Water systems design impact on utilities efficient management – Long term planning in a multi-utility Group

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Abstract
Water utilities in different countries are facing challenges in how to manage effectively their global operations. Being a capital intensive activity, the way how to design the infrastructures is an important topic and an efficient cost-effectively management is crucial in order to provide a safe and reliable service to final users. Aligned with these challenges decision-makers have to deal with an infrastructure with indefinite lives where a proper decision regarding the implementation of a solution today will always have a long term effect. In this process it's important to understand the impact that standards and/or design codes can have on systems' performance. These concerns are even more important in a Group that manages utilities in different countries with different contexts and regulatory frameworks where standards, such as, design codes can be mandatory or best practices to be followed. This paper aims to describe how design codes can influence performance and operational management practices. The systems' performance comparison will be presented having as a case study a water distribution system designed under three different countries' codes and consumption patterns. The results are acknowledged in order to understand their impact under the infrastructure asset management (IAM) policies.

Keywords
Infrastructure asset management; operational efficiency; water distribution systems design

INTRODUCTION

Water systems evolution is directly tied to the development of communities and its social trends that are continuously changing, such as consumers' behaviour pattern, technical knowledge and environmental awareness. Water distribution systems (WDS), having an "organic" behaviour, are inevitably a reflection of all of these trends. However their nature promotes an important inertia what causes, in some cases, a difference between "what we have" and "what we should have" as a network. Detailed systems' knowledge, standards and procedures, combined with proper external understanding, namely water consumption trends are crucial to support infrastructure asset management (IAM).

Marubeni and INCJ (Innovation Network Corporation of Japan) are shareholders of water utilities in different countries through different companies, e.g. Administração e Gestão de Sistemas de Salubridade, S.A. (AGS) and Aguas Nuevas, S.A.. AGS is a Portuguese multi-utility operator that manages 13 water utilities in Portugal and Brazil. Aguas Nuevas is a Chilean multi-utility operator that manages three water companies in Chile. Inside the holding companies of AGS and Aguas Nuevas, the development of standardized methodologies and procedures is a critical step for the identification of best practices. Understanding barriers and enablers associated to the standards and codes in place, in each country, is fundamental in this context particularly when technical alignment and efficient decision-making processes are required within the Group.

Standards are applied in different areas including construction, operation and maintenance. In these areas design codes can have an important influence on WDS. Networks are designed to enable different uses, from providing drinking water to industrial and commercial uses, and to standby fire-flow, as well. The design codes followed by each country to comply with these needs can be significantly diverse due to technical and economical contexts. On the implementation of IAM policies and planning future rehabilitation investments in a holding that manages water utilities in different countries it's important to know the impact of different design codes on WDS performance and service level.

LONG TERM PLANNING

The water network is a critical component of every water utility having as primary function the continuously distribution of the required water quantity with a suitable service level to all uses. Water utilities must assure the required level of service with an acceptable level of risk at a minimum cost. Planning long term investments considering the balance of performance, risk and cost must be acknowledged in order to guarantee its alignment with the design codes requirements.

Design codes can be mandatory or simply best practices standards, covering topics such as water demands, velocity and pressure ranges and firefighting requirements, among others. At the same time, WDS are designed to meet peak demands often based on "artificial" statistics and/or too broad assumptions regarding per capita values, peak factors and demand patterns.

When planning new or rehabilitation investments in WDS, utilities can face the dilemma of choosing a solution that complies with the design codes and doesn't present the best balance between the dimensions of performance, cost and risk. A typical example occurs in small and medium systems where fire-flow requirements established to emergency scenarios can lead, in normal supply situations, to low-flow conditions that contribute to the deterioration of microbial and chemical water quality. Therefore there is a need to assess the impact of different design codes in specific scenarios in order to understand its influence in the system's performance and if a difference exists it is important to continuously adapt the network, in its lifetime, during its rehabilitation interventions, towards an improved design.

WATER SYSTEMS' DESIGN CODES COMPARINSON

The design codes in Chile and Portugal are mandatory by law while in Brazil is characterized by standards with a best practices approach. In terms of network design procedures the mandatory requirements differ in each country. Chile has a national official standard (Norma Oficial de la Republica de Chile NCh691) defining general design procedures, Portugal has a decree law (Decreto Regulamentar n.º 23/95) establishing in detail several requirements regarding design conditions and Brazil has a national standard promoted by the Brazilian Association of Technical Standards (ABNT – Associação Brasileira de Normas Técnicas).

