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Urban water demand: Metropolitan aqueduct of Mérida. Some thoughts about the demand value

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Abstract: The estimation of water demand for urban water supply can be a complex procedure. Depending on project requirements, it shall achieve a sufficiently high degree of precision to enable sound- resource- use planning at multiple levels. This paper demonstrates the application of the Component- Based Methodology for the Metropolitan Aqueduct of Mérida, Venezuela. Several considerations are raised for planners within hydrological agencies as well as design engineers in general.

Key words: urban supply; water demand; demand forecasting; component methodology; planning

1 Introduction

Interest in studying water demand functions for urban use has grown in recent years, all with the aim of finding a way to minimize costs and achieve efficient water consumption, as well as establishing a better distribution among the different demands that make up the total domestic water demand, so as to make the charge for the resource much more equitable.

There are no simple guidelines for selecting the water- demand estimation method to be adopted. Therefore, the selection of such a method requires a balance among the following factors:

· The desired level of precision

· The cost of achieving this level of precision

· The additional benefits derived from a higher level of precision

This article presents, as a case study, the urban water demand of the Metropolitan Aqueduct of Libertador Municipality, Mérida State, Venezuela, which is estimated using the Component- Based Methodology. It also offers several insights regarding the influence of residential garden irrigation water on total urban water demand.

2 Estimate of water demand for urban supply

According to Cetron (1969), "Technological forecasting is defined as a prediction, with a given confidence level, of a technological achievement within a specified time frame and under a particular level of support."

As Whitford (1970) observes, this definition is not particularly useful for drinking- water- supply estimations, because this is a relatively unsophisticated technique. The same author points out that, at present, it is hard to find any example in which a meaningful confidence level can be stated for drinking- water- supply estimation work.

When discussing projection, it is generally regarded as one of the basic estimation tools. Projection may be defined as "a graphical or algebraic extrapolation of the past values of a variable, intended to predict its value for a given future time." (Whitford, 1970)

In light of the foregoing, the following question must necessarily be raised: "Why is estimation necessary?" — in this specific case, for urban- water- supply demands.

Billings and Jones (1996) have attempted to answer this question, pointing out the importance of carrying out water demand estimations and their economic repercussions on the expansion plans of supply systems, as well as the influence they may have on the design of resource conservation plans, among other no less important aspects.

Numerous methods exist for estimating water demand. The selection of these methods depends on factors such as the analyst's technical expertise, the available data, and the resources available for the estimation process. Most estimation techniques use statistical assessments of per capita (or per user) water usage rates. (Billings and Jones, 1996)

3 Demand estimation by the component method

The methodology, as indicated in the report prepared for HIDROVEN by Azpúrua (1993), is based primarily on the concept of the urban center as a consequence of an economic, administrative, or service-oriented phenomenon. With the possible exceptions of commuter towns or extra-urban industries, the urban center provides employment for its residents and surrounding areas. Consequently, this center will contain not only residential activities but also commercial and service activities, industrial activities, and public and educational activities.

In addition, each urban center has distinctive characteristics, such as climate, irrigation demand, housing types, medical and healthcare facility indices and services, to name a few, which must be taken into account when estimating the water demand of a particular urban center.

According to the aforementioned report, the water demand of urban centers will be calculated based on: the activities of their inhabitants, characteristic urban parameters and unit allocations.

This paper does not provide a detailed explanation of this demand estimation methodology; it simply presents estimated water demand values for urban supply based on this methodology. As an additional contribution, the estimation of a factor considered important to take into account as a component of demand is presented, namely water losses in the network, without entering into a greater description of the method for estimating these.

4 Water losses in the network

This value can turn out to be highly subjective and depends on the physical condition of the distribution network. Losses in networks are generally estimated at between 12% and 20%. The current global trend is to express losses in terms of the Loss Index, which has been extensively studied and characterized for urban supply networks worldwide.

This index varies according to the level of operation and maintenance of the system considered, although it may also vary depending on the physical and orographic characteristics of the terrain, road traffic characteristics, among other factors.

