Design and simulation of an alternative aqueduct network for urban population

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Abstract. Aqueduct systems help to record water consumption, being a connection between nature and the population, allowing water to be transported continuously; a good design of aqueduct networks is necessary to meet the purpose of providing the community with a technical report that can serve as a starting point to carry out a construction of the aqueduct for the public battery. This research presents the simulation of an aqueduct system by means of the epanet software according to the daily maximum flow, pressure, velocities of the distribution network, pumping time, with respect to the different pressures and diameters, diagnosing the routes, nodes, forms of access, restrictions and limitations that may affect the proper functioning of the system; In this way, the advantages and the magnitude of beneficiaries who will have this new access and improved service to meet the needs of the inhabitants are evident, according to the technical requirements of drinking water and sanitation of the technical regulation of the drinking water and basic sanitation sector, where it can be implemented by any public company in the country.

1. Introduction

Internationally shared, or transboundary, groundwater resources have long played an important role in sustaining human needs for water, e.g. agriculture and other uses, and natural ecosystems [1]. The best example in the history of city planning and administration is ancient Rome; because of its scale, the water supply system of ancient Rome is considered an outstanding achievement of hydraulic and civil engineers [2]. Approximately 43% of the world's irrigation water consumption is groundwater and groundwater is the main source of drinking water for some 2 billion people worldwide [3].

One of the biggest difficulties are the concrete cracks, mainly the temperature cracks on the surface or through the body of the aqueduct, adding the mechanism of damage and fracture of the concrete material, the temperature load during construction is very complicated and must be treated carefully and properly [4]. For this reason, some technical aspects that are needed in the aqueduct are the capacity, pressure and speed, being relevant for the safety level of the pipe, because it is high due to the influence of the pressure in the pipe [5].

In early 2018, Cape Town faced a potential water supply disaster, partly associated with a long-term drought, but also caused by population growth and lack of foresight in planning water supply infrastructure [6]. In the United States, 50% of the 39,000 hydraulically fractured wells that consumed 100 billion gallons of water are found in areas of high or extremely high water stress, i.e., semi-arid regions or regions with low precipitation [7].

In Colombia, in spite of having abundant hydraulic sources, its population faces increasing difficulties in accessing potable water, to the point that it is estimated that by 2025, 69% of the population could face a severe liquid shortage; approximately 22 million Colombians consume water
of poor quality, unsuitable [8]. The country's aqueduct systems present difficulties to reach each case due to the low investment and maintenance of the pipes and instruments of the aqueduct system, so this research would be available to the country's public service.

This article presents the design of an aqueduct system for the urban settlement in the municipality of San José de Cúcuta, Norte de Santander, Colombia, in the Antonia Santos neighborhood, through the epanet 2.0 simulation program to provide the community with a technical report for the construction of the aqueduct, this should be a worldwide approach, to make drinking water more accessible to those regions lacking this vital liquid.

This model performs simulations of the extended period of the hydraulic response of the system, forecasting the evolution of flows and velocities inside the pipes, the variations in pressure at the points of demand, the levels in the tanks, including the proportion of concentration of any circumstance at any point in the network over time and determining the time the water remains in the network as its point of origin from the different points of supply [9].

2. Methodology
The project was carried out in the municipality of San José de Cúcuta, Norte de Santander, Colombia, community of Antonia Santos, beginning with the collection of information from a census conducted for public services [10], knowing the capacity that the system must have to design and the scope of the number of beneficiaries; in addition, aqueduct design information was collected: pressures, velocities in the distribution network, pumping time, adding to this a design alternative in the epanet simulation program for a future population of 5% of the current population 7959 inhabitants, with the design parameter of the maximum daily flow; according to the indications of the manuals with norms for the development of the project: RAS (technical regulation of the potable water and basic sanitation sector) 2000 [11].

3. Result and discussion

3.1 Design flow rate
The maximum daily flow (QMD) corresponds to the maximum consumption recorded over 24 hours over a period of one year represented in Equation (1), where QMD is the average daily flow by the maximum daily consumption coefficient; for this case, pumping is to a 24-hour storage tank as in the case of this research article, resulting in 22.11 liters/second.

\[ QMD = Qmd \times K1 \]  

(1)

3.2 Pressures
Table 1 illustrates the minimum pressures in the distribution network, in this case the minimum pressures for the high level of complexity that is handled for the city of San José de Cúcuta, Norte de Santander, Colombia, should be 15 mwc and the maximum should be 50 mwc but due to the topographic conditions of the settlement, to guarantee the service to the inhabitants of the highest part of the settlement, the inhabitants of the lowest part of the settlement are affected, due to the fact that there are pressures higher than the maximum allowed, which is why it is necessary to have pressure reducing valves in these areas.

| Level of complexity | Minimum pressure (kPa) | Minimum pressure (m) |
|---------------------|------------------------|----------------------|
| Low                 | 98.1                   | 10                   |
| Medium              | 98.1                   | 10                   |
| Medium high         | 147.2                  | 15                   |
| High                | 147.2                  | 15                   |
3.3 Speeds in the distribution network

The speeds of the distribution network in this project are limited to the values established in SAR 2000[11], where the maximum speed is 1.5 m/s to 2 m/s and the minimum speed is 0.5 m/s. It must be taken into account that, if some velocities give less than 0.5 m/s, these pipelines will be able to meet future demands.

