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A model-based approach for reducing energy consumption and GHG emissions of drinking water transmission systems: a WaCCliM Project Case Study

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Abstract

The Water and Wastewater Companies for Climate Mitigation (WaCCliM) project aims to improve the efficiency of water and wastewater companies in Mexico, Peru, Thailand, and Jordan, reduce their greenhouse gas (GHG) emissions, and improve the carbon balance of the water sector, while maintaining and/or improving service levels. As part of the project, hydraulic modelling software was used to simulate the Cusco, Peru drinking water transmission system and evaluate various scenarios (water loss reduction, pump replacement, and system reconfiguration) and their energy impacts. Results showed the transmission system's pumping energy could be reduced up to 40 percent depending on the scenario. A holistic view on the total urban water cycle has also helped to identify that a combined effort to conserve water at the end user level, reduce water loss, reuse water, and rainwater harvesting will ultimately make the biggest impact on the transmission system's energy consumption and GHG emissions, and lead to the most sustainable and resilient urban water management for SEDACUSCO and the City. This study has also demonstrated that water distribution system models can play an invaluable role in water utility climate change mitigation and adaptation planning.

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Keywords: Energy; greenhouse gas emissions; hydraulic modelling; WaCCliM project

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1. Introduction

Water (drinking water and wastewater) utilities are increasingly shifting their mind set from a strictly service-oriented mind set, to a sustainable-oriented one, through which service levels are met or improved in a more sustainable and holistic way. This entails optimizing and developing urban water systems to be energy and resource-efficient, as well as to minimize costs and environmental impact. In this spirit, the Water and Wastewater Companies for Climate Mitigation (WaCCliM) project, implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the International Water Association (IWA), on behalf of the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), aims to improve the efficiency of water and wastewater companies in Mexico, Peru, Thailand, and Jordan, reduce their greenhouse gas (GHG) emissions, and improve the carbon balance of the water sector [1], while maintaining and/or improving service levels. As part of the project, GIZ and IWA have partnered with SEDACUSCO, a water utility in Cusco, Peru, to demonstrate this approach. SEDACUSCO provides drinking water and wastewater services for the Cusco metro area (population 415,000). A baseline assessment of the energy consumption and GHG emissions of SEDACUSCO’s systems was performed and found that 85 percent of the total (drinking water and wastewater) energy consumption and energy-related GHG emissions were from the drinking water abstraction / transmission system, which clearly identified SEDACUCO’s Vilcanota drinking water transmission system (Fig. 1) as the low hanging fruit for reducing GHG emissions and energy costs.

The existing system draws water from the wells at the Piñipampa Pumping Station, which are hydraulically connected to the adjacent Vilcanota River. Water is the then pumped in to EB2 and EB3, respectively in series, and ultimately from EB3 to R-12, from which water drains by gravity to the rest of the system. The total static head between R-12 and source is approximately 350 meters, which is a significant elevation difference to overcome, making the water transmission energy intensive regardless of how efficient the pumping is. Therefore, maximizing water use efficiency and pumping efficiency is critical to minimizing the pumping energy required.

Water distribution system models can be invaluable planning tools for both optimizing existing drinking water supply systems, and development of water infrastructure to meet future demands based upon projected population numbers and other activities impacting the drinking water supply supply, such as integrating water reuse, water conservation, and rainwater harvesting into total urban water cycle management solutions. Furthermore, water distribution system models can be used to evaluate the energy and greenhouse gas impacts of various planning scenarios [2]. Therefore, to meet the project objectives, water distribution system hydraulic modelling software was used to simulate Vilcanota transmission system and assess various scenarios to reduce the utility’s carbon emissions and pumping energy.

This paper details the model-based transmission system optimization study conducted to identify opportunities to reduce GHG emissions and energy consumption of the Vilcanota system, the hydraulic model construction and calibration (hydraulic and energy), and the scenario analysis and results.

2. Materials and Methods

2.1. Model Construction

A hydraulic model of the Vilcanota drinking water transmission system was constructed based upon system data and information forwarded by SEDACUSCO in various documents. This includes information on pipe diameters, pump operational data, clear well levels, storage tank information, and elevations. The model represents each of the three pumping stations that pump water from the source wells near the Vilcanota river to the R-12 reservoir, five storage tanks (R-12, R-10, R-1, R-13, and R-5), and all interconnecting pipelines (see Fig. 2 for model configuration). Documentation has been provided that confirms that R-4 (shown in Fig. 1) is part of the Piuray System (another major water supply for Cusco); therefore, it is not included in the model. The hydraulic modelling software used was WaterGEMS by Bentley System, Inc.

