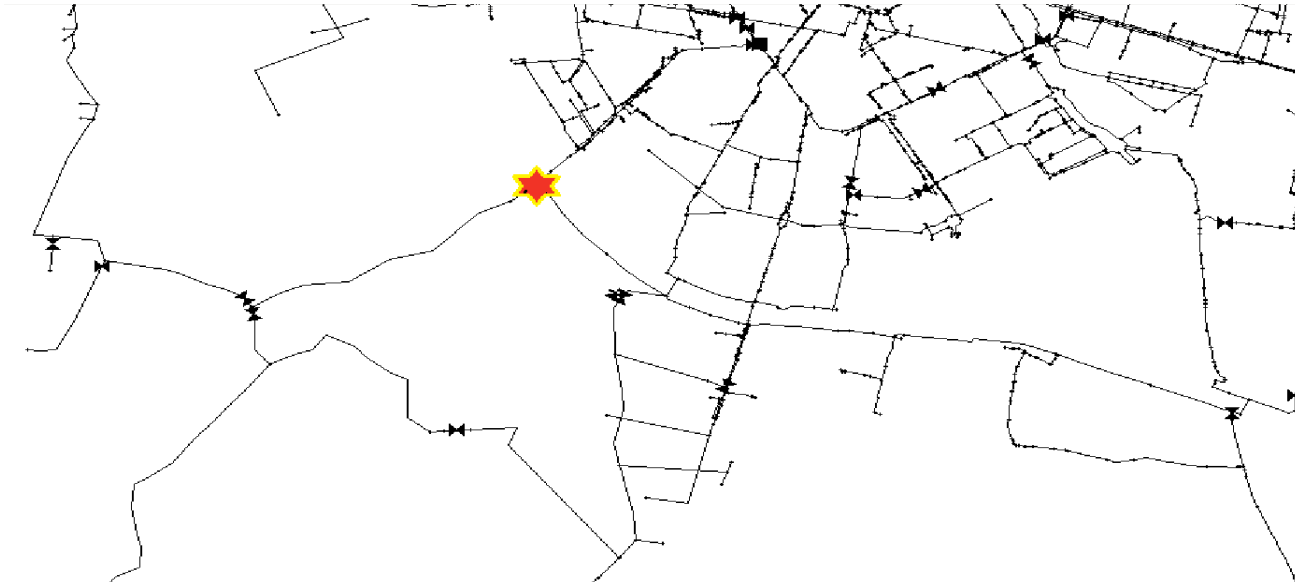


Fig.5.53:Localization of the break in “San Isidro”

It should be noted that this situation of breaking the valve of “San Isidro” is equivalent to the closure of the pipeline from “Picassent”; it can happen also for maintenance operation of the network. The important difference between these situations is the character: predictable or not.

Suppose that break, happens without warning, occurs in the joint between the arrival pipe DN1600 from “Picassent” and the valve V1 (visible in the image above). We proceed with the description of the valve of “San Isidro”, in the strategic model, just before the break.

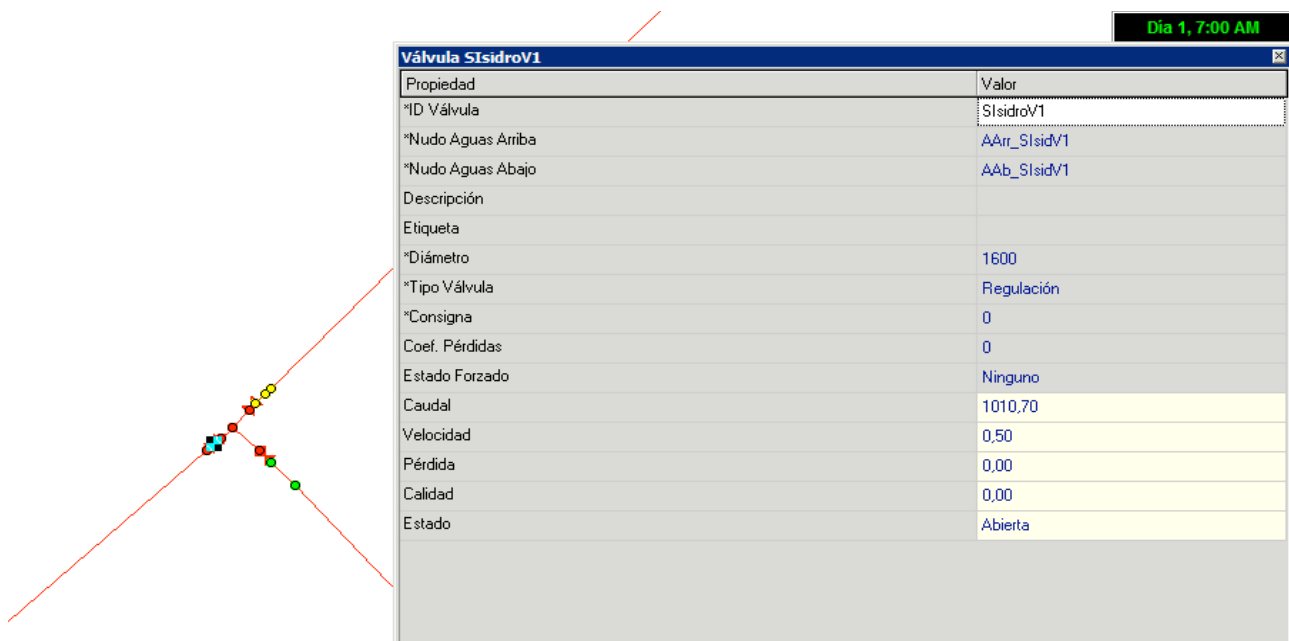


Fig.5.54:Analysis of the valve in “San Isidro” in the strategic model at 7:00 am in the day of the charging state

We continue to describe the situation of the network in Sca-Red, around the valve of “San Isidro”, when the probable rupture will occur: at 7:00 am in the day of the charging state.

