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Integral Network Management: A Case Study of Bogotá and the Empresa de Acueducto, Alcantarillado y Aseo de Bogotá, EAB ESP

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Abstract

The mere construction of water distribution networks (WDNs) doesn't necessarily guarantee the adequate provision of the service. Similarly, a growing demand for potable water cannot be solved by increasing the obtainment and production systems, and a system's lifespan doesn't exclusively depend on the quality of its components, since a proper management and maintenance are required as well. This document describes the articulation of technical and operative actions that have been applied to Bogotá WDN with the hopes of (1) generating control tools that facilitate the system's administration and operation (2) maximizing the use of the system's components, and (3) optimizes the available water.

Peer-review under responsibility of the organizing committee of the XVIII International Conference on Water Distribution Systems

Keywords:

INTRODUCTION

By regarding water as being essential to human development, nomad populations that preexisted the development of agriculture and of settlements continuously searched for water sources. These sources ultimately determined where these populations would settle. Afterwards, in order to prevent contamination of the water sources, an adequate drainage was developed, which helped protect the habitants' health. In parallel, civilizations started empirically studying and analyzing the physical laws that determined water conduction, treatment, and drainage.

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Engineering as a discipline was developed bearing in mind the importance of promoting settlements' sustainability and health conditions, specifically WDN engineering. The evolution and development of the discipline determined the appearance and development of towns and cities, a prerequisite of modernity. Likewise, the establishment of a theoretical framework for WDN engineering made possible the execution of infrastructure works. Although much has been accomplished, engineers today are still dealing with challenges. The framework that they adopt must become sustainable in the long-term. Once the infrastructure works began their operation, a new challenge appears, which consists in proving the hypotheses under which the works were constructed actually work, in other words, looking for evidence of their validity and their sustainability.

Modernity implied an additional threat to WDN operations, which consists in the availability of water worldwide as a prerequisite for our existence. This threat wasn't initially taken into account. Instead, within the development of Network Engineering the generation of supply solutions was attempted, in order to reach complete coverage within a population that required the service; this is known as provision management. However, since hydric resources are finite, financial resources are limited and the water supply service must obey an integral, technical, and corporate management, we developed the concept of Integral Network Management.

The integral management of networks seeks to maximize the utility of the available infrastructure, to optimize the utility of the available resource and to adequate the systems so that their administration is facilitated. Perhaps the first and the most important modification of this new approach is that the design must transcend its academic rigor and must be approached in a way that a system that is operable and its sustainable may be visibilized. This document describes the development of the proposed activities to maximize the utility and coverage of a network, or in other words, a higher quality of water for more people, with constructed systems that facilitate its operation and less costs.

METHODOLOGY

The first thing we did was define the strategy we were going to follow. Taking into account the size of our cities the thus the size of our WDNs, it is necessary to discretize the system in order to best define the problem, taking into account geographic and topological factors. Because of the complexities of our cities, such as Bogotá, we subdivided the WDN into smaller areas, a procedure we identified as hydraulic sectorization.

As a part of our approach, we describe a possible solution in order, in which our WDN is delimited intro sectors or service areas, independent and isolated from each other. By doing this we are able to optimize aspects such as pressures derived from the service as well as volume measurement and depuration of the invoiced volumes. This also facilitates the possibility of calculating water loss values, determining its components and causes, and managing a recuperation program that is effective in terms of costs and has the purpose to optimize the operative and commercial management. To explain all of the above we take as reference the strategies and actions implemented in Bogotá's water distribution system, managed by the Empresa de Acueducto, Alcantarillado y Aseo de Bogotá, EAB ESP.

As a tool for corporate management, EAB ESP divided the city into several service areas, and afterwards implemented hydraulic sectorization with the consolidation of 37 hydraulic sectors that operate as units that are still being controlled and monitored in a permanent manner. In this scheme, EAB ESP can comply with the regulations regarding required maximum and minimum pressures.

THE STRATEGY

Delimitation of the network into different sectors or independent and isolated service zones, in which it's possible to optimize the service pressures, macromeasure the supplied volumes, depurate the invoiced volumes, and calculate the Non-Revenue Water Index (NRW) by sectors.

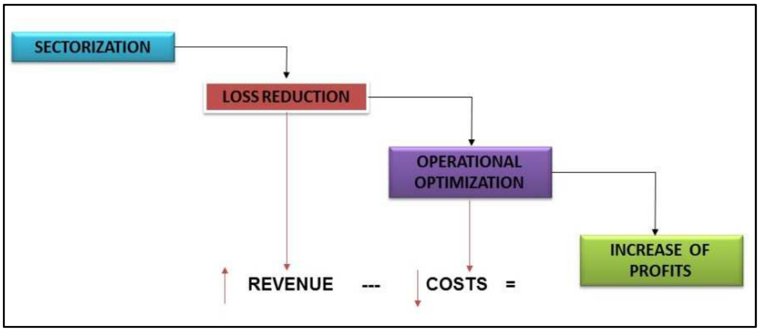

Fig. 1. Optimization of the integral management of EAB ESP.