Table 1 describes each country codes and requirements regarding minimum diameters, operating pressures, fire-flow conditions and velocity in WDS.

Table 1. Chilean, Portuguese and Brazilian water distribution system design requirements.

Minimum diameters	
Chile Official norm NCh691	Distribution network: 100 mm (it can be applied 75 mm if connected with larger pipes in a distance less than 50 m) Pipes connecting fire hydrants: 100 mm
Portugal Decree law no. 23/95	Distribution network < 20,000 inhabitants: 60 mm Distribution network > 20,000 inhabitants: 80 mm Pipes connecting fire hydrants: from 80 mm to 150 mm, according with urban area risk level
Brazil Norm NBR 12218	Distribution network: 50 mm Pipes connecting fire hydrants (for total flow Qt > 50 l/s): 150 mm
Operating pressures	
Chile Official norm NCh691	Minimum pressures: 147 kPa (15 mH_2O, dynamic condition) Maximum pressures: 686.47 kPa (70 mH_2O, static condition)
Portugal Decree law no. 23/95	Minimum pressures: H = 100 + 40n, where: H - minimum pressure (kPa); n - number of floors above ground (dynamic condition) Maximum pressures: 600 kPa (static condition)
Brazil Norm NBR 12218	Minimum pressures: 100 kPa (dynamic condition) Maximum pressures: 500 KPa (static condition)
Fire-flow condition	
Chile Official norm NCh691	$H_{fire} > 5\ mH_2O$, where: H_{fire}: pressure at a fire hydrant considering the maximum value between the maximum hourly flow and the maximum daily flow plus the fire flow range between 16 l/s and more than 95 l/s (depending on the number of habitants and fire hydrants used simultaneously)
Portugal Decree law no. 23/95	$H_{fire} > 0\ mH_2O$, where: H_{fire}: pressure at a fire hydrant considering average flow plus the fire flow range between 15 l/s to 45 l/s (depending the urban area risk level)
Brazil Norm NBR 12218	For total flow, Qt < 50 l/s – the use of fire hydrants can be dispensed. For total flow, Qt > 50 l/s – the flow rate in the fire hydrant must be accomplished (10 l/s in residential areas and 20 l/s in commercial and industrial areas)
Flow velocity	
Chile Official norm NCh691	(n.a.)
Portugal Decree law no. 23/95	Minimum velocity: 0.3 m/s (for the maximum flow in the first year of operation). Maximum velocity: v (m/s) = 0.127 $D^{0.4}$, where D is the internal diameter (for the maximum flow in the project's horizon year)
Brazil Norm NBR 12218	Minimum velocity: 0.6 m/s (for the maximum flow in the first year and in the project's horizon of operation) Maximum velocity: 3.5 m/s (for the maximum flow in the first year and in the project's horizon of operation)

When comparing each country procedures some topics are slightly different while others present a considerable difference that is important to acknowledge, namely in regard to the application of minimum diameters or velocity references.

DESIGN CODES INFLUENCE ON WDS PERFORMANCE

Case study description

The main goal of the case study is to analyse design codes impact on WDS performance. The case study analyses a real WDS from Chile considering Chilean design codes redesigned according with Portuguese and Brazilian design codes.

The WDS is a network with 12.7 km pipe length and diameters range from DN63 mm to DN200 mm. The system supplies 1,521 users with an average demand of 14.6 l/s. The analysis was supported on network hydraulic models assembled on EPANET software. Figure 1 presents the network scheme and elevation.

