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ASSESSMENT OF WATER PUMPING SYSTEM AND IMPROVEMENT IN HYDRO-ENERGETIC PERFORMANCE

Augusto da Gama Rego[1*], Aline Christian Pimentel Almeida Santos[2] and José Almir Rodrigues Pereira[3]

[1] *Instituto Federal de Educação, Ciência e Tecnologia do Pará - Campus Tucuruí, Brazil*
[2] *Faculdade de Engenharia Sanitária e Ambiental da Universidade Federal do Pará, Brazil*
[3] *Núcleo de Altos Estudos da Amazônia, Programa de Doutorado em Engenharia de Recursos Naturais da Amazônia, Faculdade de Engenharia Sanitária e Ambiental, Universidade Federal do Pará, Brazil*

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Abstract: Within the policy of sanitation services for all and the need to lower electricity consumption, the current analysis evaluates the water pumping system and defines actions for the improvement of hydro-energetic performance. The present research was divided into two sections: assessment of the water pumping system (based on hydro-energetic simulation) and an analysis of the impact of inefficiency on electric energy consumption (based on computer simulation). Results revealed that methodology was satisfactory and that the main operational issues could be identified and corrections could be computer-simulated. A potential 16% reduction in consumption and in electricity costs could be obtained.

Keywords: Performance; electrical energy-consumer; hydraulic; water supply.

[*] Correspondence to: Augusto da Gama Rego. E-mail: augusto.rego@ifpa.edu.br

INTRODUCTION

Owing to the great expansion of water supply services in Brazil (following Federal Law 11.445/2007), an increasing trend in electric energy may be observed, estimated at 10 billion kWh/years, or between 2 and 3% of the total consumption in the country (Pereira & Condurú, 2014; Gomes & Carvalho, 2012). Equilibrium between water supply and electric energy is mandatory in the wake of current energy crisis in Brazil, triggered by low water levels in water reservoirs throughout the country and the unsustainable use of water resources (Galvão & Bermann, 2015; Rego *et al*., 2013).

The alternatives for energy efficiency in conventional water supply systems are the well-known technologies widely reported in the literature (Vilanova & Balestieri, 2014). Based on data retrieved from the SCADA systems, electric energy cutbacks may vary between 10% and 50% according to control strategies and optimized operations, and they may even reach 70% with frequency inverters instead of throttle valves (New York State, 2010; Jamieson *et al*., 2007; Zhang *et al*., 2012).

A slight increase in efficiency caused by pumping optimization may cause significant savings in electric energy and expenses (Giustolisi *et al*., 2012). However, modeling operational optimization problems in water supply systems is highly difficult since it involves discrete and continuous variables and the incorporation of closed networks and temporary couplings throughout planning (Burgschweiger *et al*., 2009). Further, optimization is frequently not practical due to lack of data and conditions for its deployment (Rodríguez, 2012), mainly because most systems have only an exit pressure control of pump and motor current, both of which fail to indicate the pump's operational performance (Ahonen *et al*., 2012).

When the optimization of the operation is not enough for the required efficiency, there is a trend to opt for the maintenance or the substitution of pumps and oversized engines by adequate equipment, highly efficient electric engines and the elimination of cavitation. In fact, correct maintenance multiplies ten-fold the lifespan of the pumps (Kaya *et al*., 2008; Valdés & Esteves, 2009). The operation is undertaken by experts by assessing control of the pumping system in which the operational rules merely aim at warranting supply without taking into account electric energy savings (Costa *et al*., 2010). Therefore, the main factors that affect energy consumption in such cases are discharge, size and performance of pumps and engines, hydraulic installations and operation sites (Trujillo, 2012).

Consequently, current research provides a simple methodology to identify operational issues by monitoring hydraulic (discharge, level and pressure) and electric (tension and electric current resulting in active capacity) quantities. Research also deals with improvement activities simulated with software EPANET 2.0 and compares hydro-energetic indexes to verify the distancing between monitored and simulated scenario, the latter taken as reference. The lack of precision of Epanet 2.0 should be underscored when speed variations in pumps are simulated, since it does not duly take into account the affinity laws in the calculation of efficiency when speed changes occur in pumping systems (Marchi & Simpson, 2013).

MATERIALS AND METHODS

Study area

Current research was conducted at the Guanabara water distribution sector run by the Water Works Company of the State of Pará (COSANPA), Ananindeua PA Brazil, according to **Fig. 1**. The water distribution sector was projected to attend to 27 250 inhabitants at 0.15 m³/inhab.day water consumption per capita, with a water demand of approximately 7357.0 m³ a day (estimates for 2016). The sector comprises a sub-adductor, lower reservoir, station for treated water, upper reservoir and distribution network, according to **Fig. 2** and described below.

Research stages

Continual monitoring of hydraulic and electric parameters was initially undertaken for seven days (from the 17th to the 24th October 2014) to estimate the weekly water demand. The equipment comprised pressure.