Evolution of the sectorization:

Basing ourselves on an operational optimization proposal, we developed a corporate management tool for the administration and operation of a WDN. This tool consists in the delimitation of the network into independent and isolated hydraulic sectors, in which it is possible to calculate the water losses values and to determine its components and causes, and managing a recuperation program that is effective in terms of costs and has the purpose to optimize the operative and commercial management.

Our objectives were to disaggregate losses by sector, according to causes (technical or commercial) and formulate structured reduction projects by sector and type loss, and to optimize the water distribution system operation and management in order to improve the Quality of the service and EAB ESP's financial performance.

ACTIONS

Technical, commercial, and governmental actions were used for the development of the "Integral Network Management". In this article we will describe the first two, while only briefly mentioning the latter.

Technical Actions. These actions are divided into the following components:

Preventive and Corrective Maintenance:

This activity is associated with operative efficiency and is done to guarantee the proper functioning of the macromeasurament elements. It is also done in order to maintain pressure control and to minimize the time it takes for EAB ESP to attend and repair visible leaks within the network. The number as well as the times of these interventions is considered an important and impacting element in the management of the network; we have established all damages within the WDN must be attended in under 8 hours.

De igual manera que, con las daños, las operaciones preventivas que impactan en las pérdidas hacen parte del programa, entre dichas operaciones están las actividades de mantenimiento de la sectorización así: revisión cuatrimestral de divisorias de la subsectorización y zonas de servicio aferentes a estaciones reductoras de presión, el mantenimiento anual de las estaciones reductoras de presión y la calibración bimestral de las estaciones reductoras de presión.

Pressure control:

From a technical and economic point of view, the most efficient action one can do for loss recuperations is controlling the pressure found in the different hydraulic units of the network. Guaranteeing ways to control pressure in flat zones became a fundamental premise once we acknowledged pressure peaks, which may cause damages in the network, usually occur early in the morning.

Before beginning with the massive installation of pressure control stations, EAB ESP conducted a pilot investigation with the hopes of determining how changed in pressure affected the flow that is supplied to a hydraulic unit. This is ultimately the effect of the visible and non-visible leak within the invoiced flow. In other to do this, a closed hydraulic unit was selected, one with a single macromeasured entry that was also being fed through a pressure control station. This allowed us to evaluate scenarios with different entrance pressure values.

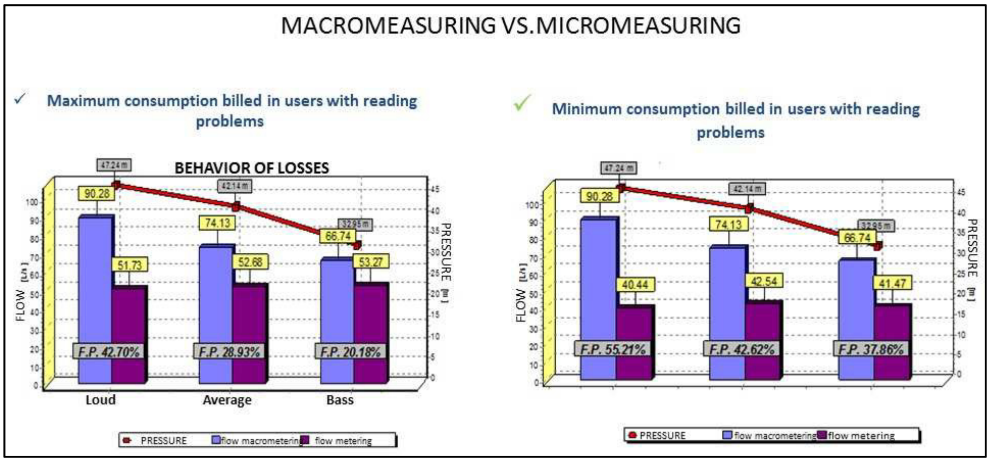

Fig. 2. Maximum and minimum consumptions billed to subscribers whose meters have reading problems.

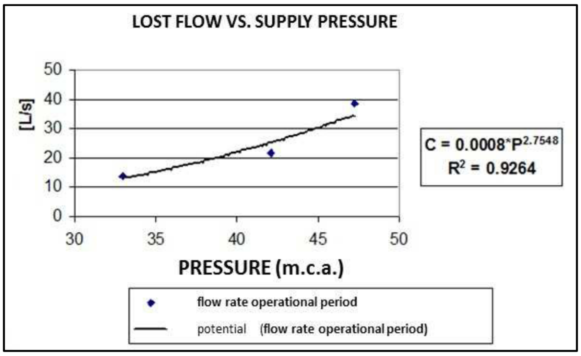

Fig. 3. Water loss vs. pressure of supply

Systematic search of leaks:

The programs used for this systematic search were determined as programs with high technical performance for loss recuperation and economic viability. In the zones in which the operation is divided, the execution of 900 km of network was programmed (this corresponds to 10% of the total network). This was done alongside the corresponding repair of damages that were found during our supervision of the network. This investigation's definition is done according to the service conditions as well as the economic indicators within the different hydraulic sectors of each zone.