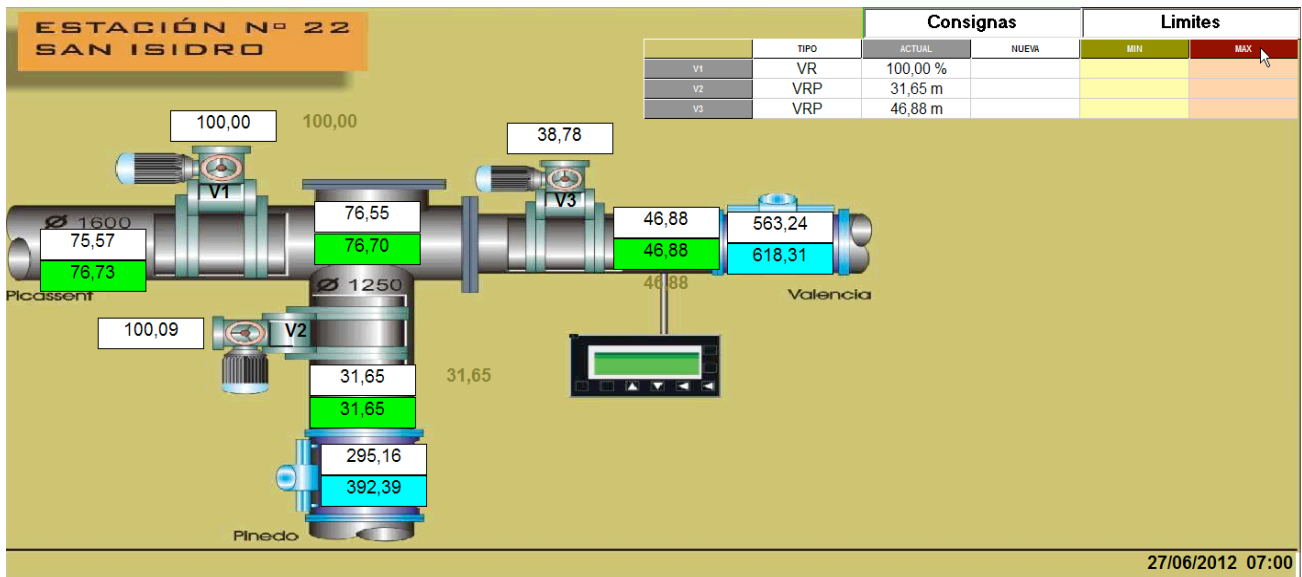


Fig.5.55:Representation of the valve in “San Isidro” at 7:00 am in the day of the charging state in Sca-Red

5.6.2 Consequence of break of the valve

As soon as the break occurs, the operator that oversees the synoptic table, notice in flowmeter of the valve, a marked difference between the real values monitored by SCADA and those simulated by the model. Processing by simulation, we imagine having to immediately close the valve. Through a remote command we try to change the valve setting and going to see what happens to the network.

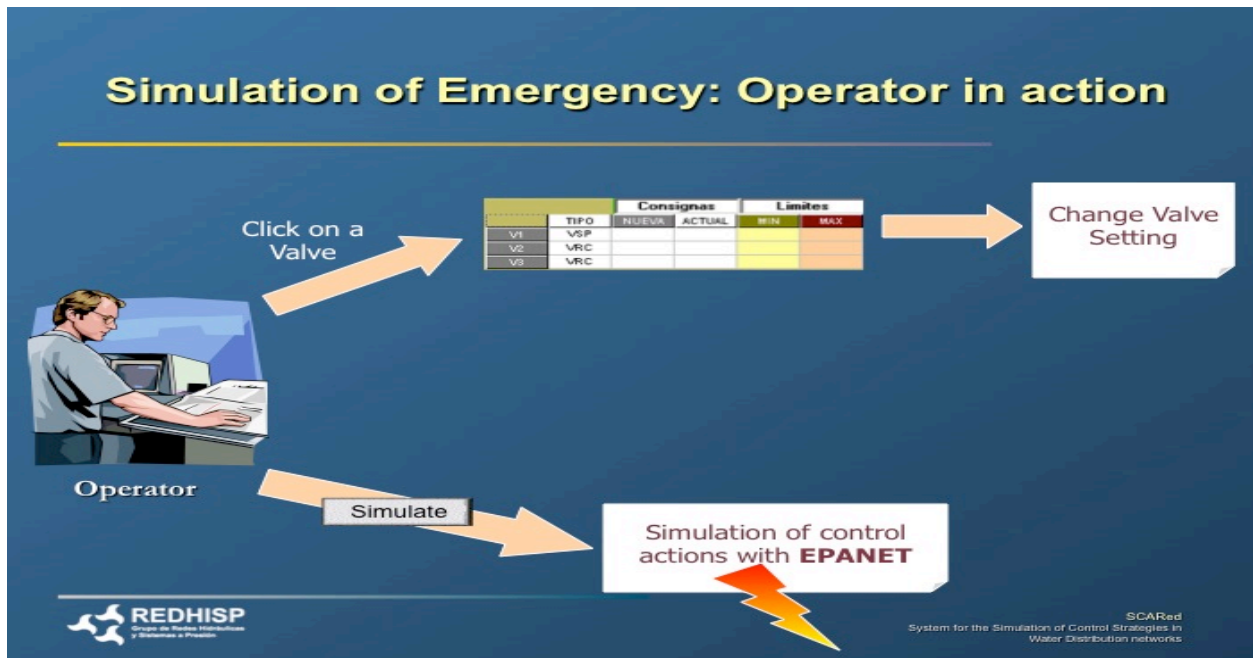


Fig.5.56:Representation of the actions of the operator in an emergency situation

The valve in “San Isidro” is a TCV (Throttle Control Valve); in this kind of valve it is possible only change the degree of openness: 0% (fully closed valve) or 100% (fully open valve).

For simulating the rupture of this kind of valve, we need to change the valve setting: selecting the valve concerned and applying a setpoint of 0% in the valve V1.

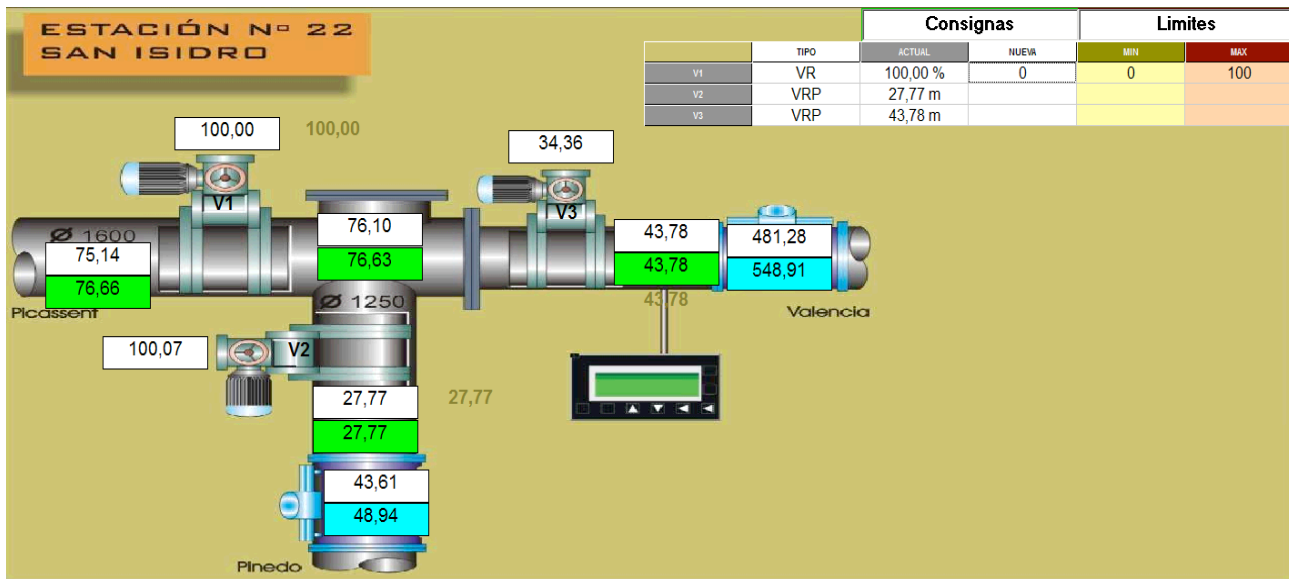


Fig.5.57: Change of valve setting: Simulation closure in the valve in “San Isidro” in Sca-Red

Simulated the closure, in this case instantaneous, we proceed with the simulation of emergency with the model in EPANET. Right now we know the values of flow and pressure that assumes the valve in the synoptic below.