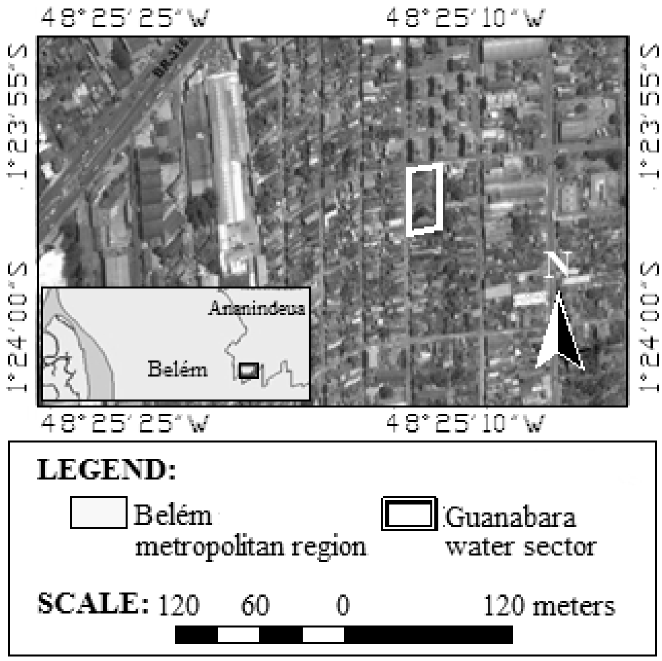

Fig. 1 Site of the Guanabara sector (GOOGLE, 2015, edited).

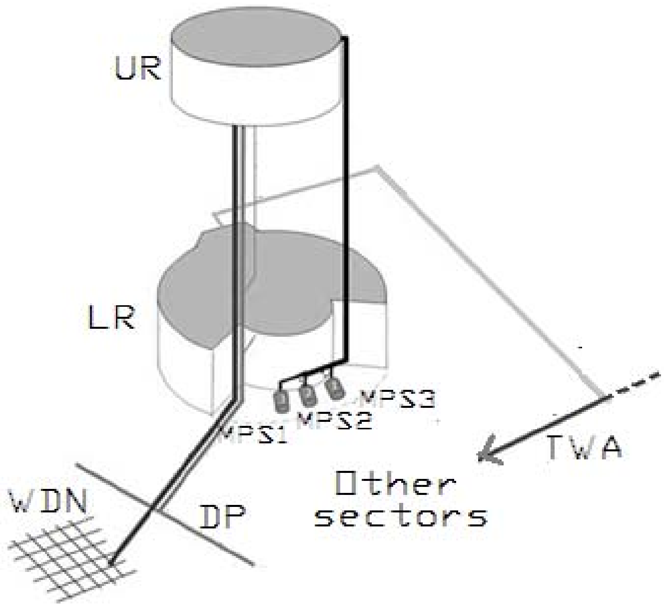

Fig. 2 Guanabara sector: Treated water adductor (TWA, 300mm diameter); Upper reservoir (UR, capacity 850m³); Motor pump systems (MPS, 3 sets 44.13 kW and 1775 RPM); Low Reservoir (LR, capacity 500m³); Water distribution network (WDN, 32 km).

differential discharge meters (discharge of the sub-adductor); two ultrasonic discharge meters (pumping and distribution discharges); ultrasonic sensor (lower reservoir level); one pressure transducer (upper reservoir level); 5 pressure transducers (suction and discharge pressure of pumps, posterior to the clamp) and 2 electric energy quality analyzers (power required by engines locked to the pumps as a result of tension and electric current monitoring).

Stage 1. Evaluation of the activity at the Guanabara sector

Four groups of specific graphs were prepared, relating hydraulic and electric amounts to identify operational problems and define the main corrections due:

(i) "water discharge × power" identifies timetable for switching on and off of water pumps to analyze extant operation modes and identify the electric capacity demanded and pumping capacities;
(ii) "Indexes of specific energy consumption × discharge pumped" identifies and compares the performance of operation modes of the pumping system;
(iii) "Pump curves × hydraulic installation curves" verifies the operation sites in the pumping system and the comparative analysis between the curves of the installed pumps and that of the manufacturer to identify equipment with low efficiency.
(iv) "Water discharge × reservoir levels" verifies level behavior of the upper and lower reservoirs with regard to water demands, and identifies inadequate valves during the operation.

Stage 2. Analysis of the impacts of inefficiency in the consumption of electric energy

Pumping system was simulated with software Epanet 2.0, taking into account water demand curve during the first day of monitoring, the hydraulic installation and the sets of engines and pumps, albeit with the manufacturer´s characteristics. Simulation also included the operational improvements identified in the previous stage, or rather, assessment of the operation at the Guanabara sector. Performance was thus verified mainly by the normalized specific energy consumption index (kWh/m³100wcm) and expenses with electric energy (R$/month).

RESULTS AND DISCUSSION

Analysis of the operation at the Guanabara sector

So that the operation at the Guanabara sector may be analyzed, the behavior of the hydraulic and electric variables, or power, should be understood. Four distinct groups of graphs were prepared: (i) variation of discharge of water pumped by the active power demanded by MPSs; (ii) the relationship between energy consumption indexes and variation in water discharge; (iii) curves of pumps and hydraulic installations; (iv) relationship between variations of the sector's discharges and variation of reservoir levels.

When pumped water discharge is analyzed with the power required by each MPS, demonstrated according to **Figs 3–9** for the other days, the following operational problems may be identified.