Experts, in order to establish parameters for estimating losses in networks, adopt the term "Non-Revenue Water" (NRW).

According to the United States Agency for International Development (USAID), Non-Revenue Water is composed of the following aspects: (Farley et al., 2008)

- Authorized but Unbilled Consumption
- Apparent Losses
- Actual Losses

To obtain the water demand using this method, it is done by adding up each of the individual components.

The demand value obtained using this methodology is useful for large-scale planning of urban water supply systems, as it provides approximate values for the quantities of water needed to meet the demands of this important service. This allows for a general estimation of the dimensions of the main components of a water supply system (water treatment plants, storage facilities, main feeders).

5 Case study

The analysis of demand of the City of Mérida, Libertador Municipality, in the state of Mérida, Venezuela, is presented as a case study, in accordance with the methodology set out.

The following parishes are excluded from the analysis: Arias, El Morro, Jacinto Plaza and Los Nevados, since these are not supplied by the Metropolitan Aqueduct of Mérida under the responsibility of the Hydrological Company Aguas de Mérida, C.A.

The data necessary for the calculation are summarized in Tables 1 and 2. The information presented corresponds, in part, to values extracted from the XIII Annual Population and Housing Census, carried out in 2001. (INE 2001) It is important to clarify that not all the information required for the demand analysis using this methodology is available in the data recorded by the National Institute of Statistics, since the Institute no longer measures certain necessary variables, such as the composition of the workforce in the productive sectors (Primary, Secondary and Tertiary) for the application of the analysis proposed by Azpúrua (1993), so some values extracted from the Report presented by the aforementioned engineer at that time are used.

Table 1 shows the total population for the parishes considered, according to the 2001 Census. Table 2 reflects, according to the 2001 Census, the housing composition for the parishes included in the case study.

Given that the statistical information consulted is limited, or not available, in relation to the estimation methodology developed, some parameters, such as the percentage of the economically active population, grouped under the term "Dispersed Industry" and "Concentrated Industry", were extracted from the report presented to Hidroven by Azpúrua (1993) according to his estimates for the year 2000. In the case of the value of Floating Population, it is calculated based on the population residing in hotels or similar.

Table 1. Population, by Parish, in the Libertador Municipality, Mérida State

Municipality	Parish	Population
Libertador	Antonio Spinetti Dini	26,463
	Caracciolo Parra Pérez	10,611
	Domingo Peña	21,188
	El Llano	9,953
	Gonzalo Picón Febres	5,466
	Juan Rodríguez Suarez	15,073
	Lasso De La Vega	12,559
	Mariano Picón Salas	15,253
	Milla	20,861
	Osuna Rodríguez	19,335
	Sagrario	6,644
Total		**163,406**
[Source: INE (2001)]		

Table 2. Housing composition in the Libertador municipality, Mérida State

Housing Type	Percentage
Quinta	0.06%
Casa	46.71%
Apartamento	51.54%
Rancho c/s	0.41%
Rancho Evol	1.04%
Rancho s/s	0.24%
Total	**100.00%**
[Source: INE (2001)]	
Note: Rancho Evol: Upgraded informal dwellings with block- constructed walls and sanitary services Rancho s/s: Informal dwellings without sanitary services	

Table 3 presents a summary of the data entered into the program for estimating urban demand for this case study.

Regarding the estimation of physical losses, according to the Diagnostic Report prepared by TAHAL Consulting Engineers, LTD (1998), the losses correspond to 20% of the total demand, that is, a Loss Augmentation Factor of 1.20.

Table 3. Summary of data for calculating demand

Parameter	Value	Source
Housing composition	(See Table 2)	INE, 2001
EAP percentage	40.4	INE, 2001
Floating- population percentage	3	Azpúrua, 1993
Student- population percentage	40.9	INE, 2001
% of Sector II within the EAP	20	Azpúrua, 1993
% of Sector III within the EAP	79	Azpúrua, 1993
Concentrated- industry (IC) percentage	30	Azpúrua, 1993
Deconcentrated- industry (ID) percentage	70	Azpúrua, 1993
Climate	Type 1	Azpúrua, 1993
Industrial level	Type C	Azpúrua, 1993
Development level	Level 2	Azpúrua, 1993
Note: EAP: Economically Active Population IC: Concentrated Industry ID:ID: Deconcentrated Industry		

6 Results

Applying the methodology described, the results are obtained, by components, shown in tabulated form in Table 4.