Table 2. Network-Nodes.

| ID     | Node | Height (m) | Base Demand (LPS) | Demand (LPS) | Height (m) | Pressure (m) |
|--------|------|------------|-------------------|--------------|------------|--------------|
| Connection 2 | 347.25 | 0.00       | 0.00              | 369.66       | 22.41      |
| Connection 3 | 341.77 | 0.64       | 0.64              | 367.32       | 25.55      |
| Connection 4 | 305.00 | 0.47       | 0.47              | 367.23       | 62.23      |
| Connection 5 | 348.31 | 0.66       | 0.66              | 367.26       | 18.95      |
| Connection 6 | 343.11 | 1.80       | 1.80              | 366.55       | 23.44      |
| Connection 7 | 310.59 | 0.20       | 0.20              | 357.14       | 46.55      |
| Connection 8 | 282.22 | 0.45       | 0.45              | 356.27       | 74.05      |
| Connection 9 | 272.07 | 0.20       | 0.20              | 356.10       | 84.03      |
| Connection 10 | 283.1  | 2.35       | 2.35              | 356.09       | 72.99      |
| Connection 11 | 275.09 | 0.55       | 0.55              | 356.07       | 80.98      |
| Connection 12 | 281.62 | 0.62       | 0.62              | 355.94       | 74.32      |
| Connection 13 | 303.35 | 0.88       | 0.88              | 356.83       | 53.48      |
| Connection 14 | 316.39 | 0.20       | 0.20              | 357.13       | 40.74      |
| Connection 15 | 322.43 | 0.77       | 0.77              | 358.21       | 35.78      |
| Connection 16 | 325.60 | 0.20       | 0.20              | 358.24       | 32.64      |
| Connection 17 | 309.26 | 3.42       | 3.42              | 356.99       | 47.73      |
| Connection 18 | 333.07 | 0.26       | 0.26              | 359.55       | 26.48      |
| Connection 19 | 323.86 | 0.31       | 0.31              | 359.30       | 35.44      |
| Connection 20 | 330.26 | 0.91       | 0.91              | 363.22       | 32.96      |
| Connection 21 | 338.82 | 1.32       | 1.32              | 363.21       | 24.39      |
| Connection 22 | 352.06 | 1.21       | 1.21              | 365.44       | 13.38      |
| Connection 23 | 352.13 | 0.70       | 0.70              | 365.45       | 13.32      |
| Connection 24 | 341.48 | 1.07       | 1.07              | 362.90       | 21.42      |
| Connection 25 | 323.40 | 0.57       | 0.57              | 364.96       | 41.56      |
| Connection 26 | 314.69 | 0.24       | 0.24              | 364.87       | 50.18      |
| Connection 27 | 301.95 | 0.77       | 0.77              | 364.67       | 62.72      |
| Connection 28 | 288.49 | 0.56       | 0.56              | 356.23       | 67.74      |
| Connection 29 | 323.24 | 0.27       | 0.27              | 362.33       | 39.09      |
| Connection 30 | 323.24 | 0.27       | 0.27              | 362.33       | 39.09      |
| Connection 31 | 270.00 | 0.00       | 0.00              | 304.91       | 34.91      |
| Connection 32 | 270.00 | 0.00       | 0.00              | 305.00       | 35.00      |
| Connection 33 | 270.00 | 0.00       | 0.00              | 371.56       | 101.56     |
| Connection 34 | 270.00 | 0.00       | 0.00              | 370.68       | 100.68     |
| Connection 35 | 270.00 | 0.00       | 0.00              | 370.68       | 100.68     |
| Reservoir 1  | 370.00 | NA         | -20.95            | 370.00       | 0.00       |
| Reservoir 30 | 305.00 | NA         | -1.01             | 305.00       | 0.00       |

NA: Not available; m:meter, l: liter; s: second; mwc: meter of water column.