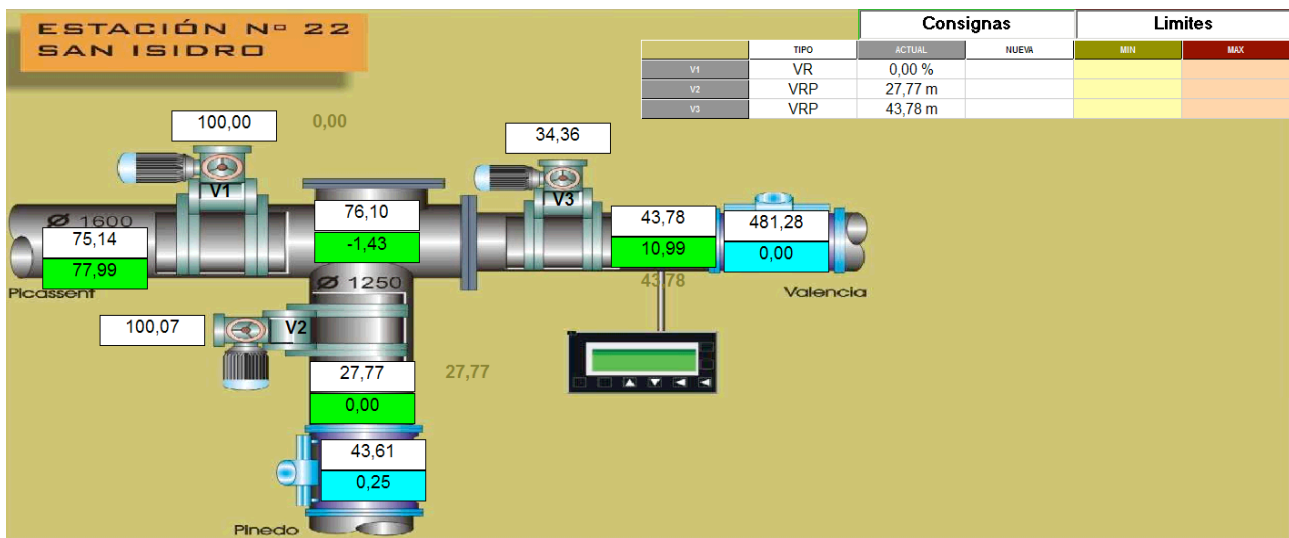


Fig.5.58: Representation of the first instant immediately after closing the valve in Sca-Red

Now connecting SCA-Red with EPANET, we can try to simulate the break of the valve in “San Isidro”.

Representing the network in the instant after the break, namely the closure of the valve, in the following pictures we can see that a good part of the network takes low values both of pressure and flow, values so low as to not provide the service. It is an extremely critical situation because although the network is connected in parallel to other lines that reach all points of the network also if we close such line, however the closing of a main adduttrice as that coming from “Picassent” will put the system in crisis. This is manifested by the lack or insufficiency of water in all those points in which the pressure is less than 20m or a flow rate less than 10 liters for second (LPS); in the next following pictures, the nodes in blue and the blue zone in the map of isolines of pressure represent the points of the network without the regular service.

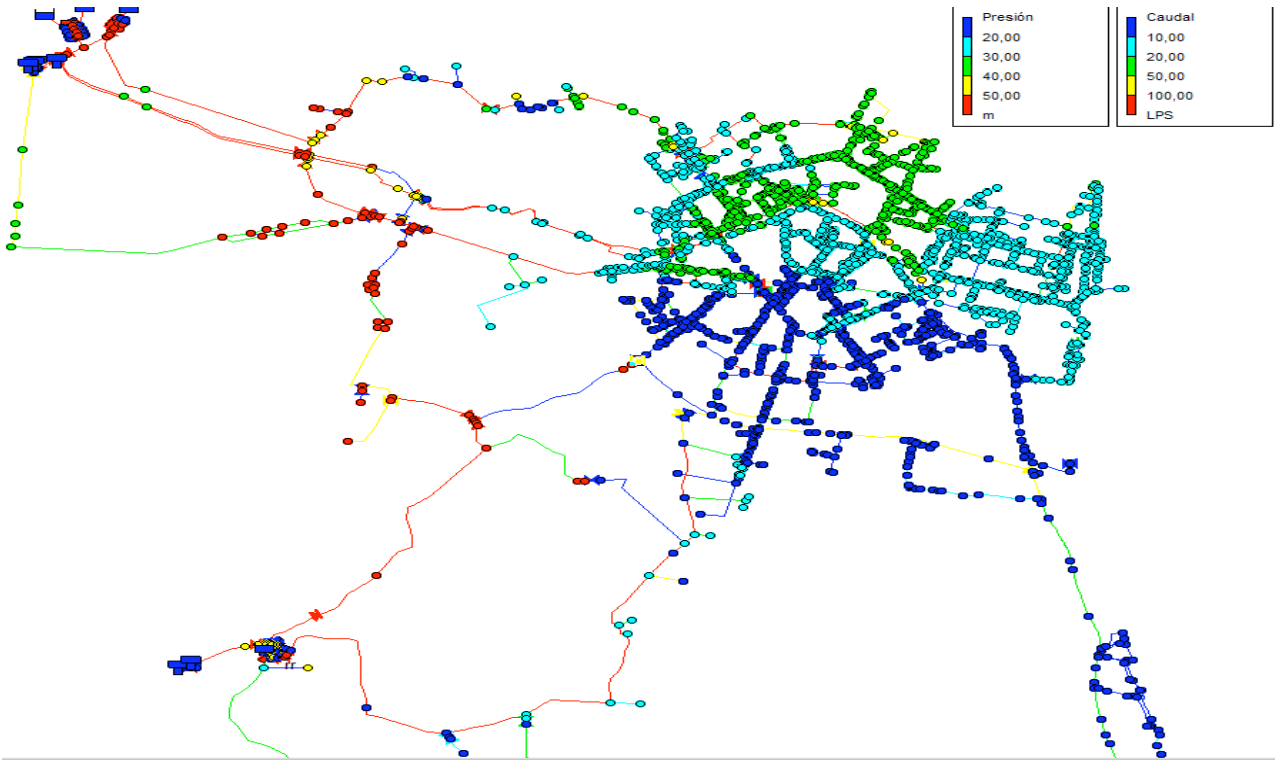


Fig.5.59:Representation of flows and pressures in the network immediately after closing the valve at 7:00 am