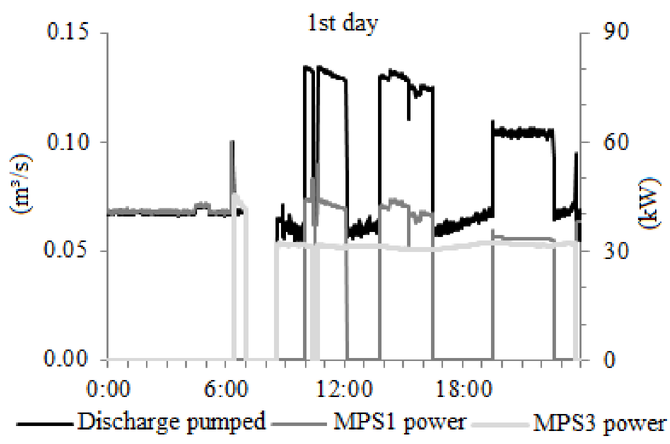

Fig. 3 discharge pumped × power on first day.

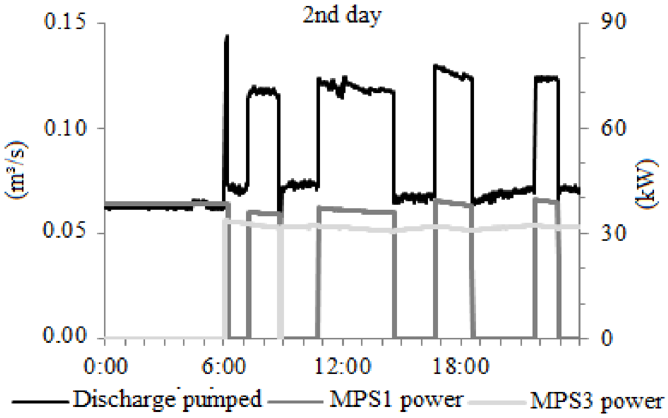

Fig. 4 Discharge pumped × power on second day.

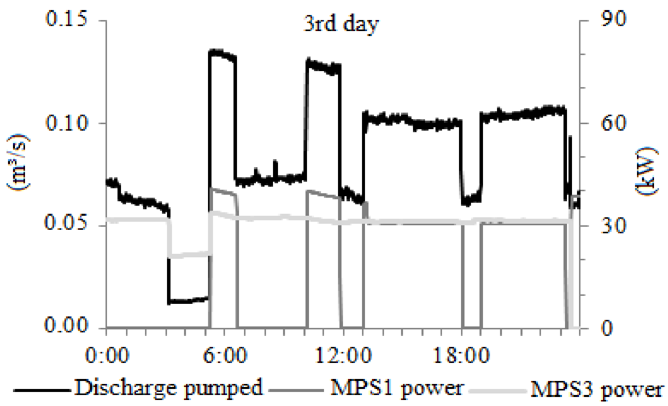

Fig. 5 Discharge pumped × power on third day.

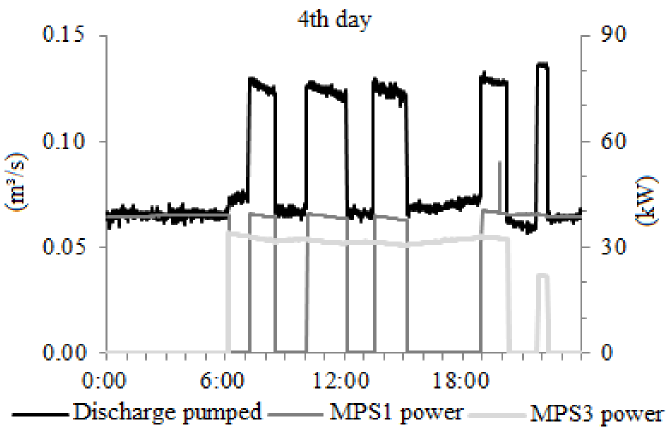

Fig. 6 Discharge pumped × power on fourth day.

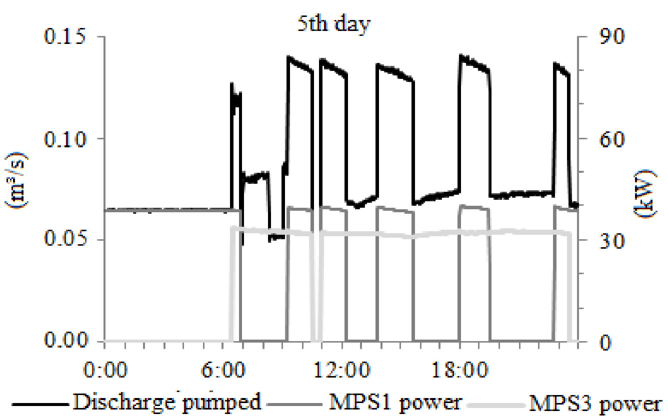

Fig. 7 Discharge pumped × power on fifth day.

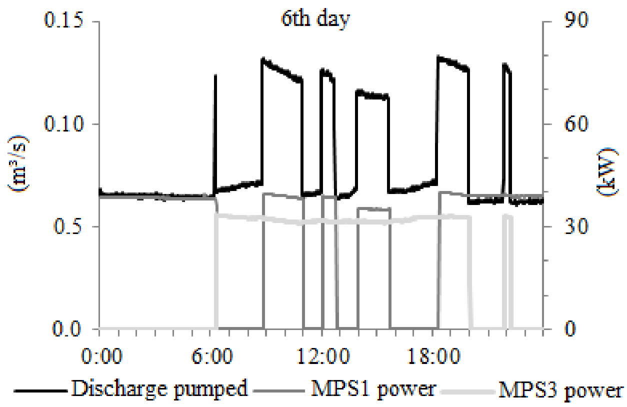

Fig. 8 Discharge pumped × power on sixth day.