Network renovation:

These consist of projects that have a smaller loss recuperation potential with a higher investment cost. Their impact must be taken into account by associating these projects to the patrimonial and accountable recuperation of the pipelines. This is done by perceiving the network as an asset of the company that loses its value with time and whose replacement allows to keep it updated and maintained. Our proposal is to consider the pipeline's lifespan and perform gradual replacements, so that by the end of its lifespan the pipeline has been replaced in its totality.

Macrometer:

We suggest the implementation of permanent and temporal flow measurements, such as: Treatment Plants Exit (Permanent), Hydraulic Sectors (Permanent), Profitable Hydraulic Sectors (Permanent), Investigation Districts (Temporal), Investigations (Temporal), and Special Operations (Temporal).

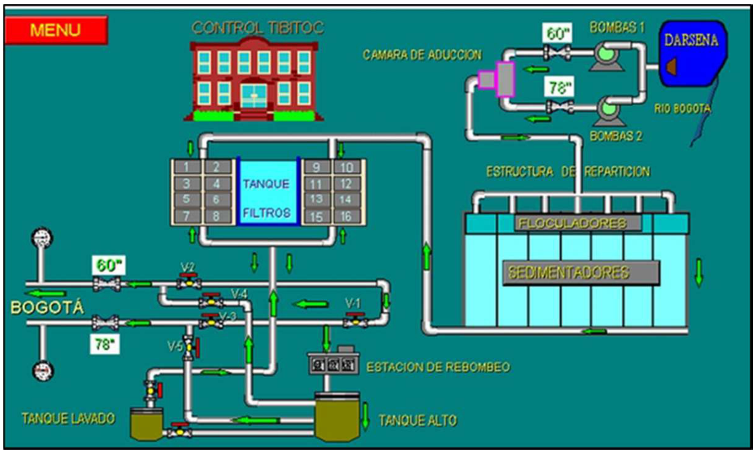

Fig. 4. Simplified unitary process of the Tibitoc plant.

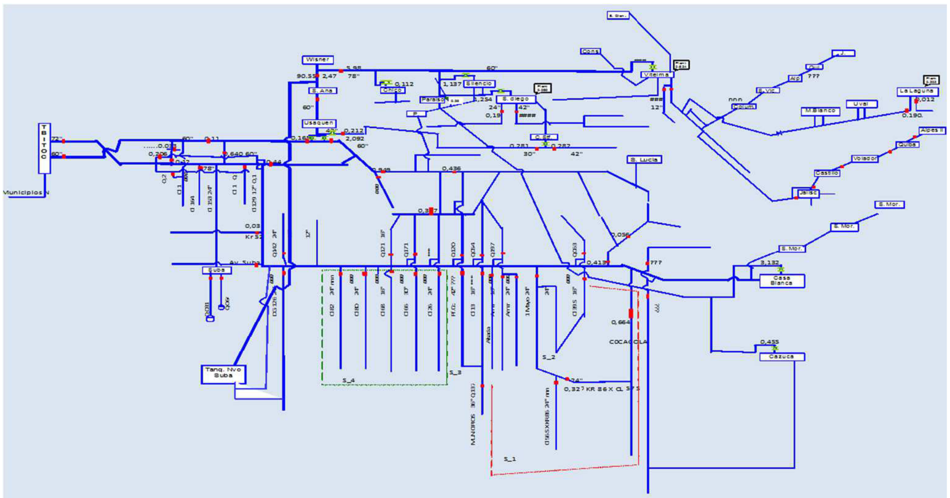

Fig. 5. City supply and distribution.

Energy efficiency aspects:

If there exist topographical differences in the system that require the existence of pressure regulation, then not dispersing the available energy and using it instead to generate new energy is an option. In the case of Bogotá, the variation in elevation of the different localizations of the system's elements was taken advantage of, considering the most reliable flow is the one that corresponds to the supply of potable water. This way, three hydroelectric central were constructed and are still in operation. The energy generation capacity of each our hydroelectric centers are:

- PCH Santa Ana: 7.7 MW
- PCH Suba: 2.8 MW
- PCH Usaquén: 1.8 MW

The generation must be complemented by the control and monitoring of the energetic aspects. The objective here is to guarantee a systematic programming to evaluate the operative site's consumption and the supervision procedures with which the inefficiencies in energy consumption are identified, and to achieve a proper identification of those components in the site that have a representative consumption. This is done by evaluating the present efficiency and comparing it to a theoretical reference, and using the available technology within EAB ESP that reach the maximum efficiency and maximum profit.