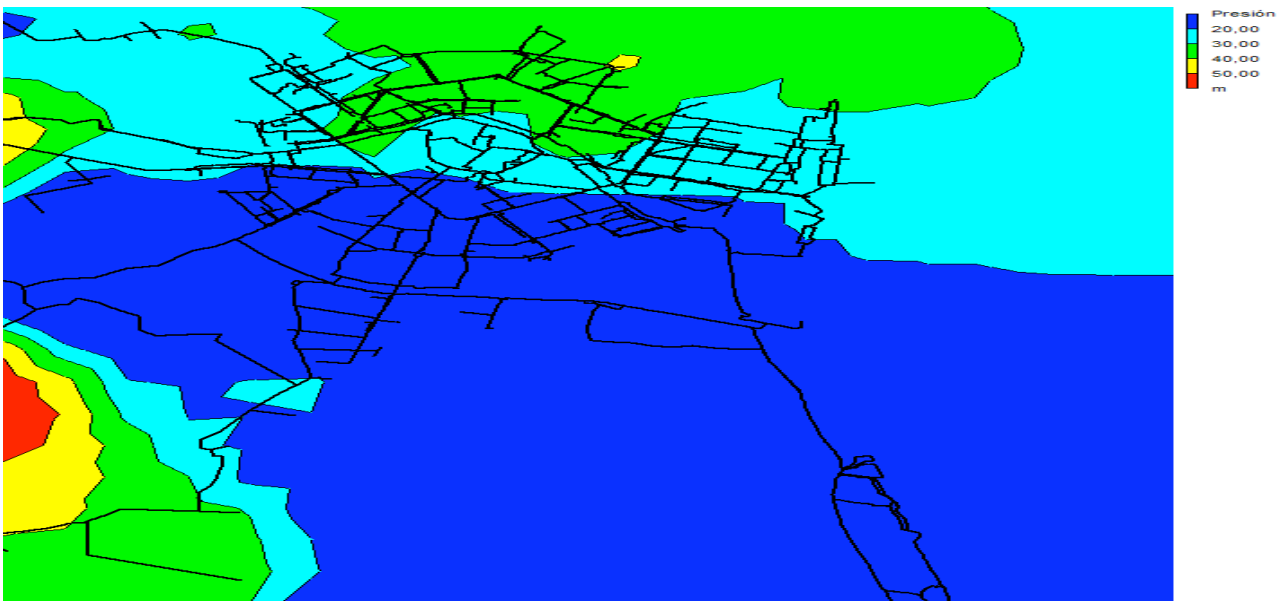


Fig.5.60:Map of isolines of pressure of the network after closing the valve at 07:00 am

Let us now analyze the path of water from “Picassent” and passing through the valve of “San Isidro”; this path would have to reach, in the worst case, the most distant point of the network in “Malvarrosa”.



Fig.5.61: Tracking of the path: “Picassent”– “Malvarrosa” with localization of the break in “San Isidro”

Tracing the longitudinal profile relative to the path towards Malvarrosa: the representation of the piezometric head in the two valves (V1 and V3) during the break, we can note in the path from the tanks of “Picassent” (point 1 in the map) up to “San Isidro” (point 2 in the map) the service is not guaranteed: the piezometric head is below the level of the ground; while there will be an almost acceptable situation (about 20m of pressure) in the stations of "P.Galdos" and “Tres Forques” (points 3 and 4 in the map) until to "Malvarrosa" (point 5 in the map), with a minimum level of service, because in this part of the network the water will come by a different path: from the tanks of "La Presa".

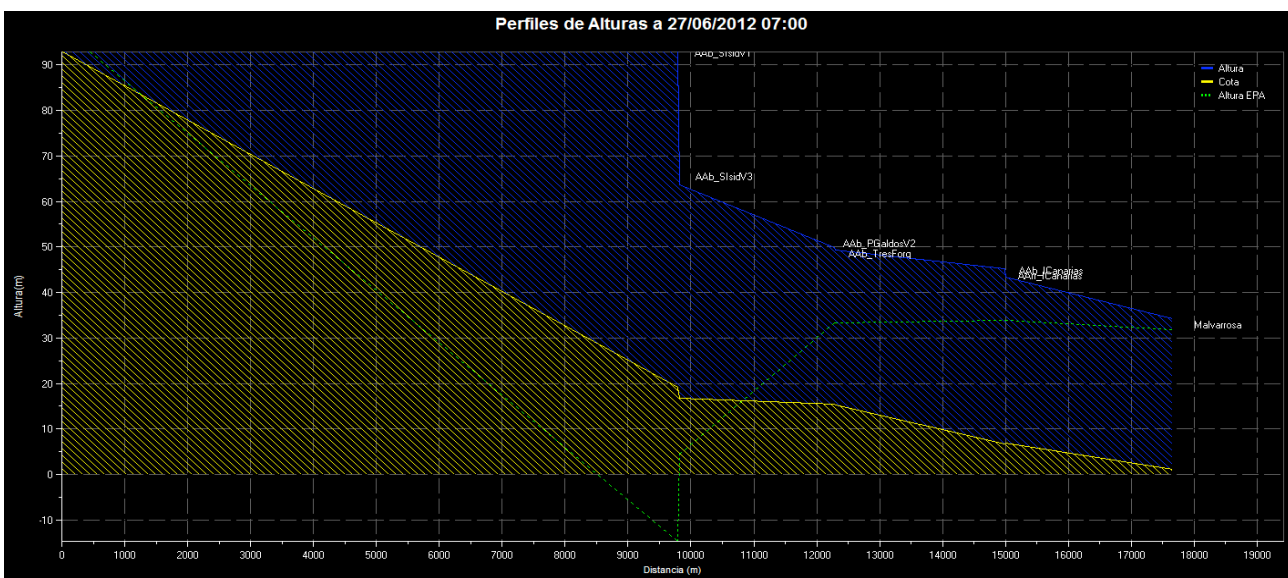


Fig.5.62: Longitudinal profile of heights (yellow) and pressures (blue) at 07:00 am during the break in Sca-Red

With the help of the hydraulic simulator we can pull out some important graphs that show how the flow and the pressure up/down varies, during the day, in the valve where rupture occurs (V1).