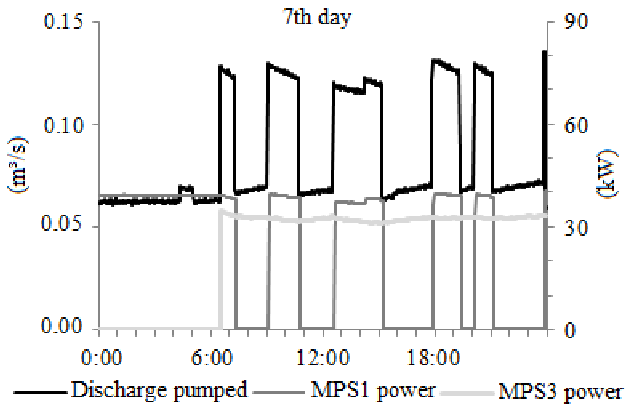

Fig. 9 Discharge pumped × power on seventh day.

A comparative graph was prepared between indexes of specific energy consumption in MPS 1 and MPS 3 to prove the lower efficiency of the former. The lowest specific energy consumption (SEC) occurs with MPS 3 alone, followed by SEC with MPS 1+3; the highest occurs with MPS 1 alone according to **Fig. 10**.

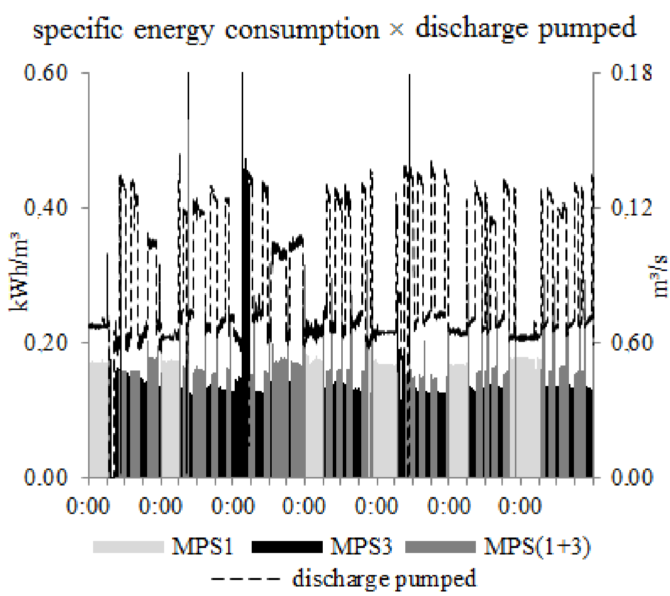

Fig. 10 Energy consumption indexes in operational modes.

Besides comparing energy consumption indexes, curves of pumps and hydraulic installations of the operation with MPS 1 and MPS 3 alone were investigated. Data on 30-min functioning were selected at random: from 20:10 to 20:39 on 22/12/2014 for MPS1 and from 12:20 to 12:49 on 21/12/2014 for MPS 3. Curves were prepared with mean rates of each variable according to **Table 1**. Rates determined the desired curves according to **Eqs 1–3** (**Table 2**).

$$H = a + b \times Q^2 \quad (1)$$

$$H_S = H_O + \left[\frac{H_N - H_O}{{Q_N}^2}\right] \times Q^2 \quad (2)$$

$$H_B = H_P + \left[\frac{H_N - H_O}{{Q_N}^2}\right] \times Q^2 \quad (3)$$

where: H: manometric height of curve (m); a: linear coefficient of the equation; b: angular coefficient of the equation; Q: pumping discharge with manometric height (m³/s); H_S: manometric height of the curve of the hydraulic installation (m); H_O: highest unfavorable geometric dis level (m); H_P: discharge pressure with MPS in shut-off (m); H_N: discharge pressure at the operation point (m); Q_N: pumping discharge at the operation point (m³/s).

Table 1. Monitored data for selected intervals

Information		MPS1	MPS3
Discharge (m³/s)		0.063	0.068
Pressure (wcm)	Suc	-5.94	-5.78
	Rec	31.43	31.34
Total Head (wcm)		37.97	37.39
Power (kW)		38.85	31.43
Usage		61.50%	71.38%
kWh/m³		0.17	0.16
kWh/m³100wcm		0.44	0.43

Table 2. Data for pump and hydraulic installation curves

Plot	Hydraulic System	MPS1	MPS3
H_o (wcm)	-	33.15	33.15
H_P (wcm)	-	50.2	51.2
H_N (wcm)	-	37.39	37.97
Q_N (m³/s)	-	0.063	0.068
a	33.15	50.2	51.2
b	1,058.0	-3,196.6	-2,816.1

In the model shown according to **Fig. 11**, each important point may be identified for the analysis of the curves produced, given according to **Fig. 12**, where P is the position of pressure of the pumps in shut-off position; N shows the operation points of each pump curve; O is the geometric gap of the hydraulic installation. The identification of the difference between the operation points of each pump curve is greatly relevant, where MPS (least efficient) has the lowest pumping capacity when compared to the other curves, especially the pump curve on the manufacturer's manual.

