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STEADY STATE FLOW ANALYSIS OF MANSO WATER SUPPLY SYSTEM

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ABSTRACT

The Rio Manso System is essential for supplying water to the Metropolitan Region of Belo Horizonte (RMBH), Minas Gerais State. This system withdraws water from the Manso reservoir and the Paraopeba river, transporting it through an integrated network of pipelines, reservoirs, and pumping stations. This study presents a steady-state hydraulic analysis of a 14 km segment of the Manso distribution network, focusing on the reach between pumping stations EAT-3 and reservoir R-6. A hydraulic model was developed using EPANET software based on publicly available data, including flow rates, pumping pressures and reservoir levels. Five operational scenarios were simulated to assess system performance under varying water surface elevations in key reservoirs. Results indicate that the system can deliver the design flow rates with the current configuration. However, flow rates are highly dependent on the configuration of the pumping system and, most critically, on the water levels in the upstream and downstream reservoirs adjacent to each pumping station. Additionally, flow diversions between CT-4 and R-6 were found to reduce the volume of water reaching reservoirs R-7 and R-6, highlighting the importance of integrated operational planning.

Keywords: *Water security; water supply; hydraulic analysis; Rio Manso; EPANET*

1. Introduction

The Rio Manso Water Supply System (MWSS) is essential for supplying water to the Belo Horizonte Metropolitan Region (BHMR), Minas Gerais State (PMBH, 2016). It withdraws water from the Manso reservoir and the Paraopeba river near the city of Brumadinho, Minas Gerais State, treats it at the Manso Water Treatment Plant (ETA Manso), and distributes it through a complex network of reservoirs, pumping stations and pipelines, ensuring reliable water delivery across the region (Copasa, 2009). The MWSS was originally designed in 1988 and started operation in 1992. The design included different development phases to increase the capacity of the system in the future due to increase in population (e.g. twining of pipelines, increasing water treatment station and pumping station capacity and increasing number of tanks).

The Belo Horizonte Metropolitan Region (BHMR), Minas Gerais State, experienced a major water-supply crisis in 2015 due to a long drought period (De Melo et al., 2020). In January 2019, the Brumadinho tailings dam failed compromising the water withdraw from the Paraobeba river, and reducing the water production in the Rio Manso Water Supply System (MWSS). These events raised a red flag about the water security of the supply of the BHMR.

This paper presents a hydraulic assessment of the current capacity of the system between pumping station RAT/EAT-3 and tank R-6 including scenarios to optimize the flow rates across the system. A steady-state flow analysis of this reach has been completed using EPANET software and publicly available data (Copasa, 2009; Arsae, 2013; PMBH, 2016).

2. Description of the system

The studied reach between pumping station RAT/EAT-3 and tank R-6 is represented in Figure 1. It includes the following parts: (i) an upstream tank (RAT) connected to pumping station EAT-3 by twin 1.8 m diameter pipelines (length ≈115 m each). The EAT-3 pumps water into tank CT-4 through two paralel pipelines (with 1.5 m diameter and 1.7 m diameter) over approximately 2.13 km. From tank CT-4 to tank R-7 the water flows by gravity initially through two paralel pipes (with 1.5 m diameter and 1.8 m diameter) for a length of 9.2 km and then through only one 1.5 m diameter pipe for a distance of 7.44 km. Tank R-7 is connected to pumping station EAT-4 by two paralel pipes (with 1.5 m diameter and 1.8 m diameter) with a lenght of 0.2 km. Pumping station EAT-4 pumps water to tank R-6 initially through two paralel pipes (with 1.5 m diameter and 1.6 m diameter) for a length of 2.1 km and then through only one 1.5 m diameter pipe for a distance of 4.25 km. Figure 1 shows a schematic of Manso Water Supply System from RAT to R6.