Control Center:

Automatic operation of the matrix system, including monitoring, supervision and telecommand, which allows to control the macro distribution, as well as the flow, the levels and the pressure planes in real time. This means assimilating and perceiving the hydraulic configuration of the city's WDN as an industrial processes, one that can be susceptible to automation.

The EAAB design and constructed the Operative Control Center from which the operation and control of the city's aqueduct matrix system is done via a continuous follow up of the system's operative parameters. This so that a rational and efficient management of the available hydric resource can be achieved while maintaining the adequate conditions of the service's quality and reliability, even in contingency situations.

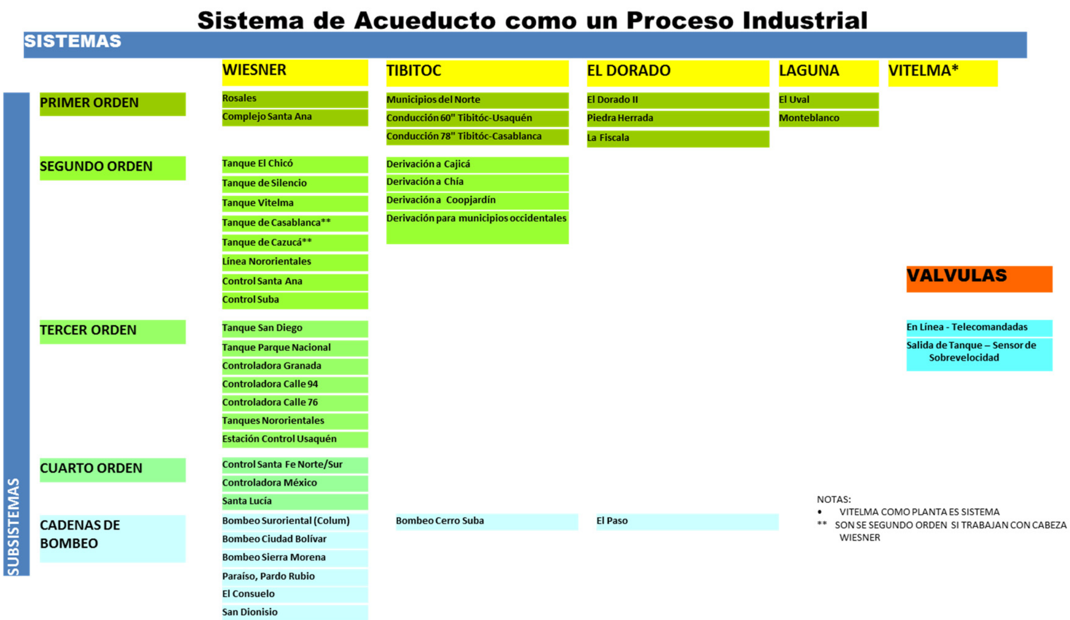

Fig. 6. The system as an industrial process; order of priorities within the Control Center.

Commercial Actions. These actions are divided into the following components:

Harmonization of the billing cycles with the hydraulic sectorization:

Association of the consumption points of hydraulic sectorization with the harmonization of the billing zones so that the billing points of a single hydraulic sector in a specific billing zone can be grouped and the macrometer values can be compared with the billing of a geographic zone of corresponding to a specific period.

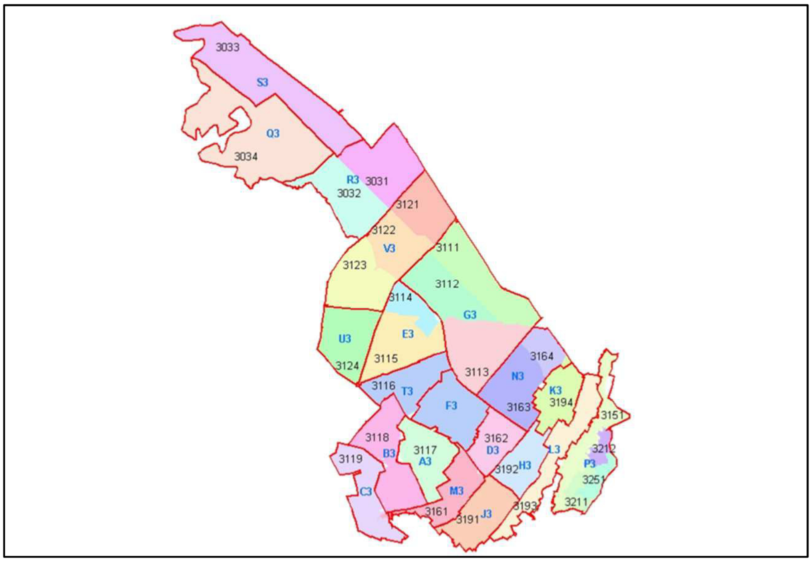

Fig. 7. Cycle Harmonization of hydraulic sectorization, by cycles.