3.4 Pumping time
As stated in Ras 2000 title B.8.1 (Scope of pumping stations) [12], the capacity of the pumping station must be QMD if pumping is performed 24 hours. For this case, the pumping time used was 24 hours, for this time the model proposed in epanet complies.
| ID Line | Length (m) | Diameter (mm) | Roughness (mm) | Flow (LPS) | Speed (m/s) | Unitary loss (m/km) | Friction factor | Condition |
|---------|------------|---------------|----------------|------------|-------------|---------------------|----------------|-----------|
| Pipe 1  | 174.00     | 203.2         | 0.0015         | 21.96      | 0.68        | 1.94                | 0.017          | Open      |
| Pipe 10 | 155.18     | 76.2          | 0.0015         | 1.11       | 0.24        | 1.05                | 0.026          | Open      |
| Pipe 17 | 92.98      | 76.2          | 0.0015         | 1.34       | 0.29        | 1.46                | 0.025          | Open      |
| Pipe 20 | 1000.00    | 76.2          | 0.0015         | 0.18       | 0.04        | 0.03                | 0.032          | Open      |
| Pipe 22 | 1000.00    | 76.2          | 0.0015         | -2.03      | 0.45        | 3.03                | 0.023          | Open      |
| Pipe 33 | 99.46      | 76.2          | 0.0015         | 1.01       | 0.22        | 0.88                | 0.027          | Open      |
| Pipe 34 | 107.00     | 76.2          | 0.0015         | 0.00       | 0.00        | 0.00                | 0.000          | Open      |
| Pipe 37 | 100.00     | 76.2          | 0.0015         | 1.01       | 0.22        | 0.88                | 0.027          | Open      |
| Pipe 38 | 100.00     | 76.2          | 0.0015         | 0.00       | 0.00        | 0.00                | 0.000          | Open      |
| Pipe 39 | 764.43     | 76.2          | 0.0015         | 1.01       | 0.22        | 0.88                | 0.027          | Open      |
| Pipe 40 | 121.47     | 203.2         | 0.0015         | 21.96      | 0.68        | 1.94                | 0.017          | Open      |
| Pipe 41 | 349.81     | 76.2          | 0.0015         | 0.47       | 0.10        | 0.24                | 0.033          | Open      |
| Pipe 42 | 218.54     | 304.8         | 0.0015         | 20.85      | 0.29        | 0.25                | 0.019          | Open      |
| Pipe 43 | 124.44     | 76.2          | 0.0015         | 4.90       | 1.08        | 14.54               | 0.019          | Open      |
| Pipe 44 | 124.44     | 76.2          | 0.0015         | 4.90       | 1.08        | 14.54               | 0.019          | Open      |
| Pipe 45 | 182.61     | 254           | 0.0015         | -5.95      | 0.12        | 0.06                | 0.024          | Open      |
| Pipe 46 | 246.14     | 76.2          | 0.0015         | 1.58       | 0.35        | 1.95                | 0.024          | Open      |
| Pipe 47 | 98.19      | 76.2          | 0.0015         | 1.01       | 0.22        | 0.89                | 0.027          | Open      |
| Pipe 48 | 353.38     | 76.2          | 0.0015         | -0.77      | 0.17        | 0.56                | 0.029          | Open      |
| Pipe 49 | 355.12     | 152.4         | 0.0015         | 10.38      | 0.57        | 2.01                | 0.019          | Open      |
| Pipe 50 | 965.63     | 76.2          | 0.0015         | 3.92       | 0.86        | 9.74                | 0.020          | Open      |
| Pipe 51 | 455.61     | 76.2          | 0.0015         | 1.56       | 0.34        | 1.91                | 0.024          | Open      |
| Pipe 52 | 336.74     | 76.2          | 0.0015         | 3.16       | 0.69        | 6.63                | 0.021          | Open      |
| Pipe 53 | 338.15     | 76.2          | 0.0015         | 3.16       | 0.69        | 6.64                | 0.021          | Open      |
| Pipe 54 | 324.58     | 76.2          | 0.0015         | -1.07      | 0.23        | 0.98                | 0.027          | Open      |
| Pipe 55 | 92.96      | 76.2          | 0.0015         | -0.39      | 0.08        | 0.17                | 0.035          | Open      |
| Pipe 56 | 249.72     | 76.2          | 0.0015         | 4.67       | 1.02        | 13.31               | 0.019          | Open      |
| Pipe 57 | 236.17     | 76.2          | 0.0015         | 2.3        | 0.50        | 3.78                | 0.022          | Open      |
| Pipe 58 | 212.65     | 76.2          | 0.0015         | 5.38       | 1.18        | 17.19               | 0.018          | Open      |
| Pipe 59 | 102.33     | 76.2          | 0.0015         | -1.82      | 0.40        | 2.49                | 0.023          | Open      |
| Pipe 60 | 182.06     | 76.2          | 0.0015         | 3.30       | 0.72        | 7.19                | 0.020          | Open      |
| Pipe 61 | 134.10     | 76.2          | 0.0015         | 3.54       | 0.78        | 8.12                | 0.020          | Open      |
| Pipe 62 | 207.77     | 76.2          | 0.0015         | 2.95       | 0.65        | 5.86                | 0.021          | Open      |
| Pipe 63 | 192.86     | 76.2          | 0.0015         | 2.93       | 0.64        | 5.79                | 0.021          | Open      |
| Pipe 64 | 190.31     | 76.2          | 0.0015         | 1.39       | 0.30        | 1.55                | 0.025          | Open      |
| Pipe 65 | 233.15     | 76.2          | 0.0015         | 0.87       | 0.19        | 0.68                | 0.028          | Open      |
| Pipe 66 | 398.20     | 76.2          | 0.0015         | 1.37       | 0.30        | 1.52                | 0.025          | Open      |
| Pipe 67 | 258.27     | 76.2          | 0.0015         | 0.81       | 0.18        | 0.61                | 0.029          | Open      |
| Pipe 68 | 323.93     | 76.2          | 0.0015         | -0.62      | 0.14        | 0.38                | 0.031          | Open      |
| Pipe 69 | 245.27     | 76.2          | 0.0015         | -0.36      | 0.08        | 0.15                | 0.036          | Open      |
| Pipe 70 | 309.45     | 76.2          | 0.0015         | 2.16       | 0.47        | 3.38                | 0.023          | Open      |
| Pipe 71 | 313.36     | 76.2          | 0.0015         | -0.19      | 0.04        | 0.04                | 0.035          | Open      |
| Pump 35 | NA         | NA            | NA             | 1.01       | 0.00        | -66.65              | 0.000          | Open      |
| Pump 36 | NA         | NA            | NA             | 0.00       | 0.00        | 0.00                | 0.000          | Closed    |