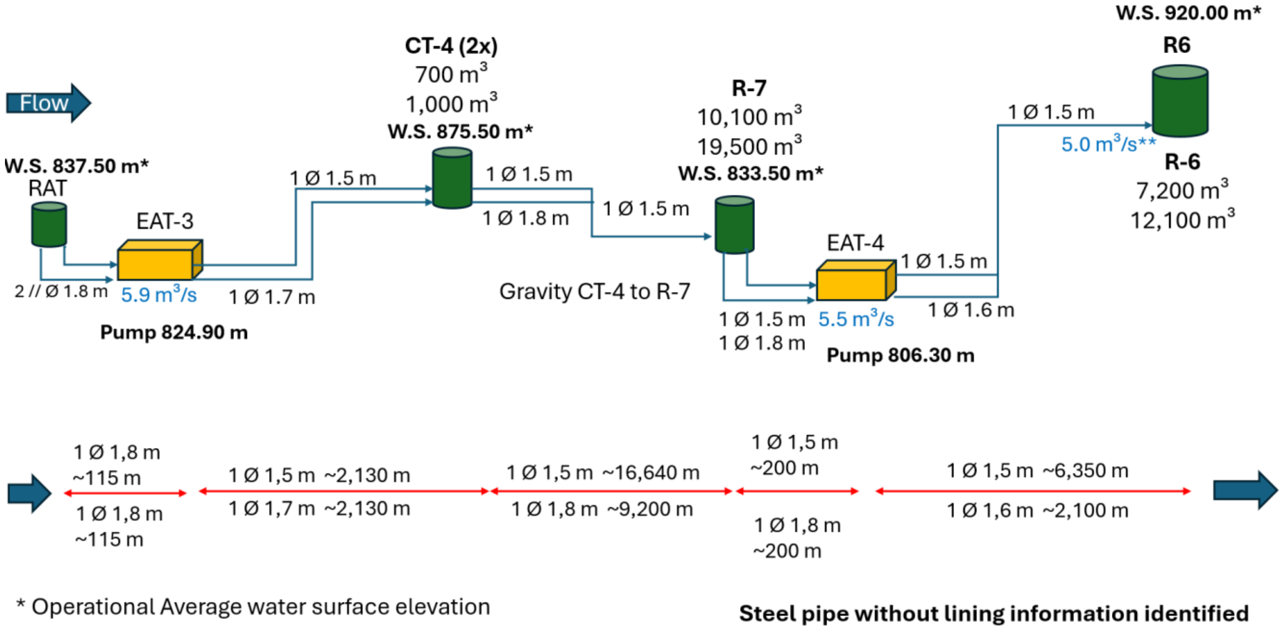

Fig. 1. Manso Water Supply System schematics (source: Authors based on public data).

EAT-3 pumps water from RAT to CT-4 using a mixed fleet of centrifugal pumps in parallel operation. EAT-3 has 2 units Type A (KSB), 4 units Type B (KSB) and 2 units Type C (Flowserve). The Type A pumps has capacity to pump Q ≈ 420 L/s at HP ≈ 42 m. The Type B has capacity to pump Q ≈ 1,060 L/s at HP ≈ 42 m. The Type C pumps have a capacity of Q ≈ 2,333 L/s at HP ≈ 42 m. The normal operating mix fleet adopted in this study is 1×A + 3×B + 1×C.

The EAT-4 pumps water from tank R-7 to R6 also using mixed fleet of centrifugal pumps in parallel operation. EAT-4 has 2 units Type A (Sulzer), 4 units Type B (Sulzer) and 2 units Type C (Flowserve). The Type A pumps has capacity to delivery 470 L/s at HP ≈ 107 m. The Type B pumps has capacity to pump Q ≈ 1,020 L/s at HP ≈ 107 m, and the Type C pumps have the capacity to pump Q ≈ 2,200 L/s at HP ≈ 107 m. The normal operating combination adopted in this study is 1×A + 3×B + 1×C.

3. Hydraulic Analysis

For the hydraulic analysis the system can be divided in 3 main sections: (i) RAT to CT-4 via EAT-3 pumping station, (ii) CT-4 to R-7 (gravity driven) and (iii) R7 to R-6 via EAT-4 pumping station. The EAT-3→CT-4 and R-7→EAT-4 pipeline are fully duplicated, whereas CT-4→R-7 and EAT-4→R-6 are partially duplicated (see Figure 1).

3.1. Hydraulic Model

Hydraulic analyses were performed with EPANET (Environmental Protection Agency Network Evaluation Tool)[1]. Given the complexity of the supply system, several assumptions were required to represent it in EPANET: (i) steady water levels (temporal variation < 0.5%); (ii) carbon-steel pipelines with absolute roughness = 0.05 mm; (iii) intermediate derivations between RAT and R-6 were neglected; and (iv) minor head losses were simplified due to data limitations. Figure 2 shows the MWSS EPANET model between RAT and R-6.

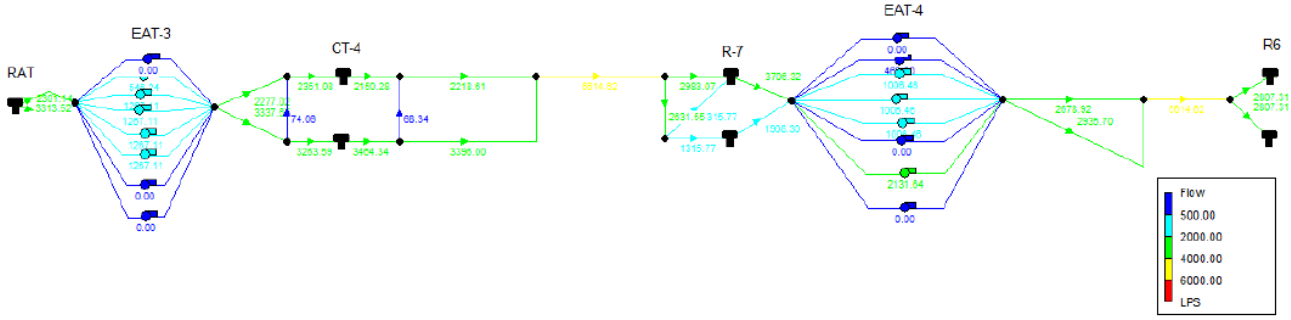

Fig. 2. Manso Water Supply System EPANET model.