Dynamic update of user census:

Permanent update of the user's detailed cadastral, from two points of view: quantitative, seeing that the existing consumption points are reflected and taken into account in the commercial data bases of the billing process, and qualitative, seeing that the characteristics of the existing consumption points are reflected and taken into account in the commercial data bases of the billing process.

Improvements to the commercial operation management:

Loss management can be regarded as an integral management in itself, one that includes all of the commercial activities within EAB ESP, such as installation to the connection to the main network, activation of the consumption points of the commercial system, and imperceptible internal leaks, etc.

Governmental Actions. The Colombian government, within the implementation of adequate legislation and technical normativity of water, must also adopt programs that encourage rational use of the resource on behalf of the users. The installation of low-consumption apparatuses within households, in order to save water, is also important. Likewise, campaigns associated with the rational utility of the resource must be promoted in order to generate awareness of the monetary and environmental use of an excessive use of water.

RESULTS

REGARDING THE STRATEGY

-Distribution in 5 different zones in the city (Fig. 8).

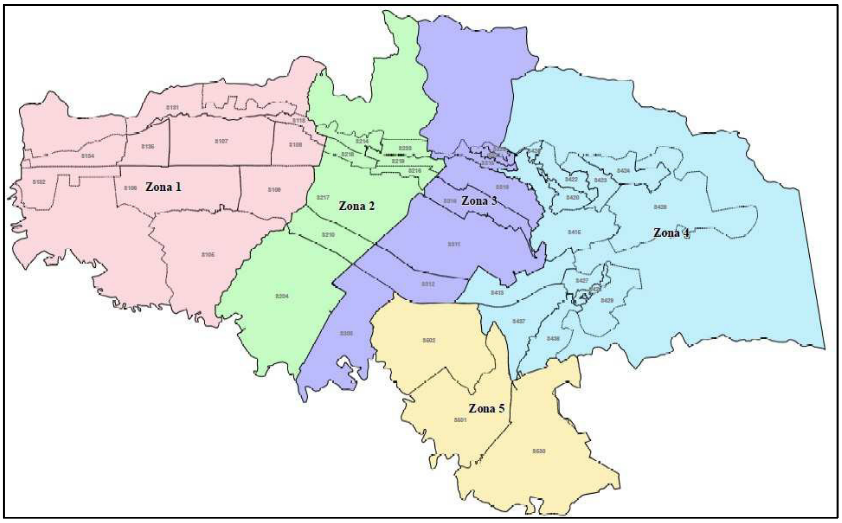

Fig. 8. Distribution of zones in Bogotá.

REGARDING THE TECHNICAL AND COMMERCIAL ACTIONS

Hydraulic sectorization was designed and constructed (**¡Error! No se encuentra el origen de la referencia.**); management zones were implemented according to hydraulic sectors (**¡Error! No se encuentra el origen de la referencia.**); sectorization was adopted as tool for corporate management (**¡Error! No se encuentra el origen de la referencia.**); dispersed geographic control for the evolution in consumption was performed (Fig.12); typologically and geographically oriented loss control projects were implemented; operative policies based on consumption evolution were adopted, such as pressure control every 25 meters of topographical differences and pressure control in flat zones; the time taken to attend damages in the network was optimized (Fig. 13). Finally, in terms of the commercial actions, the billing cycles were harmonized with the established hydraulic sectors.

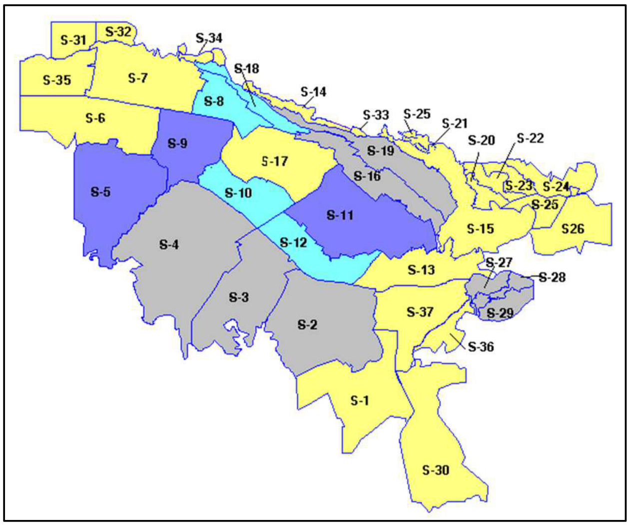

Fig. 9. Sectorization in the city of Bogotá.