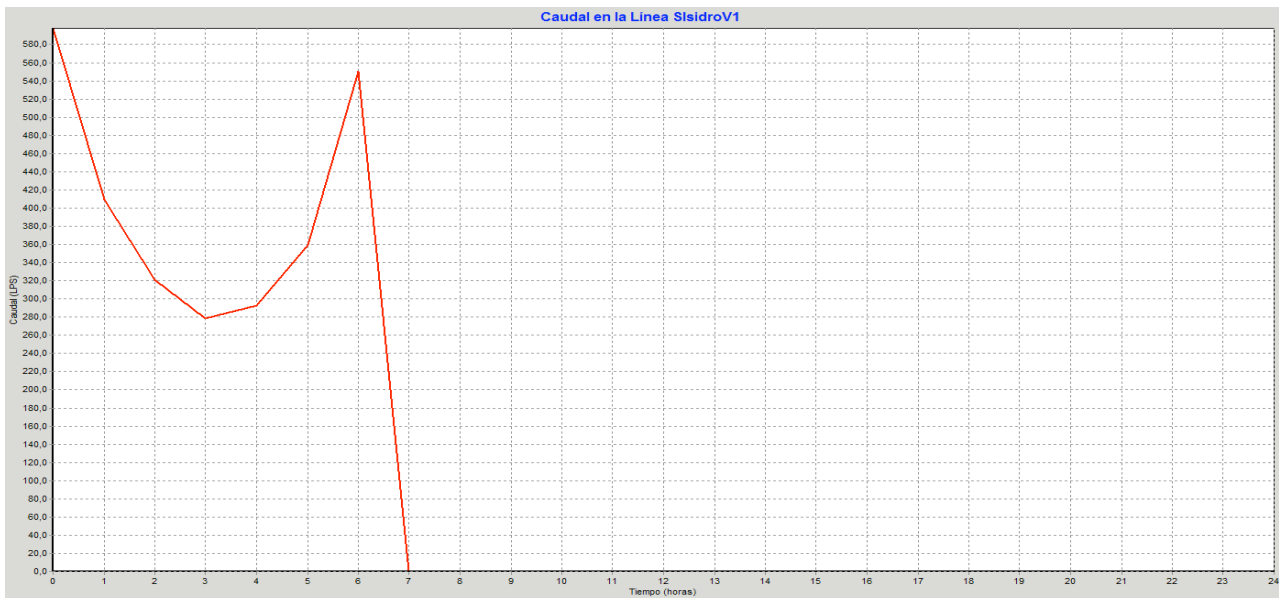


Fig.5.63:Flow passing through the valve V1in "S.Isidro" in the day of the break

- Pressure Up continues constant for about 4 hours and subsequently undergoes a rise of about 25m and is maintained constant on 100m for the entire day;
- Pressure Down immediately undergoes drop of about 110m and in the next hour increments of 25m and afterwards the pressure drop remains constant for about 3 hours on -120m.

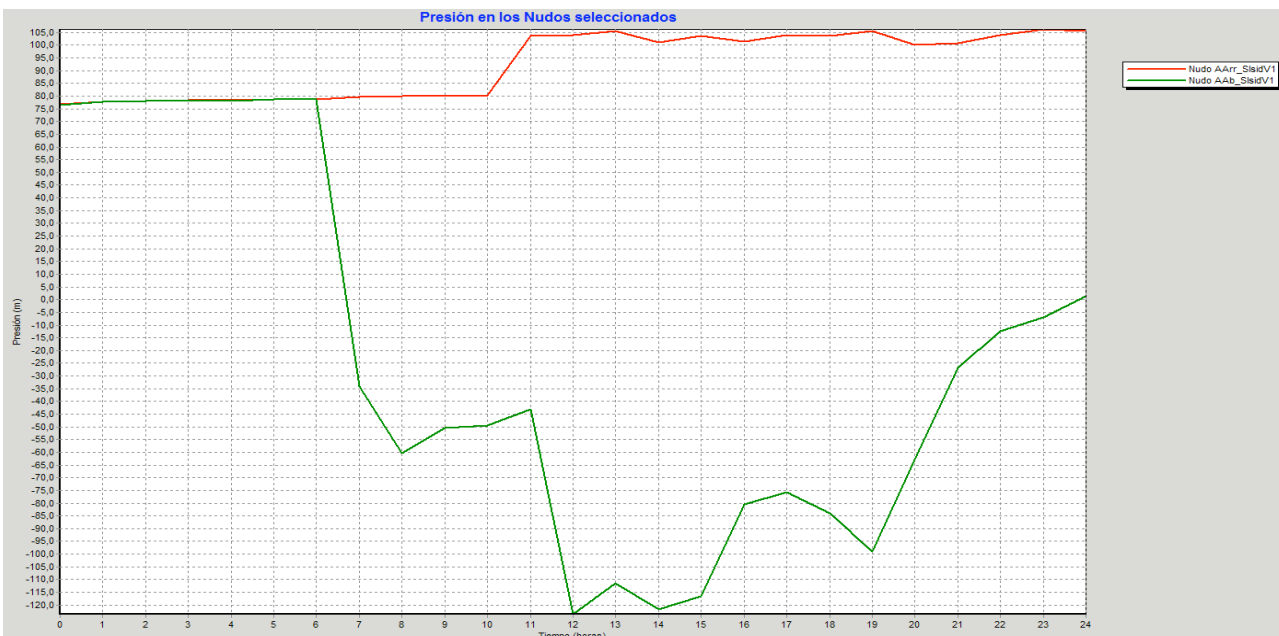


Fig.5.64:Pressure Up/Down in the valve V1in "S.Isidro" in the day of the break

In the following graphs you can see how varies the pressure comparing the normal operating with the emergency situation (when closing the valve) in the valve where rupture occurs (V1) and in the valves present in the two successive ramifications (V2 and V3).

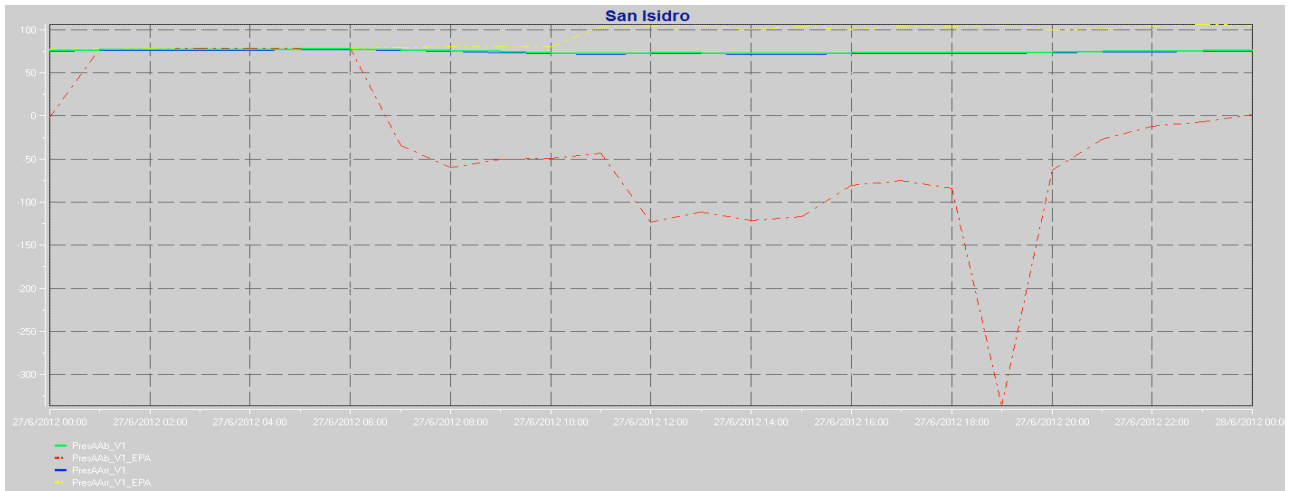


Fig.5.65:Pressure Up/Down in the valve V1 in “S.Isidro” with and without the break in Sca-Red