When water discharge and reservoir levels of the Guanabara sector are analyzed (according to **Figs 13–19**), the following problems may be identified:

(i) When the level of the upper reservoir is at its maximum, the valve of the water distribution pipe in the upper reservoir (UR) is closed. Maneuver is normally tied to the supporting MPS shut-off of the pumping station for treated water (PSTW) (when pumped water discharge decreases for the first level). Consequently, pressure in the water distribution network is less due to the load loss caused by the maneuver, with possible liabilities for the population, especially people living at the end of the line (places with the lowest pressure).

(ii) When the reservoir level is at its minimum, the valve of the water distribution pipe in the UR is opened. Maneuver is normally tied to the functioning of MPS of the PSTW (when pumped water discharge increases for the second level). The open valve increases pressure in the network, with an improvement in water distribution, even though the UR becomes a passage box and forces MPS to work for more time than required, with a lessening of its efficiency.

(iii) The bad use of reservoir levels is another relevant point. The UR normally functions without reaching the project´s minimum and maximum water levels, respectively 1.00 m (3 times the diameter 300 mm, since there are no vortex suppressors) and 6.80 m, as a passage box.

(iv) Further, if the contract for the prevision of electric energy takes into account differentiated billing in non-peak hours (0:00 to 19:59 and 21:00 to 23:59) and peak-hours (18:00 to 20:29, with a higher billing), liabilities will be enormous since UR at 18:00 normally features low water level.

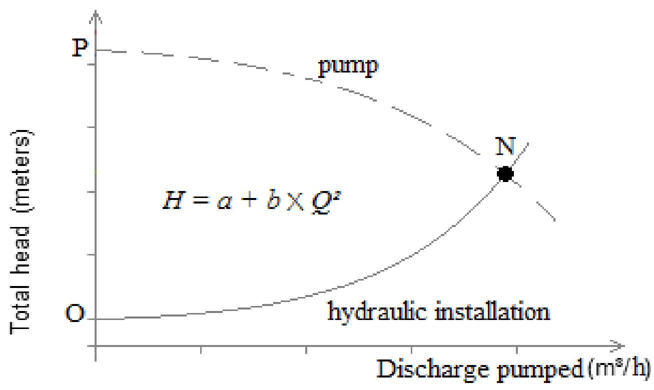

Fig. 11 Pump curve × hydraulic installation curves.

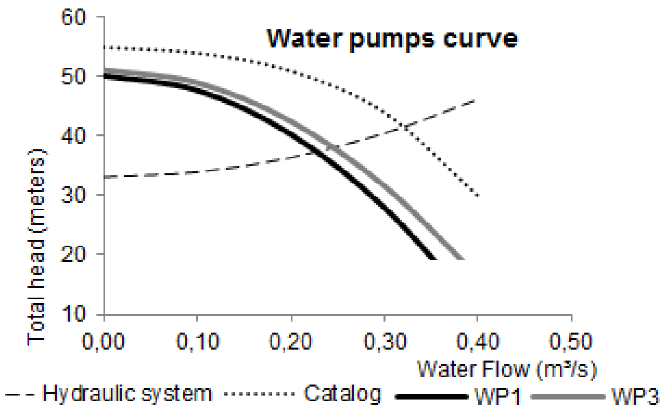

Fig. 12 Pump curve × hydraulic installation curves.

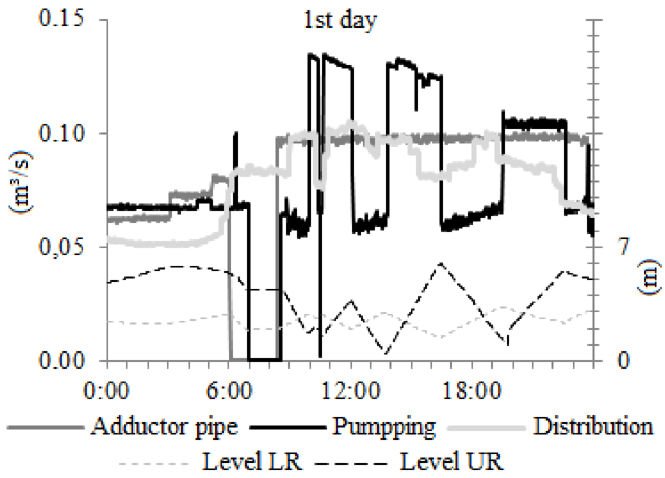

Fig. 13 Water discharge × level of reservoir on fisrt day.

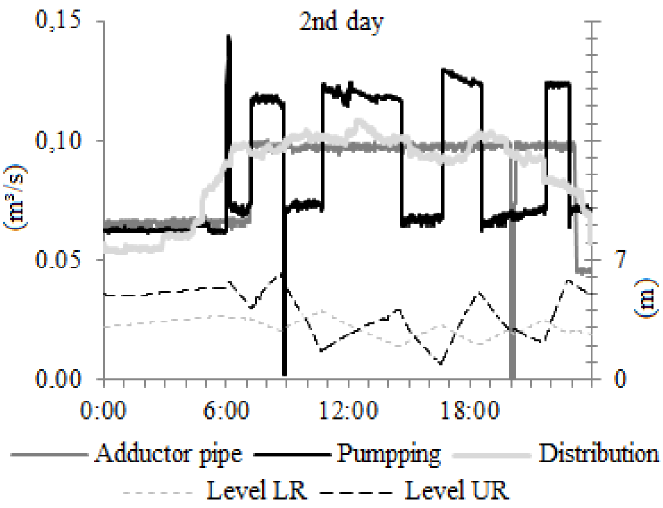

Fig. 14 Water discharge × level of reservoir on second day.