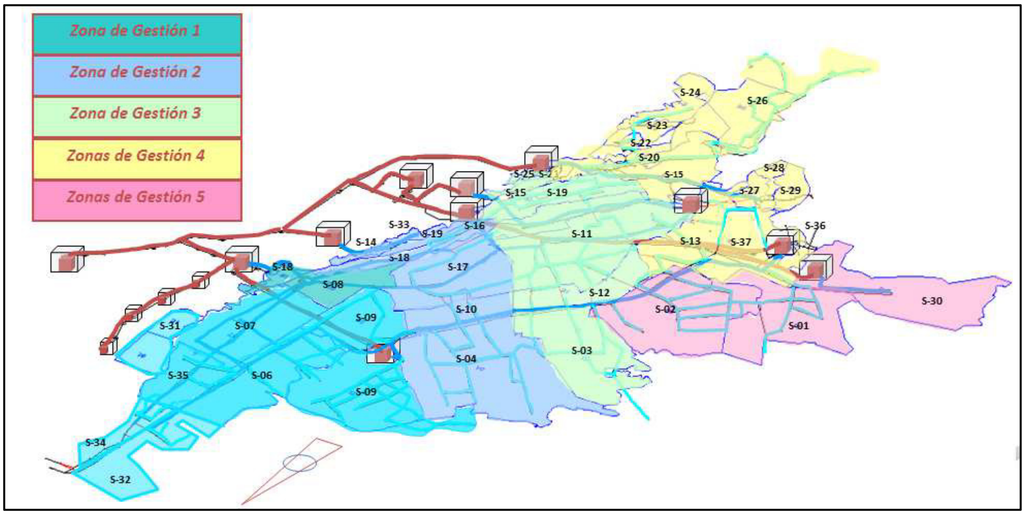

Fig. 10. Management zones, hydraulic sectors.

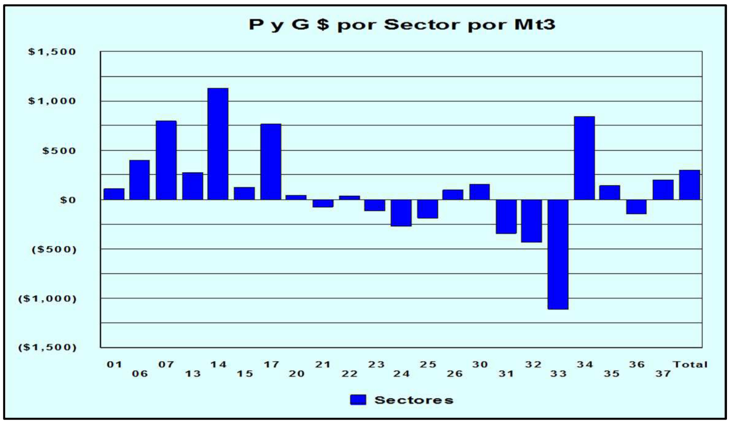

Fig. 11. Losses and gains by sector.

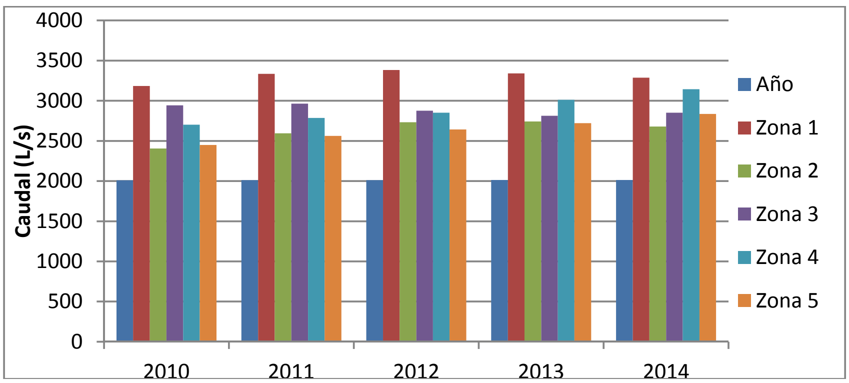

Fig. 12. Dispersed geographic control for the evolution in consumption in different zones.

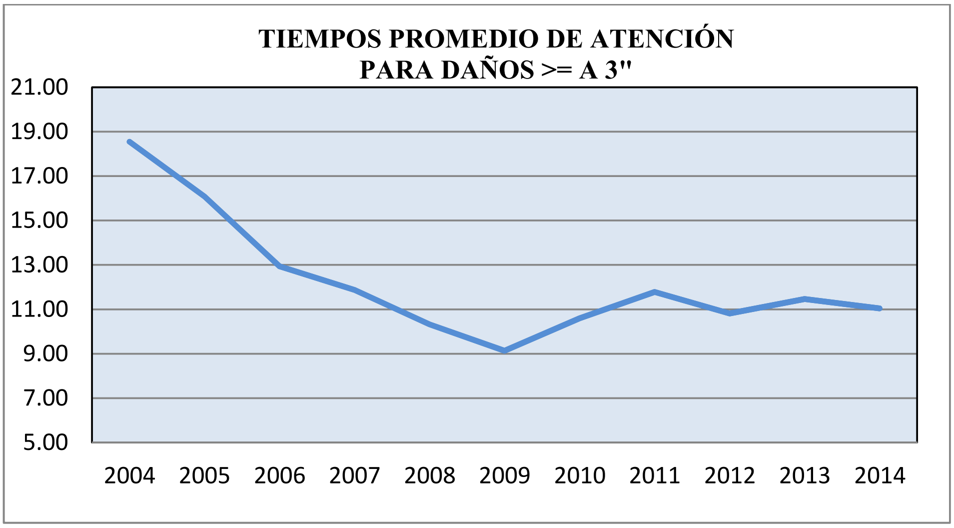

Fig. 13. Average time taken to attend damages in the pipelines.