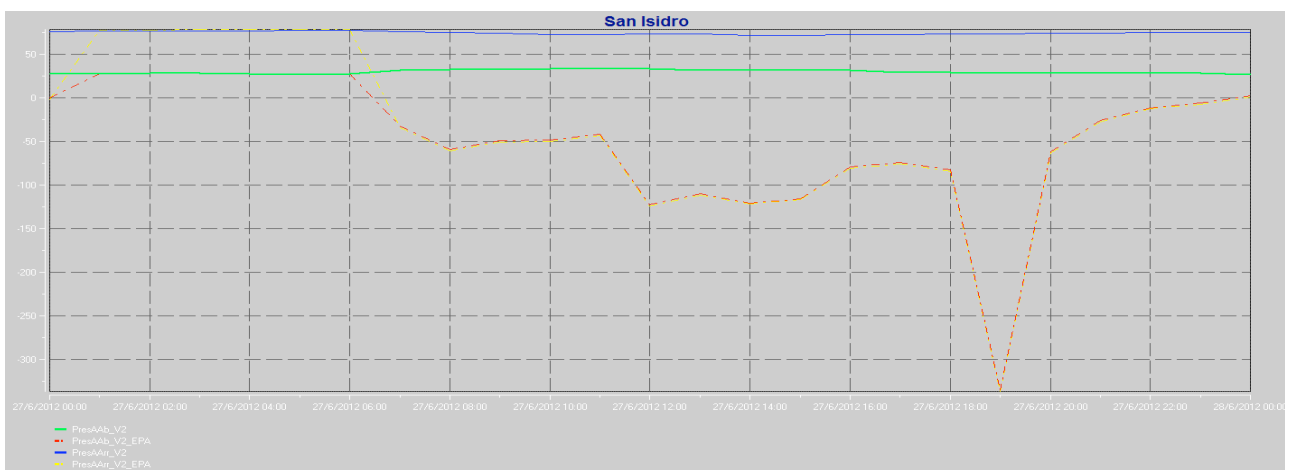


Fig.5.66:Pressure Up/Down in the valve V2 in “S.Isidro” with and without the break in Sca-Red

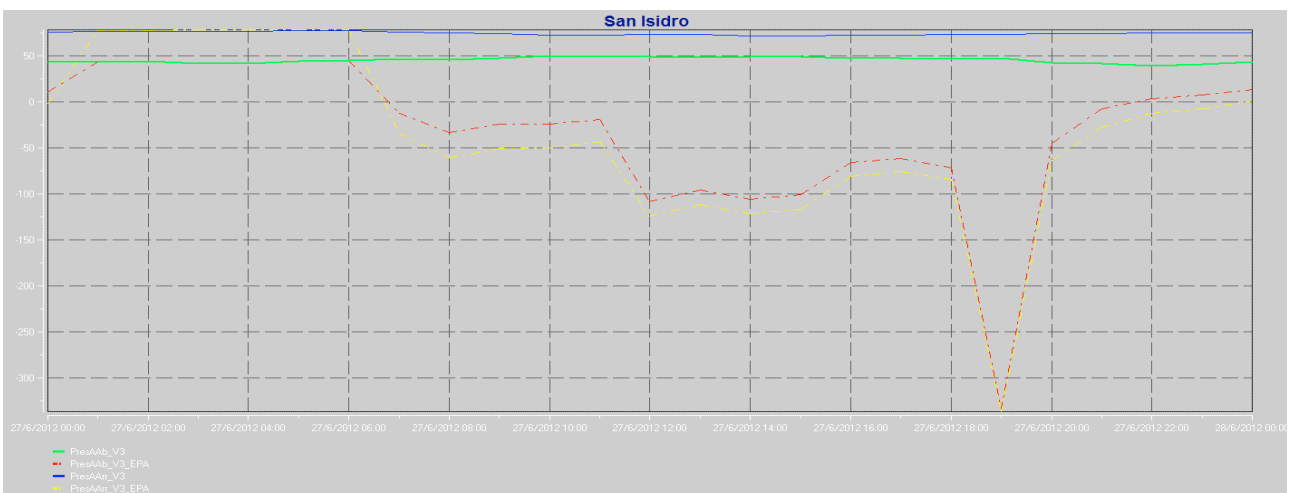


Fig.5.67:Pressure Up/Down in the valve V3 in “S.Isidro” with and without the break in Sca-Red

Analyzed the downstream part of the break, we continue now going to consider what happens upstream: what will happen in the tanks of "Picassent" as soon as the flow is stopped by closing valve.

The valve closed there will be a reversal of flow: the flow that running down to "San Isidro", now a part will be taken back to tanks of "Picassent" and part will be divided into abstractors present upstream of the break. This inversion of the flow will produce increased levels in the tanks that show in the following figure.

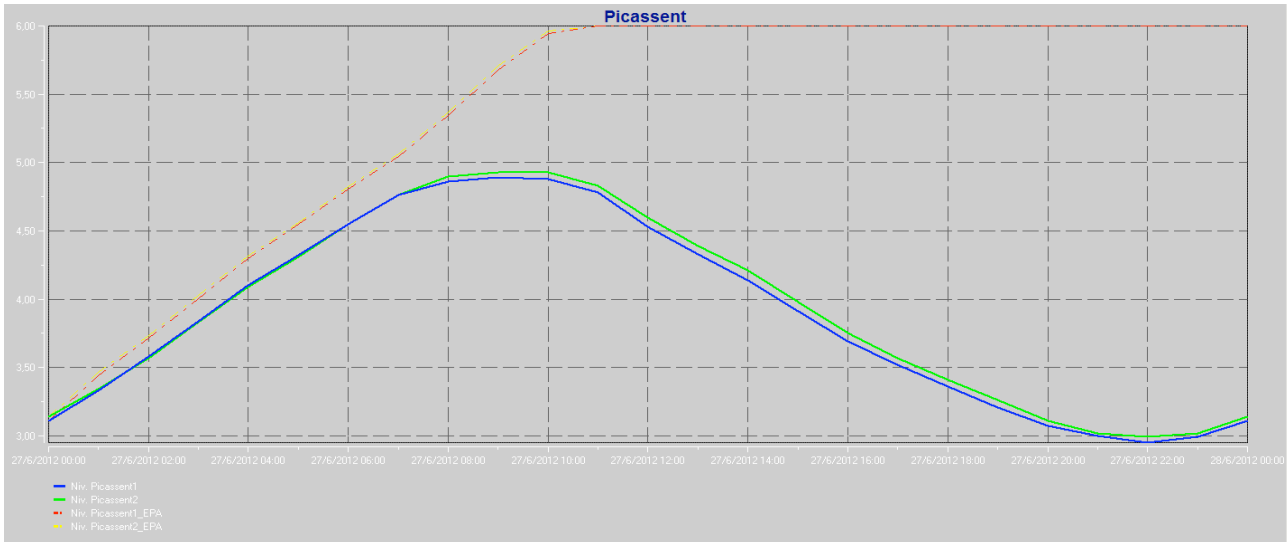


Fig.5.68: Levels in tanks of "Picassent" with break (red and yellow lines) and without break (green and blue lines) in Sca-Red