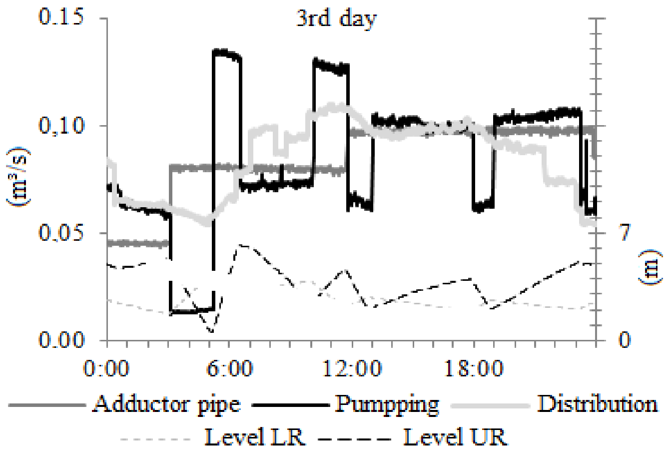

Fig. 15 Water discharge × level of reservoir on third day.

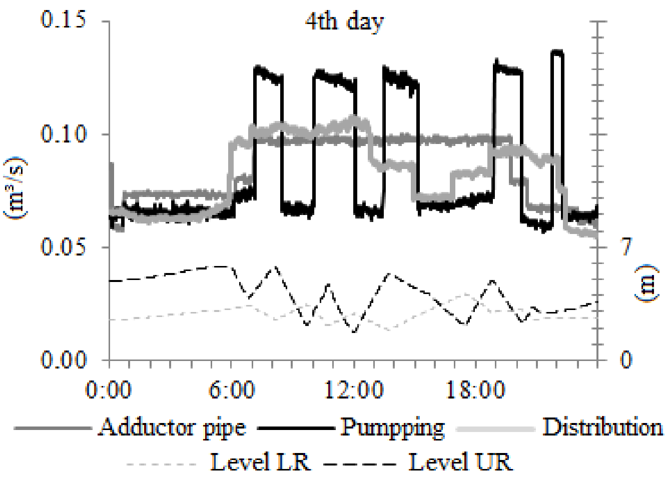

Fig. 16 Water discharge × level of reservoir on fourth day.

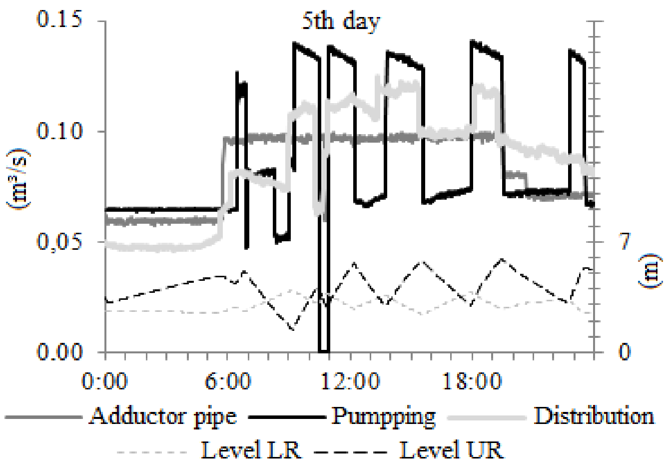

Fig. 17 Water discharge × level of reservoir on fifth day.

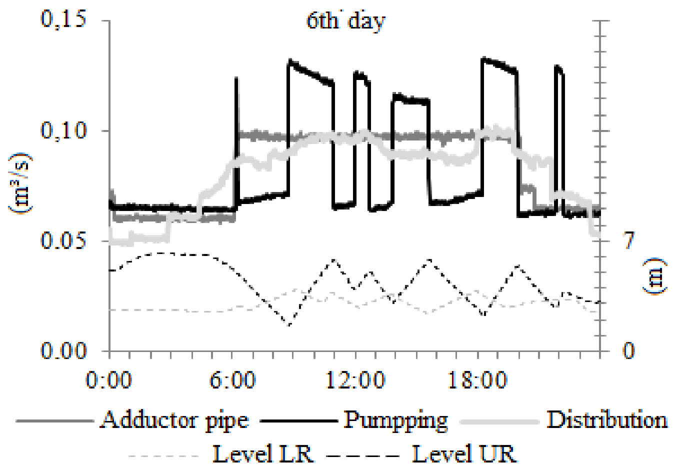

Fig. 18 Water discharge × level of reservoir on sixth day.