REGARDING THE EVOLUTION OF CONSUMPTION AND SUPPLY

There was a dramatic change in the provision per capita in Bogotá; from provisions of more than 200 liters per habitant per day, this changed to 110 liters per habitant per day, or even 90 liters in specific points. In other words, consumptions per bill in 2009 were of 13.42 m^3 per month, while in 2014 they were of 11.94 m^3 per month. There was also a reduction in the value of water losses per user per month (from 21.03 m^3 in 1993 to 7.13 m^3 in 2014).

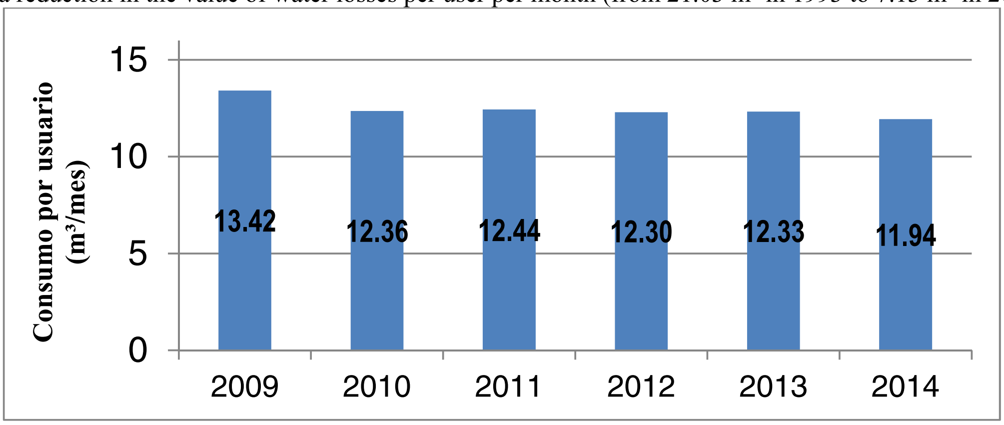

Fig. 14. Residential consumption per user.

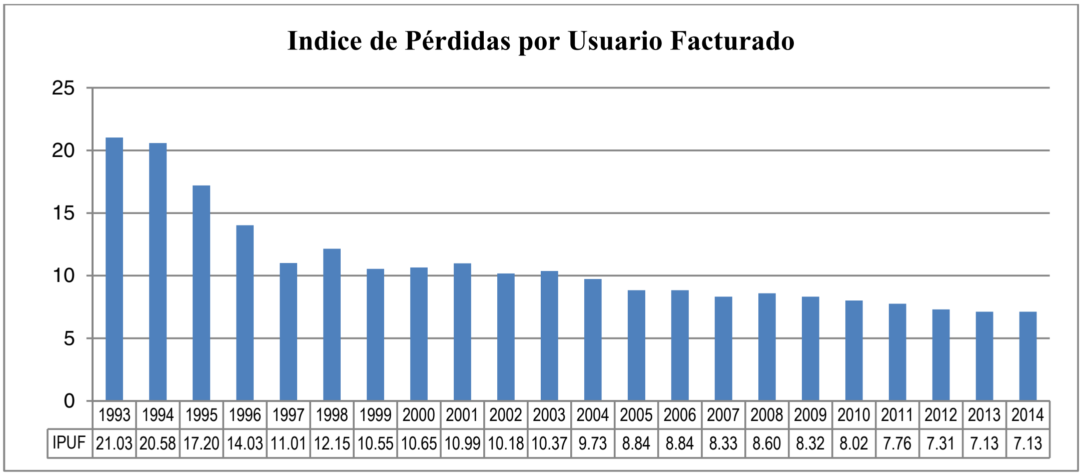

Fig. 15. Water losses index pero billed user.

Regarding the supply, in 1994 in Bogotá the supply consisted of 17.99 m^3. This value was expected to grow to become 26 m^3 for the year 2002, which meant the expansion project would have to be operating by this date. What actually happened was that, with the already mentioned Integral Network Management, the supplied value for the year 2002 was 14.14 m^3 and for 2015 was 15.71 m^3. Additionally, the modification of supply and its evolution implied a modification in the necessity for expansion projects, as well as the moment in which these would be done. The need for expansion in Bogotá was thus postponed and the financial means could be used for institutional strengthening.