Final evaluation break: "San Isidro" constitutes an extremely critical point of the network: watershed crucial point of almost all the flow from "Picassent". As such, a possible problem in this point sends in crisis almost half part of the system, as we have seen in the map of isolines of the pressures about 50% of the users in the South of Valencia would be devoid of water; the quality of service would be missing both from the point of view of the pressures and of the flow. Additionally, there will be more high flow in the abstractors present upstream of the break, and above all a high return flow to the tanks which would cause a considerable increase likely to reach level of alert in the same.

5.6.3 Solution to break of the valve

Having regard to gravity of the situation just described, since it is a pipe which makes a connection between tanks and the distribution of mesh nets, have been used technical devices of considerable importance as the realization of **emergency bypass** that connect the ends of these pipes, in order to avoid the presence of dead points and to ensure the supply of each point of the network in case of break or during maintenance works; in almost all cases of rupture of the supply pipelines: tank-network, the solution to solve the problem of water deficiency in that part of network served by supply pipelines is **take advantage of the reserves of water present in the other tank and make use of secondary paths**. In this case it will need to use the tanks of "La Presa" and through the pipeline from Nacional III (where the valve is normally closed), it will be possible to provide the necessary water to the network.

For all those critical points, described above, were used bypass of the same diameter of the pipe, which will replace. These emergency bypass does not appear in the model in use since their presence is not decisive for the use of the same, in fact, will only be used in emergency situation as they have the task of ensuring continuity of service.

The levels of the tanks in “Picassent” represents a critical situation should be monitored because the maximum level of the tanks is about 6m. To safeguard the limit threshold would be appropriate to disconnect some of the pumps that are in operation when the rupture occurs. In the following images is shown the operations that are made to control the level in the tanks of “Picassent” and as such level accordingly varies, remaining within acceptable values and away from a possible state of alert.

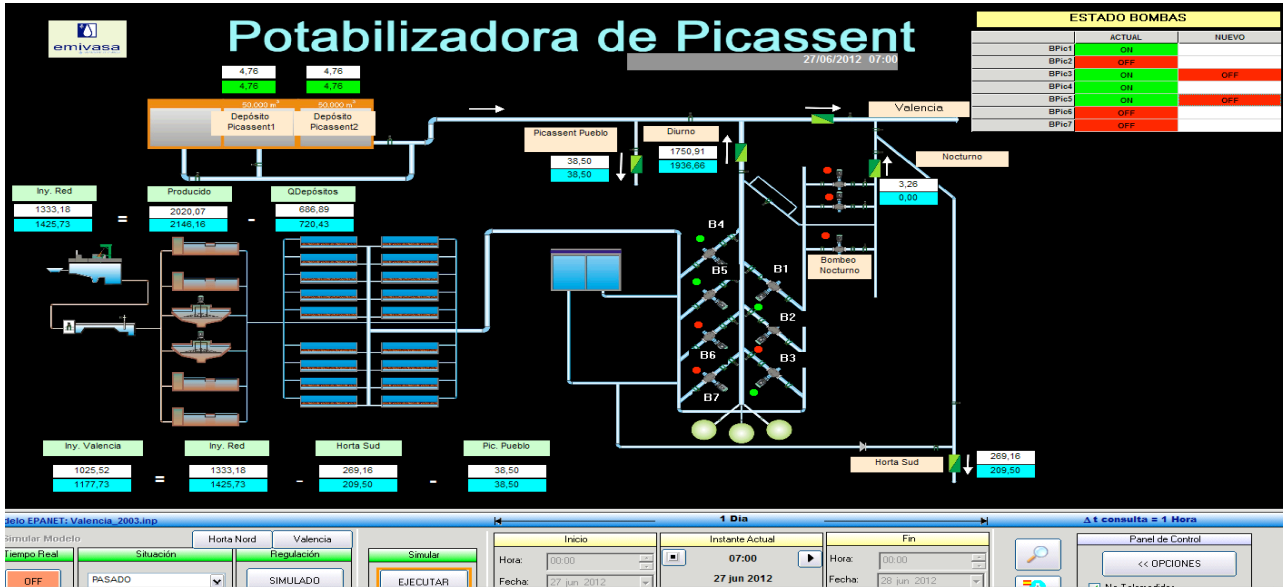


Fig.5.69: Change the status of some pump just break happens in Sca-Red

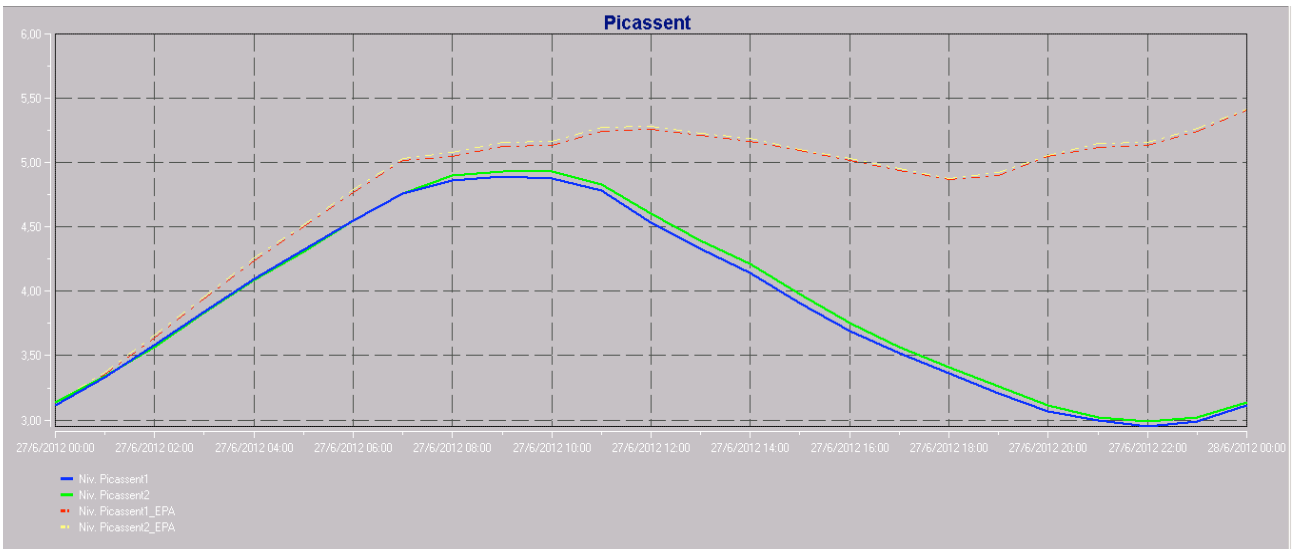


Fig.5.70: Levels in tanks of “Picassent” during the operation to safeguard the maximum level for break (red and yellow lines) and without break (green and blue lines) in Sca-Red

5.7 Real-world applications of model to water supply system in Valencia

An efficient management of the network of Valencia through the use of the model requires cartographic information and real measures. They require powerful analytical tools for dealing with geo-referenced information, SCADA and telereading. Through the integration of the model with GIS, SCADA and using data analysis tools, we managed to find a practical solution capable of taking decisions during the planning, management and operation in water supply systems.