Azpúrua (1993) reported an average demand value of 249 L/cap/d for the city of Mérida in 1990, excluding network losses. Through linear extrapolation, this value reaches 257 L/cap/d for the year 2000.

Based on the data for the year 2001, the calculated demand value, excluding network losses, is 262.46 L/cap/d, as shown in Table 4. In this case, population, housing- composition and student- population data were extracted from the XIII Population and Housing Census. Therefore, the 2001 demand value is regarded as adjusted to the real- world conditions of the urban core selected for the case study, despite difficulties in obtaining the information required for applying the methodology.

TAHAL (1998) estimated a demand of 481 L/cap/d for the year 2000, based on field measurements and their own projections. On the other hand, according to Mora et al. (2006), the average consumption for the city of Mérida in 2003, excluding physical losses, amounted to 310 L/cap/d. This value is also higher than the theoretical value calculated by applying the component- based method.

The above implies that the theoretical demand does not match the actual demand observed in the city. Hence, it is important to have tools that enable simple, rapid and efficient estimation of these key parameters.

For example, the influence of irrigation water allowance on domestic demand has been verified for the case study. To this end, all coefficients were kept as constant parameters, except for the recommended irrigation allowance for residential gardens and green areas. According to Table 5, this baseline value is 0.58 L/m²/d for the present case. The demand was then calculated by varying this irrigation allowance, which took the following values (in the same units): 0.5, 2.0, and 2.25.

Table 4. Demand estimation results using the Component-based Method

Characteristics of the study site	
Housing Composition (%)	
Country estates	0.06
Single-family houses	46.71
Apartments	51.54
Serviced informal dwellings	0.41
Unserviced informal dwellings	0.24
Upgraded informal dwellings	1.04
Socio-Economic Data (%)	
Economically Active Population (EAP) (%)	40.4
Floating-population (%)	3
Student-population (%)	40.9
Industrial Development Level	
Percentage of Sector II within the EAP	20
Percentage of Concentrated Industry (IC)	30
Percentage of Deconcentrated Industry (ID)	70
Percentage of Sector III within the EAP	79
Data for Network Loss Calculation	
Loss Augmentation Factor	0
Network density (m/cap)	0
Linear Loss Index (L/m/d)	0
Demand Results (L/cap/d)	
Domestic demand	159.94
Commercial-service demand	25.21
Public-educational demand	31.4
Industrial demand	31.51
Floating-population demand	14.4
Sub-total demand	262.46
Demand for network-loss compensation	0
Total urban demand	262.46

Table 5 summarizes the total-demand results for each component, derived from the above-mentioned analysis.

Table 5. Demands for different garden irrigation allowances

Irrigation allowance (L/m²/d)	0.5	0.58	2	2.25
Domestic demand (L/cap/d)	159.63	159.94	165.6	166.6
Commercial-service demand (L/cap/d)	25.21	25.21	25.21	25.21
Public-educational demand (L/cap/d	31.4	31.4	31.4	31.4
Industrial demand (L/cap/d)	31.51	31.51	31.51	31.51
Floating-population demand (L/cap/d)	14.4	14.4	14.4	14.4
Sub-total demand (L/cap/d)	262.15	262.46	268.12	269.12
Network-loss compensation demand (L/cap/d)	0	0	0	0
Total urban demand (L/cap/d)	262.15	262.46	268.12	269.12

As can be observed and logically expected, as the irrigation allowance increases, the domestic demand rises, while the remaining demand- components remain constant. This occurs because irrigation water use in this model only affects the domestic- demand component.