NA: Not available
3.5 Design alternative
The tank located in the neighborhood of Antonia Santos, city of San José de Cúcuta, Norte de Santander, Colombia, does not work, that is, it does not have the necessary water supply to supply the inhabitants of the subnormal settlement of Brisas del Mirador that is located in the neighborhood of Antonia Santos, city of San José de Cúcuta, Norte de Santander, Colombia. The company providing the service has a long-term project that consists of putting a network of 36 inches from where it simulated in epanet in order to supply the service to the inhabitants of the sector. The future conditions are simulated; in the modeling a reservoir is located, the height of the site, plus the pressure of the service, in the epanet program the reservoir is an inexhaustible source of water, in this way the condition is set to the program that in this place there will be one that will guarantee the water supply.

According to Table 2, a pressure reducing valve must be installed to reduce the pressures in the 4, 8, 9, 10, 11, 12, 13, 27 and 28 nodes, since they exceed a pressure of 53 m and the maximum condition was 50 mwc due to the level of complexity of the sector, while in Table 3, for the flow and wall coefficients, reaction speed and quality gave a value of zero, but some pipes have a velocity between 0 m/s and 1.18 m/s, not complying with the minimum permitted velocities of 0.45 m/s and maximum of 5 m/s.

3.6 Simulation
Figure 1 illustrates the simulation of the new aqueduct design for the Antonia Santos neighborhood in the city of San José de Cúcuta, Norte de Santander, Colombia, according to the pressure, diameter, nets and knots previously determined.

4. Conclusions
The supply of water available to all is a benefit that many countries and urban areas do not have, due to the poor design and construction of its aqueduct, causing it to be unaffordable or unfit for human consumption, an issue that occurs in the neighborhood of Antonia Santos, San Jose de Cucuta, Norte de Santander, Colombia, which has a population of 7959 inhabitants in this settlement area; There is a problem concerning the need for water supply that has affected them for years, living indignantly, even when a service is provided provisionally in a distribution network.
The scientific study yielded results by means of a census of the population, inspection of the terrain, and needs of the population, solid data for the design of the aqueduct of the Antonia Santos settlement, San José de Cúcuta, Norte de Santander, Colombia, obtaining that the maximum daily flow is 22.11 l/s, maximum design speed of the aqueduct is 1.5 m/s to 2 m/s and minimum speed of 0.5 m/s, using a pumping time of 24 hours. The minimum pressure level of 15 mwc and maximum of 50 mwc, but depending on the topographical conditions of the settlement we find high and low areas, which have more flow pressure than ideal, for this reason it is recommended to install pressure reducing valves in nine connections that have pressures greater than 50 mwc.

It is estimated that the future population will be 7959 inhabitants and 1896 dwellings, with an average daily flow of 18.42 l/s, a minimum daily flow of 11.05 l/s, a maximum daily flow of 22.11 l/s, a minimum hourly flow of 33.16 l/s, i.e. an estimated 200 l/inhabitant/day and a low density of 100 dwellings/hectare/inhabitant. With this simulation, it is expected to have information that contributes to the improvement of the living conditions of inhabitants of different sectors, being the basis of studies for public or private sector projects.

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