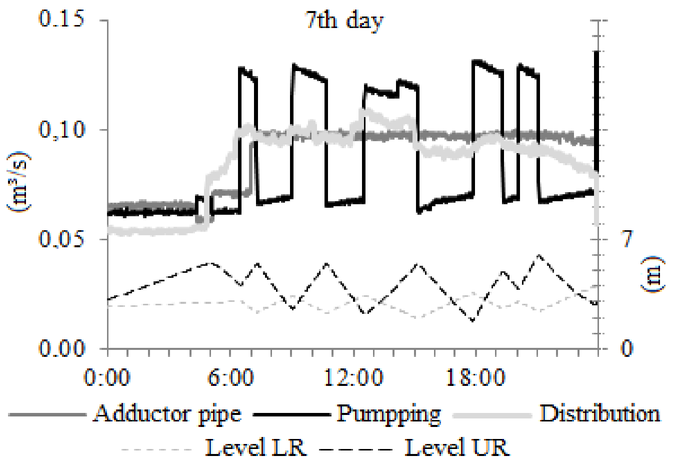

Fig. 19 Water discharge × level of reservoir on seventh day.

Impacts due to inefficiency in the consumption of electric energy

The operation of the Guanabara sector was conducted by a simulation with Epanet 2.0 taking into account water demand curve on first day and new hydraulic and electro-mechanic installations. The simulation was a success according to **Fig. 20**. According to **Fig. 21**, about the reference behavior for the most relevant hydraulic and electric variables:

(i) there are no valve maneuvers in the descent piping from the UR to the distribution network, nor in the valves of the pump discharge piping;
(ii) UR levels occur correctly between minimum and maximum rates;
(iii) there is no prolonged pump operation; there is a partial pause in the pumping system at the peak hour due to maximum UR level at 18:00 when only one MPS functions, for a short time, in the case of a new agreement with billing differentiation of electric energy.

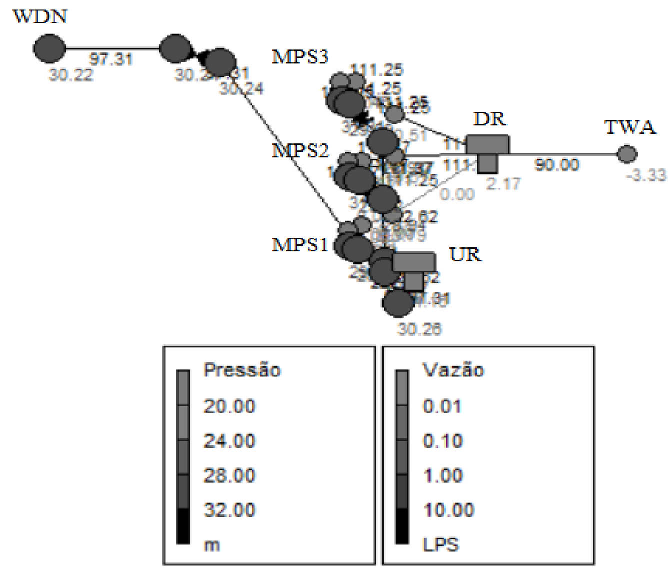

Fig. 20 Epanet 2.0 simulation of operation at the Guanabara sector.

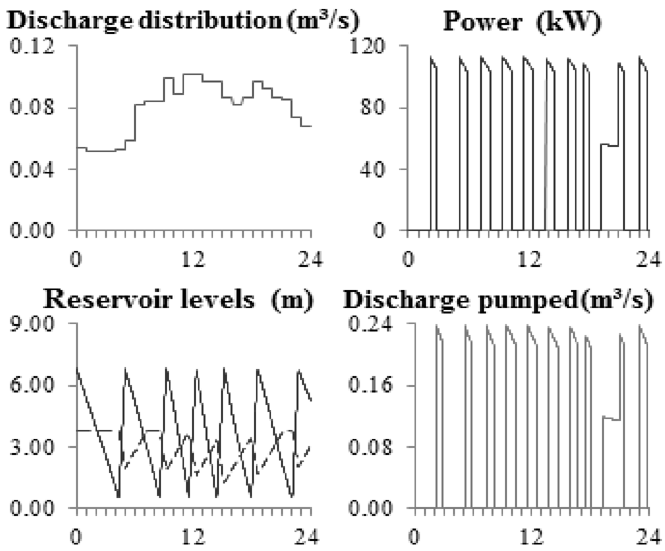

Fig. 21 Behavior of hydraulic and electric amounts at the simulated sector.

Reference system, with a performance similar to current operation conditions, was defined by the simulation of the activities according to **Fig. 22**. However, the above occurs due to the influence of discharge valve at the power demanded by MPSs according to **Fig. 23**. If the pumping system of the Guanabara sector had to operate with all the discharge valves open, the power rates required and the index mentioned above would surely have been higher in monitoring. However, corrections occurred with a 16% decrease in the consumption of electric energy and expenses. Simulation showed a reduction in the consumption of electric energy from 30.868,24 kWh/month to 25.816,34 kWh/month according to **Fig. 24**, coupled to lowering of costs from R$ 7.408,38 to R$ 6.195,92 for a billing of 0.24 R$/kWh according to **Fig. 25**.

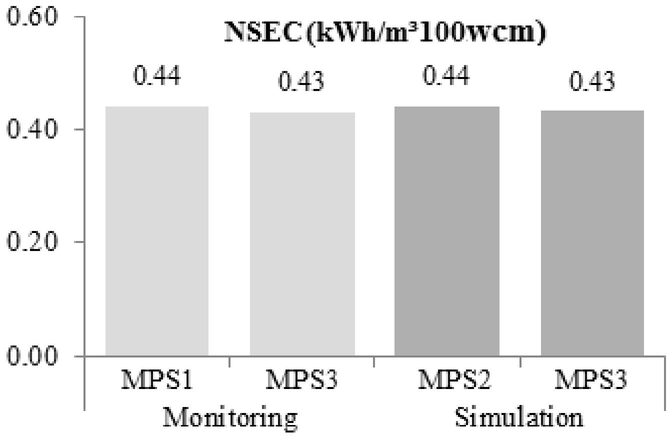

Fig. 22 Comparative NSEC (kWh/m³ 100wcm).