Taking the domestic demand under an irrigation allowance of 0.58 L/m²/d as the central value (100 %), the percentage curve presented in Figure 1 was generated. A straight- line fit was applied to this curve, and the fitted equation is shown in the figure.

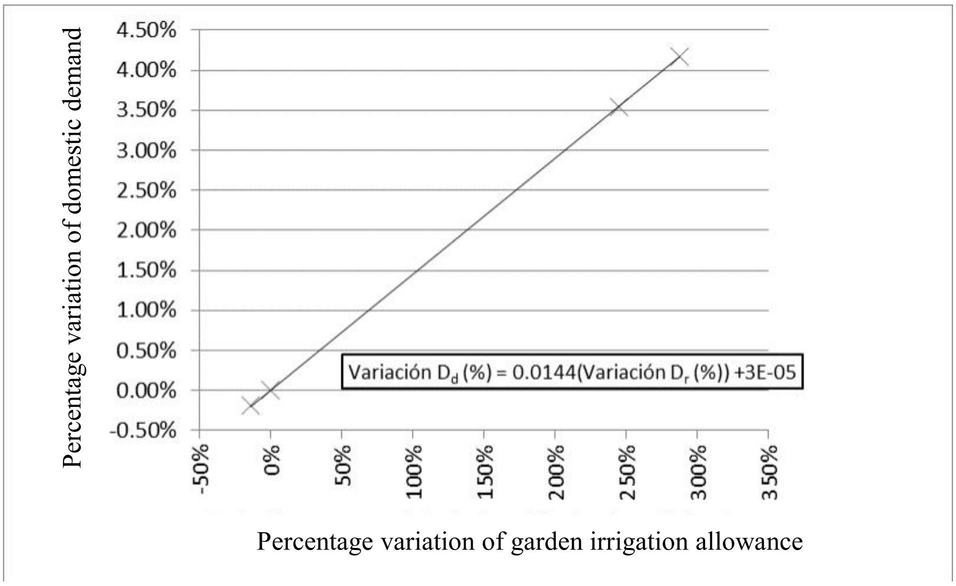

Figure 1. Percentage variation of domestic demand as a function of percentage variation in garden irrigation allowance

Note: D_d: Domestic- household water demand; D_r: Garden irrigation water demand.

It can be concluded from the previous figure that the change in domestic demand with respect to garden irrigation allowance is very small. That is, even when the irrigation allowance is tripled (an increase of 300 %), the rise in domestic demand does not exceed 4 %.

In other words, according to the fitted equation, to achieve a considerable increase in domestic demand, for example of 10 %, the garden irrigation allowance would need to be increased by approximately 1,400 %.

The above- mentioned findings are supported by Baumann et al. (1998), who discuss the "myth of excessive irrigation on residential lots". Based on studies carried out in California, USA, they demonstrate that residential users rationally use water for garden irrigation; their actual irrigation volumes are even lower than the theoretical water requirements of the plant species planted in home gardens.

The author also points out that in the eastern region of the United States, where rainfall is sufficient to sustain residential green areas, irrigation water is only occasionally used for these green spaces during summer.

In accordance with the above- mentioned analysis, it can be stated that excessive water consumption for garden and green- area irrigation—which is also commonly used for vehicle washing as part of domestic demand—does not significantly affect the overall magnitude of domestic demand.

In the case of rural water- supply systems, where water from the distribution network is commonly used for crop irrigation, the foregoing statement may not hold true. Firstly, the area allocated for irrigation is considerably larger. Furthermore, it should be noted that crop irrigation demand can be estimated at approximately 1 L/s/ha, which equals 8.46 L/m²/d. These two factors directly affect the "Domestic Demand" component and may increase its magnitude for rural water- supply systems.

In the case of Mérida city, given its local characteristics, after domestic demand, the largest-magnitude demand component is industrial demand, followed by public-educational demand, and commercial-service-sector demand.