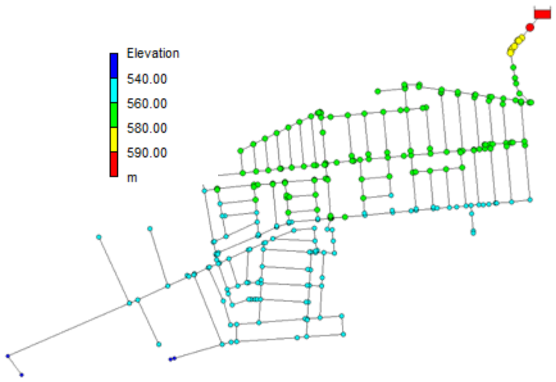
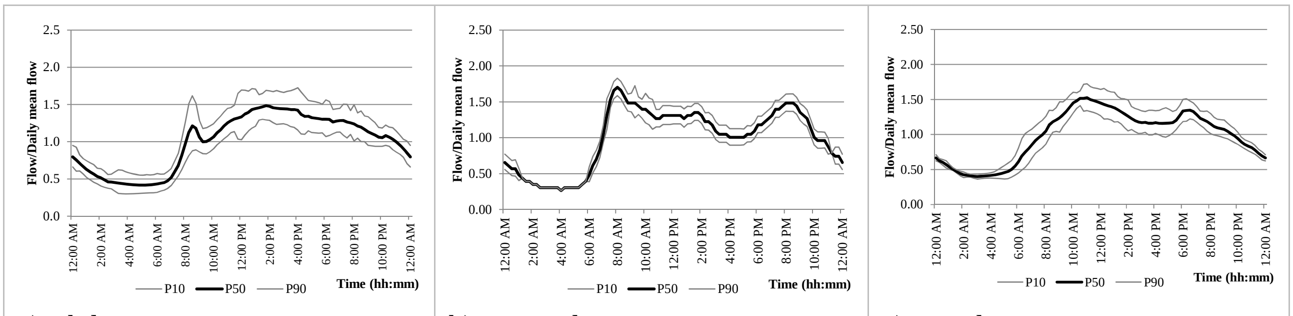


Figure 1. Case study network's scheme and elevation.

The network redesign was developed considering real demand patterns of daily workdays in Portuguese and Brazilian networks with similar characteristics. Figure 2 shows the dimensionless consumption patterns from the three systems of each country.



a) Chile b) Portugal c) Brazil

P10 – percentile 10; P50 – percentile 50; P90 – percentile 90

Figure 2. Dimensionless consumption patterns in networks of Chile, Portugal and Brazil.

The three demand patterns are referred mostly to domestic uses, nevertheless present very distinct behaviours. The pattern regarding the case study network, Chilean pattern, is characterized by two peak demands that occur at 8AM and 1PM. The other patterns also present two peak demands, the Portuguese at 8AM and 8PM, the Brazilian at 10AM and 6PM.

The hydraulic models developed to support this analysis were based on reliable GIS' data (geographic information system), SCADA (supervisory control and data acquisition) and billing system. For each modelling simulation it was considered the demand pattern of each country with a 15 minutes time step.

The WDS redesign according to each country rules presents some differences regarding pipes' diameters when comparing the Chilean real network with the Portuguese and Brazilian networks (Figure 3).