The simulated scenarios were: (i) Scenario 1: average water levels at the tanks; (ii) Scenario 2: maximum flow in the CT-4 → R-7 section; (iii) Scenario 3: maximum flow delivered by EAT-4; (iv) Scenario 4: maximum flow delivered by EAT-3; and (v) Scenario 5: maximum constant flow in the entire system (RAT → R-6). Table 1 summarizes the water-level settings adopted for each scenario. We simulate all five scenarios under normal configuration and "all pumps on" configuration at EAT-3 and EAT-4.

Table 1. Reservoir water surface elevation used in the simulations.

Scenario	Water Surface Elevation (m)			
	RAT	CT-4	R-7	R-6
Scenario 1	837.50	875.50	833.00	920.00
Scenario 2	839.94	880.00	830.00	917.50
Scenario 3	839.94	880.00	836.00	917.50
Scenario 4	839.94	872.70	830.00	917.50
Scenario 5	837.40	871.00	835.96	918.50

3.2. Results and discussions

Using average water levels in the reservoirs (Scenario 1), the flow rates at R-6 is 5,431 L/s under normal operation, increasing to 6,656 L/s with all pumps activated.

The maximum flow rates that EAT-3 can pump (Scenario 4) is 6,675 L/s under the normal configuration (EAT-3 and EAT-4 each operating 1×Type A + 3×Type B + 1×Type C), achieved when RAT is at maximum level (El 839.94 m) and CT-4 at a low level (El 872.70 m). For the configuration with all pumps operating (2×A + 4×B + 2×C at both stations), the flow rates can reach 10,060 L/s.

The maximum flow rates in the CT-4 to R-7 reach (Scenario 2) is 6,817 L/s when CT-4 is at maximum level (El 880 m) and R-7 at minimum level (El 830 m), with the following pump configuration EAT-3: 2×A + 4×B + 2×C and EAT-4: 4×B + 2×C.

The maximum flow rates that EAT-4 can pump (Scenario 3) is 5,742 L/s under the normal configuration (1×A + 3×B + 1×C at both stations), obtained when R-7 is at maximum level (El 836 m) and R-6 at minimum level (El 917.50 m). For the configuration with all pumps operating (2×A + 4×B + 2×C at both stations), the flow rates can reach up to 7,044 L/s.

The maximum constant flow rates that can be sustained end-to-end from RAT/EAT-3 to R-6 (Scenario 5) is 5,687 L/s with the following pump configuration EAT-3: 2×A + 4×B and EAT-4: 1×A + 3×B + 1×C. This maximum constant flow rates can reach up to 6,465 L/s with EAT-3: 2×B + 1×C and EAT-4: 1×A + 4×B + 2×C. This scenario indicates that the R-7/EAT-4 to R-6 pipeline is the critical reach governing system capacity.

[1] EPANET is a freely available, open-source program for simulating pressurized water-distribution systems. Further information is available at: https://www.epa.gov/water-research/epanet

Results are presented in Table 2 for the normal configuration and Tabel 3 for “all pumps on” configuration at EAT-3 and EAT-4.

Table 2. Summary for normal configuration of the pumps at EAT-3 and EAT-4.

Scenario	Flow rates (L/s)		
	RAT/EAT-3 to CT-4	CT-4 to R7	R7/EAT-4 to R6
Scenario 1	5,932	6,283	5,431
Scenario 2	5,626	6,817	5,131
Scenario 3	5,626	6,384	5,742
Scenario 4	6,675	6,287	5,131
Scenario 5	5,615	5,615	5,615

Table 3. Summary for “all pumps on” configuration of the pumps at EAT-3 and EAT-4

Scenario	Flow rates (L/s)		
	RAT/EAT to CT-4	CT-4 to R7	R7/EAT-4 to R6
Scenario 1	8,692	6,283	6,656
Scenario 2	6,944	6,817	5,834
Scenario 3	8,231	6,384	7,044
Scenario 4	10,060	5,685	6,682
Scenario 5	6,455	6,455	6,455

4. Conclusions

Variations in reservoir water levels directly affect end-to-end flow rates across the pipeline. Under normal operation, the maximum flow rates deliverable by EAT-4 is 5,742 L/s, increasing to 7,044 L/s with all pumps on configuration. However, the maximum constant flow rates that can be sustained through the entire system is 5,687 L/s under normal configuration of the pumps and 6,465 L/s under an optimized pump configuration (EAT-3: 2×Type B + 1×Type C and EAT-4: 1×Type A + 4×Type B + 2×Type C).

The hydraulic analysis showed that with the existing pumps and motors, it is possible to increase the steady state flow rates of the entire system by lowering the water surface level in R-6. The reach from R-7/EAT-4 to R-6 was identified as the critical hydraulic constraint on system capacity. In practical terms, the “all pumps on” configuration was not the optimal configuration. The management of water levels in the tanks combined with an optimized operation of the pumps results in higher flow rates in the system.

Investments are being made by the state company[2] to increase the MWSS capacity, including changes in the water treatment plant and new pipelines and pumping systems and tanks to improve the water security for the BHMR.

Additional analysis for the operation of the new Manso system is using artificial intelligence methods and digital twins is recommended and could improve system efficiency.

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