In addition, the influence of physical water losses on total demand is analysed, assuming that all other demand components remain constant. That is, suppose that the manager of the water utility, or any other practitioner, estimates a given demand value for a city —for example, 600 L/cap/d for Mérida city— together with an estimated loss-augmentation factor of 20 %.

With the demand-components kept constant, the network-loss value can be easily estimated using a spreadsheet. Losses can be expressed either in L/cap/d or as an index.

As an illustration of this, Table 6 presents different values obtained by alternative loss-estimation methods for an estimated total demand of 600 L/cap/d, which are compared against the baseline values of the case study.

Table 6. Estimation of network losses for a given total demand

Data for calculation of network losses	**Case study**	**Loss-augmentation factor**	**Density ＞20 connections/km**	**Density ＜20 connections/km**	**Density ＜20 connections/km**	**Density ＜20 connections/km**
Loss-augmentation factor	1.2	2.3				
Network density(connections/capita)			0.17	0.17		
Loss index(L/conn/d)			309	1,985.50		
Percentage-based loss index					20	128.61
Linear loss index(L/m/d)						
Demand-calculation results (L/cap/d)						
Domestic demand	159.94	159.94	159.94	159.94	159.94	159.94
Commercial-service demand	25.21	25.21	25.21	25.21	25.21	25.21
Public-educational demand	31.4	31.4	31.4	31.4	31.4	31.4
Industrial demand	31.51	31.51	31.51	31.51	31.51	31.51
Floating-population demand	14.4	14.4	14.4	14.4	14.4	14.4
Sub-total user demand	262.46	262.46	262.46	262.46	262.46	262.46
Network-loss demand	52.49	337.54	52.53	337.54	52.49	337.54
Total urban water demand	314.95	600	314.99	600	314.95	600
Note:	Note: L/conn/d = Litres per connection per day; L/m/d = Litres per metre of pipeline per day.					

According to our case study, keeping the data values shown in Table 4 and assuming an initial loss-augmentation factor of 1.20 for a total population of 176, 250 inhabitants, the network losses are estimated at 107.08 L/s.

However, for a fixed water allocation of 600 L/cap/d, the loss-augmentation factor changes to 2.3. That is, network losses account for 130 % of the subtotal of demand components, which yields a flow rate of 688.6 L/s attributed solely to network losses.

Losses of approximately 20 % of the demand subtotal would equal 309 L/conn/d under the conditions where the connection density per kilometre of feeder pipeline is less than 20, and the overall average connection-per-capita density defined for the city of Mérida is 0.17. That is, 309 litres are lost each day for every connection to the main feeder pipeline.

Based on the above-mentioned analysis of network losses, this paper aims to highlight the significance of network losses as a component of urban water demand. Losses can account for substantial volumes of treated water. Among other consequences, this constitutes forgone revenue for the water utility company. Such lost income could otherwise be invested, for instance, in infrastructure projects to improve water-supply services.

The analyses presented in the preceding paragraphs are of particular interest to urban planners and water- supply utilities. If the percentage composition of total demand by its individual components is well understood, it becomes possible, among other things, to plan urban growth as an integrated socio- cultural and economic centre. It allows anticipating water- resource requirements for each sector, as well as the theoretically estimated water consumption volumes of the studied urban area.

7 Conclusion

It has been demonstrated by means of the component- based method that excessive irrigation- water consumption does not significantly affect urban domestic water demand. Nevertheless, this conclusion is not necessarily valid for rural water supply systems.

For urban planners, having a tool capable of rapidly evaluating potential growth scenarios for urban water demand is of great importance. It enables them to make sound decisions concerning various future investment plans, among other matters.

Given their inherent complexity, this paper does not aim to define the managerial rules that should prevail within a water- supply utility for developing operational plans for future demand assessment. Instead, it merely presents a tool that can swiftly quantify the potential outcomes generated by such operational plans.

Regarding demand estimation using the component- based method, it is worth emphasizing that the statistical data required for its implementation are not fully available in this country. Therefore, as a further research direction, it is recommended to adjust the parameters adopted in this methodology for urban- area demand estimation according to available local data.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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