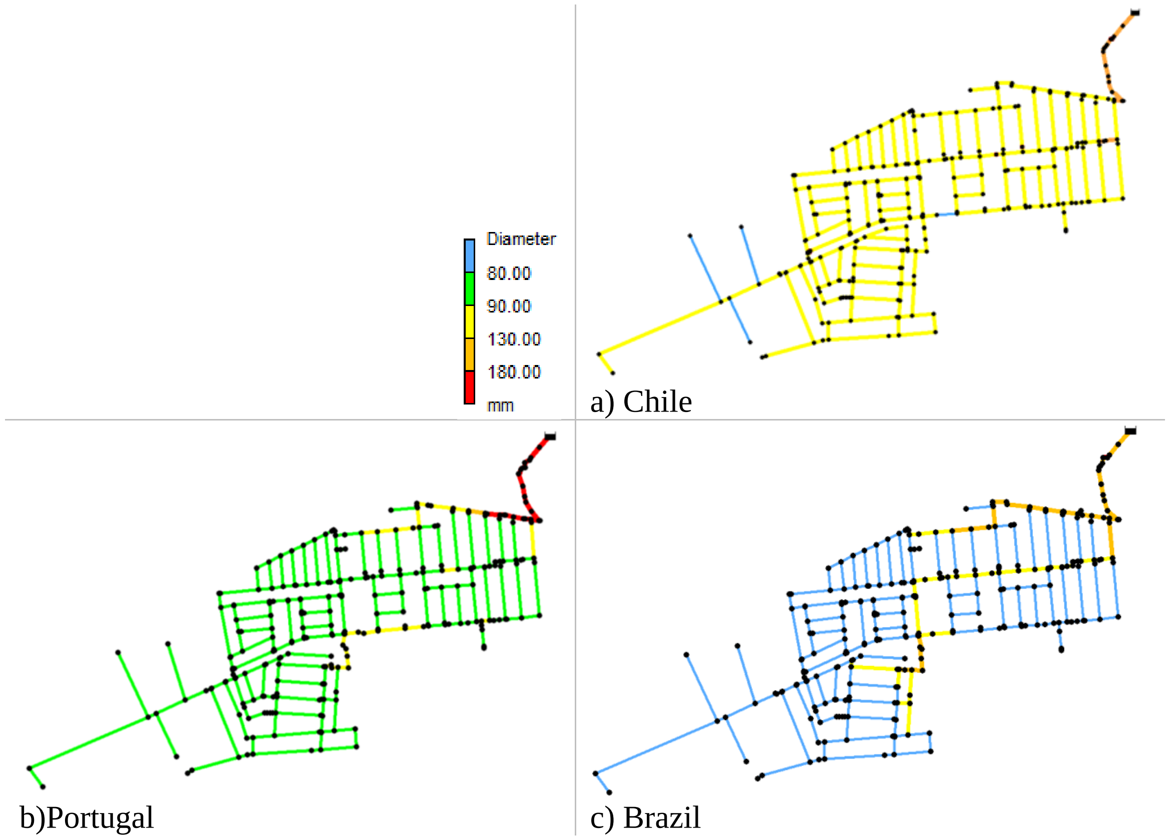


Figure 3. Diameters comparison in the Chilean, Portuguese and Brazilian networks.

Approximately, 90% of the Chilean and Portuguese networks present DN110 and DN90, respectively while 73% of the Brazilian network is in DN63 (Figure 4).

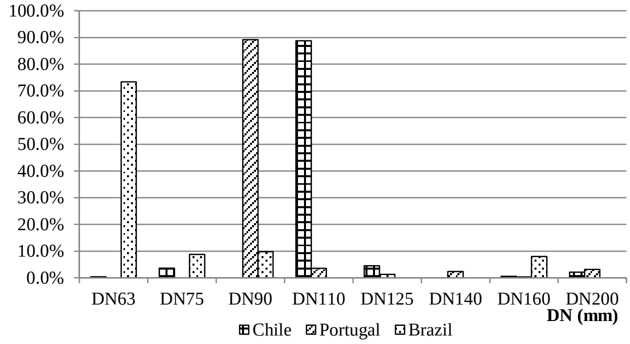
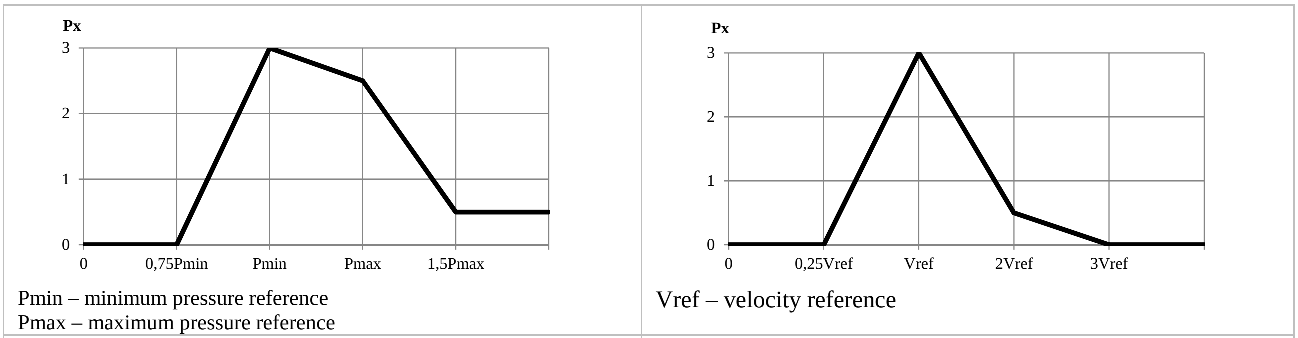


Figure 4. Diameters distribution in the Chilean, Portuguese and Brazilian networks.

WDS analysis based on performance

The performance analysis was supported by pressure and velocity indexes (Px) based on performance functions (Alegre and Coelho, 1992). Figure 5 presents the performance functions of pressure (Figure 5 a)) and velocity (Figure 5b)) used to evaluate the network.



a) Pressure performance function | b) Velocity performance function

Figure 5. Pressure and velocity performance functions.