Summarizing, typical scenarios where **Agua de Valencia S.A.**, the company that manages the water supply system in Valencia, needs, an almost daily basis, of use of the model are:

- Knowledge of hydraulic variables of extreme importance (pressure, flow, levels in tanks, ect...) in all the network and also in points non telemetered; aspect of economic importance, considering the cost of the equipment, in this way the company will install devices only relevant key points and at the same time know the state of the network in all other respects;
- The deviation between the measured and actual values, stored in the data base from SCADA, and those calculated from the model will enable to calibrate the same, on condition that the values measured by the sensors are devoid of anomalies;
- For maintenance planning, the company is able to determine which are the days when it is convenient to make changes to the network to help maintain the same; it is clear that a replacement of a pipe will be scheduled in the days and hours of minimum consumption while on a routine cleaning of a tank will occur in the days and hours of maximum consumption in such a way as to have low storage levels;
- In case of population and/or industrial growth with the definition of new sectors together to consequently additional demands, the model will be of fundamental importance like a plan directory for the expansion of the network; in fact to solve the project problems of the network, it will be able to estimate, for example, the diameters necessary for the new flow rates and managing to predict the behavior of the whole system and the quality of service with new connections;
- During emergency situations, will be to ease the location of the damage, since the continuous monitoring of the network, and it is possible predict how the network will react in the following hours and how to act in an optimal way in order to restore the conditions of service;
- The management of the network, through the sectorization of the network in DMA, will be more profitable for the estimation of the flow balance necessary for the study of the efficacy and the degree of efficiency of each sector and for global system.

Chapter 6: Conclusions and future research

6.1 General conclusions about the work

The elaboration of this project, starting from the protection of water resources (water intended as an essential element of the territory and of the environmental system and an irreplaceable asset for the development of various human activities and the improvement of quality of life) in order to succeed the real aim of this work: the need of the mathematical models for the management of operations in water distribution networks, is nowadays a tool of vital importance to the whole of humanity. Moreover, the use of tools such as SCADA, GIS, Epanet, makes us even more skilled at being able to control large networks of metropolitan areas. **Aguas de Valencia S.A.**, since 1993 moved, in collaboration with the **University Polytechnic of Valencia**, forward to the preparation of the first static model of the arterial network of the city; after nearly 20 years of investigation and development are managed to set up some hydraulic models, which even today they can not do without them. The objective of this work focuses on the description and usage of mathematical models employed in distribution networks.

In the first part we focused on the packaging of the model, describing all the data and tools necessary for obtaining a simulator as reliable as possible.

The second step is centralizing on the description of the SCADA software as a means of supervision and control, from it we analyzed the application directly and as close as possible to our use: an essential tool for network management developed primarily for use hydraulic model as a background in order to help network operators to take more reliable decision by increasing the amount of information on the system.

The last part of the work, however, particularly significant from the practical point of view is aimed at a direct application of the model to the water supply system in Valencia. Described main characteristics of the network and its representation in the model used for the strategic management of the network; then analyzed the network during the year 2012, by selecting the significant study period and loading the data required for simulation in the hydraulic model. Launched the simulation, examined the results obtained in the model by analyzing the network in its most important hydraulic variables necessary to explain the state of the network complying with the objectives of a water supply system. Additionally simulate a probable case of emergency, underlining the importance of SCADA, as an instrument of opinion, and the help of the model to make decisions to better manage the operations of intervention. Finally, **Aguas de Valencia S.A.** shows all situations in which the model is called into question to cope with all the management operations in a water distribution network.

6.2 Usefulness of the project: optimization of network through the use of model

The objectives to be reached with the development of this work is basically grouped under 3 basic aspects and in general coincide with the objectives of the company to meet the demands of users and to optimize costs to ensure that service:

1. Improve the quality of service to user;
2. Improve the response capacity under conditions of abnormal operation;
3. Reduce the cost of operation with an optimization of energy consumption.

6.3 Future development: optimal resource management and leak detection in detailed model

Future developments concerning optimal management of the network, can be oriented in a first step, to the analysis of the various factors that justify the uncontrolled consumption as counter errors, without reading supplies, illegal connections, leaks detected in bells location, attributable to latent leaks minimum night flow and its distribution in the network, etc...

Although the water balance of the system, taking into account the state of the valves of the network and balances volumes differentiating between basic sectors and sectors grouped accompanied at a current application to new features designed to decompose different components of the uncontrolled consumption:

- Development of databases for analyzing complementary night minimum consumption and peak consumption observed over time in the various sectors hydrometric, for the purpose of:
 - * Relate the minimum consumption in each sector with the type of subscribers, accountants and sector connection;
 - * Observe the evolution of minimal consumption and daily and seasonal variations, as well as their tendency;
 - * Observe the evolution of the coefficients peak demand in each sector and relate to other parameters, such as population movements, leading activities, types of supply, etc...;
- Broadening the types contemplated in the current database to determine water volumes registered with the effect of validating this information;
- Development of additional databases and associated forms to assess unrecorded consumption;
- Identify latent leaks on a network and analyze its dependence on pressure and other factors (state of pipes, materials, methods of attachment, diameters, lengths, etc...) in order to distribute the leakage and facilitate their location or obtain structural index sectors leak.

Another area of future development is targeted on energy management system and the optimization of power consumption in the sources of supply. The minimization of the energy consumption in pumping stations is a classic problem. However, the energetic management takes into account many other factors such as water management led to the tanks as a function of its height and degree of filling, the regulation of the valves control the pressure, the pressure setpoint setting, the lost by friction in pipes, the energy loss associated with leakage, etc...Through proper database, and with the help of a hydraulic model, it is possible to continuously monitor and detailed fate of all energy supplied to the system and get energetic management indicators, and based on them to adopt strategies to improve the overall efficiency of the entire delivery system. The sectorization of the network can be a key factor in reducing the energy consumed and also the reduction of leakage.

Today, network sectoring is the most commonly used strategy to improve management and increase network performance. It basically consists of dividing the network into several smaller hydraulic sectors (DMA), where water inlets and outlets are perfectly controlled. This simplifies the task of carrying out periodic water balances in each of the sectors, and allows water loss volume to be assessed for a given period of time.

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