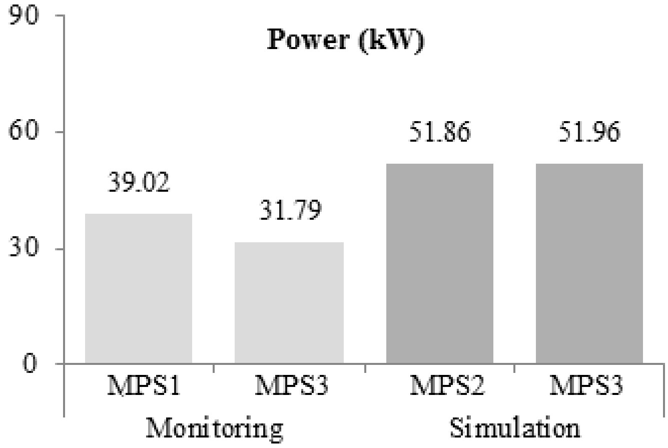

Fig. 23 Comparison of power required.

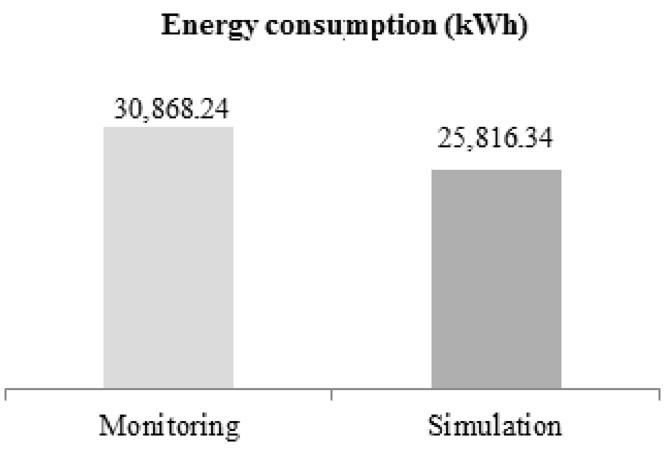

Fig. 24 Comparison between energy consumption.

At first, more complex optimization methods were not required to predict and improve performance. Knowledge on the pumping system operation by monitoring hydraulic and electric amounts and the simulation of operational improvement actions were sufficient for the reduction of electric energy consumption and its costs.

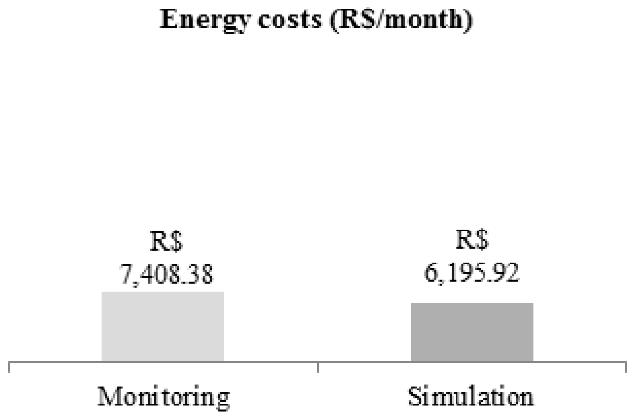

Fig. 25 Comparison between electric energy costs.

CONCLUSIONS

Monitoring, relationship and analysis methodology of hydraulic and electric amounts proved to be satisfactory for the issue involving current research and may be repeated. The performance of the pumping system and the identification and application, by hydraulic simulation, of activities for the improvement of the diagnosed scenario in the Guanabara sector of the municipality of Ananindeua, Pará State, Brazil, could be assessed by using such resources.

It must be highlighted that one of the most important points for the positive results of current research consisted in data survey, at every minute, during the entire hydro-energetic monitoring. The identification of specific actions was thus possible, such as valve maneuvering and turning on and off of electric motors. This was not the case in the monitoring by public works companies with data retrieval at every hour. The acquisition of exclusive equipment for such activities is recommended, such as discharge gauges, level and pressure meters, and quality analyzers of electric energy.

Graphs elaborated on “water discharge × power”, “energy consumption indexes × pumped water discharge”, “pump curves × curves of hydraulic installations” and “water discharge × reservoir levels” were excellent tools for the identification of operational anomalies in pumping systems. The main aspects in current investigation were the bad use of useful water volume of the upper reservoir, handling of valves of the water distribution pipes, pumps working with impaired discharge valves (off the correct operation), prolonged time of the operation and the discrepancy between their pumping capacity. Assessment of performance of the pumping system of the Guanabara sector detected inadequate operations, albeit with possibilities of recuperation.

It is highly relevant that evaluations must be constant as decrease of water losses is achieved so that the pumping systems are always updated, according to water demands. Current analysis showed that hydro-energetic efficiency measures, based on costless or low-cost actions, have a great capacity in decreasing costs.

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