According with these functions lower Px values indicate poor performance level while higher values correspond to higher performance levels. The three networks were evaluated assuming the references of pressure and velocity presented in Table 2.

Table 2. Reference values of pressure and velocity.

Variable	Reference values
Pmin	20 mc.a.
Pmax	70 mc.a.
Vref	0.6 m/s

Maximum and minimum pressure (Px_{max}, Px_{min}) and velocity (Vx_{max}, Vx_{min}) indexes were evaluated at lower and higher consumption hours according to each country demand patterns considering three different scenarios: a) A - normal operation; b) B - normal operation plus fire flow demand of 15 l/s in a specific point of the network, corresponding approximately to the fire-flow consider in Chile and Portugal for networks with minimum fire risk level; c) C - global demand increasing considering a duplication of the average flow. Table 3 presents Px results for scenario A, B and C.

Table 3. Px results for scenarios A, B and C.

Px	Scenario A			Scenario B			Scenario C		
	Chile	Portugal	Brazil	Chile	Portugal	Brazil	Chile	Portugal	Brazil
Px_{max}	2.89	2.89	2.89	2.92	2.90	2.95	2.90	2.89	2.89
Px_{min}	2.91	2.92	2.91	2.57	2.86	0.73	2.10	2.57	2.07
Vx_{max}	2.90	2.93	2.92	2.64	2.62	2.15	2.57	2.45	2.39
Vx_{min}	0.61	0.85	1.05	0.85	1.17	1.75	1.06	1.49	1.94

In scenario A, normal operation, the three networks present very similar results regarding Px_{max}, Px_{min} and Vx_{max} with values above 2, meaning that the hydraulic performance is good. Higher differences are in Vx_{min} where Chilean and Portuguese networks present the lowest performance ($Vx_{min\ Chile}$ = 0.61 and $Vx_{min\ Portugal}$ = 0.85). This result is due to the firefight requirements of the design codes which obliges the use of minimum diameters in Chile and Portugal higher than in Brazil.

In scenario B, results show that for a fire-flow of 15 l/s, the Brazilian network cannot entirely respond to minimum pressure references, presenting a Px_{min} equal to 0.73 and below 1. On the other hand, as expected, all three networks present higher Vx_{min} than in scenario A.

In scenario C all networks present very similar regarding Px_{max} when compared with scenario A. The hydraulic performance of Px_{min} and Vx_{max} slightly decreases, nevertheless presents values above 2 which can be considered a good performance level. Additionally, in scenario C all networks increase their performance of minimum velocities, Vx_{min}, however their value is still below 2 meaning that some parts of the networks maintained low-flow conditions, which can lead to water quality deterioration. In the three countries it's important to analyse the systems and define operational procedures including discharges practices in specific points of the network that can minimize water quality problems.

CONCLUSIONS

Planning long term investments under a sustainable basis requires a deep knowledge of systems and its evolving contexts. This requirement is an important challenge for a Group that manages utilities in different countries where mandatory or normative design procedures and codes can be very distinct.

In the case study the application of design codes from Portugal and Brazil in a real Chilean network was analysed. Results show that design codes in the considered countries lead to different networks. In Chile and Portugal firefight requirements oblige the application of minimum pipes' diameters while in Brazil this rule is only applied in networks with demands above the case study system. Despite these differences all three networks present a very similar hydraulic performance in terms of pressure and velocity.

Three scenarios were analysed, normal operation, firefight situation and a global demand increasing. In a scenario of normal operation all networks present low-flow conditions that can lead to water quality deterioration obliging utilities to implement operational procedures to minimize this problem. In a firefight situation it became clear that, in this case study, the network design according with Brazilian codes doesn't have capacity to guarantee minimum pressure requirements. In a scenario of global demand increasing all networks present a good resilience level, maintaining a similar performance to a normal operation scenario.

From an holding's perspective the work developed enabled a benchmarking process between WDS and promoted a better understanding of differences regarding design procedures and its impact on systems' performance. The results are very important to support IAM policies inside the Group providing valuable information and contribution to a more effective sustainable management. It was important to acknowledge, as well, that, in the case study considered scenarios, the differences between the three countries were not relevant enough to promote distinguished approaches in the IAM policy that should be promoted in an aligned and standardized way within the Group.

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