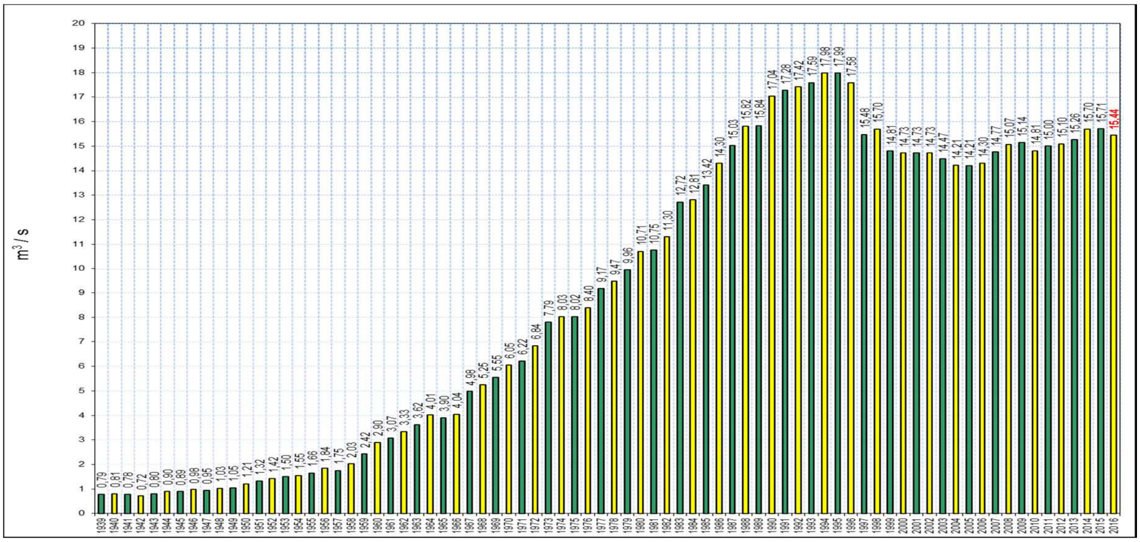

Fig. 16. Evolution in the demand in Bogotá from 1939 to 2016

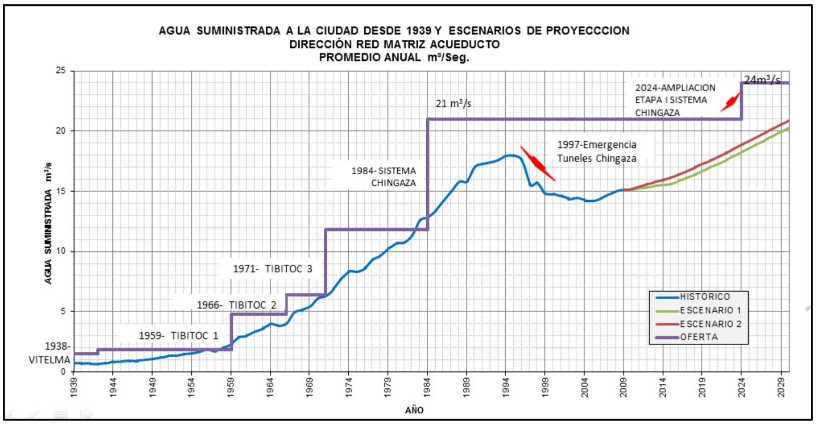

Fig. 17. Water supply in the city and projection scenarios.

CONCLUSIONS

The Integral Management of Distribution Networks allows the optimization of the resource's utility and that of the existent infrastructure, so that investments for expansions can be postponed and the available financial resources can be used for other purposes, such as better coverage and institutional strengthening.

The rational use of the hydric resource doesn't generate inconveniences for the use and has positive environmental implications.

YEAR	VOLUME SUPPLIED (Mm^3) - 5 million inhabitants	VOLUME LOSSES (Mm^3) - 8 million inhabitants	Million mens
1995 Whitout project	567 Mm^3	207 Mm^3	5'500.000
2014 with project	494 Mm^3	172 Mm^3	8'500.000

Fig. 18. Volume supplied, volume of losses and population

References

[1] M. Jiménez Aldana, Acueducto de Bogotá, La Sectorización Hidráulica como estrategia de control de pérdidas en sistemas de acueducto (2002).
[2] Dirección Red Matriz Acueducto, Acueducto de Bogotá, Manual de Operación (2015).
[3] División Centro de Control, Acueducto de Bogotá, Pautas de Operación (2016).
[4] Reglamento técnico del sector de agua potable y saneamiento básico RAS – 2000
[5] LEY 373 DE 1997(Junio 6): Por la cual se establece el programa para el uso eficiente y ahorro del agua
[6] Norma Técnica Colombiana NTC 1500 "Código Colombiano de Fontanería"
[7] DECRETO No. 3102 DE 1997 (diciembre 30)
[8] Comisión de Regulación de Agua Potable y Saneamiento Básico – CRA