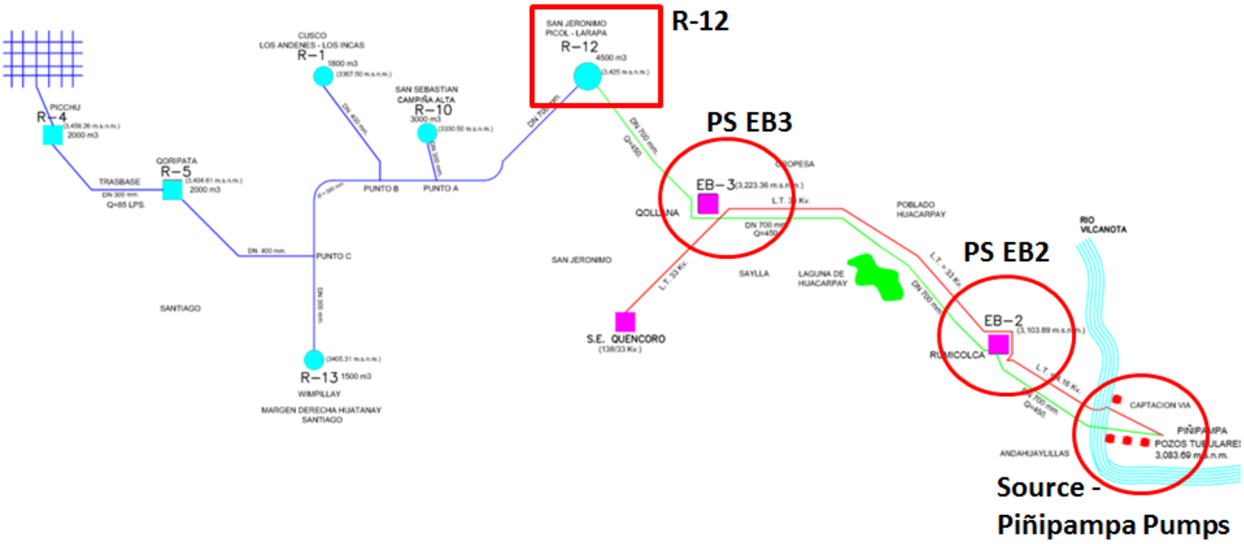

Fig. 1. Vilcanota drinking water transmission system schematic; green line is drinking water transmission pipeline, whereas blue is distribution system pipeline; transmission system pumping stations are encircled in red, while the main storage tank R-12 is in the red square.

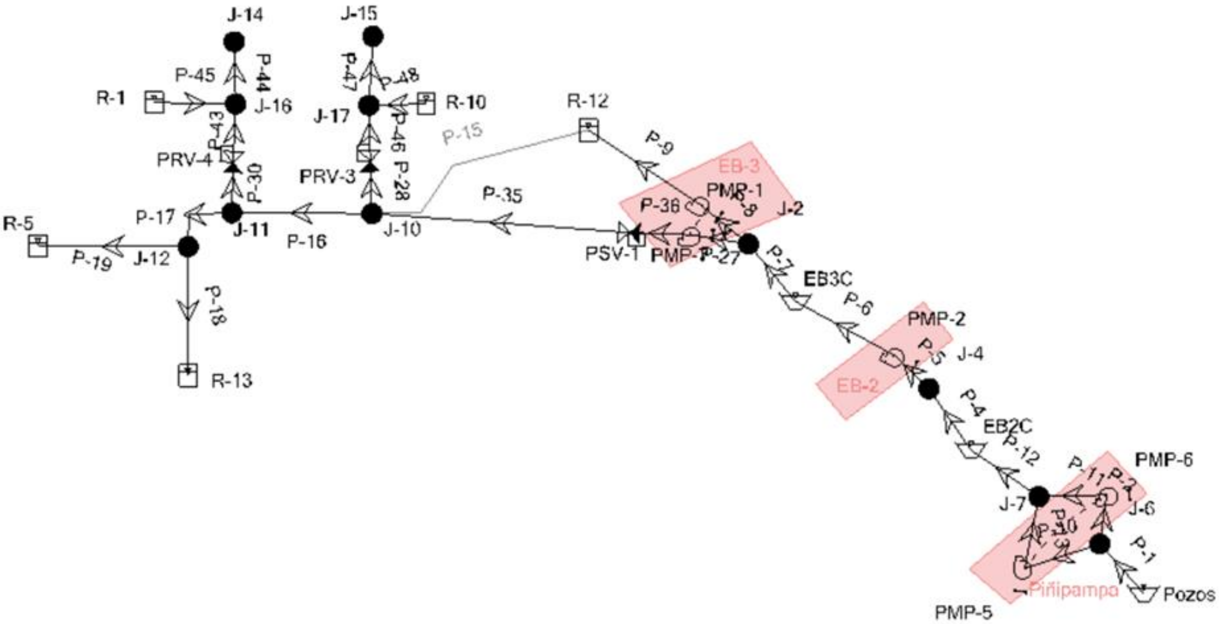

Fig. 2. Vilcanota drinking water transmission system hydraulic model layout

To model the current pumping, only the three pumping stations and the R-12 storage tank were active in the model for the existing scenario. The current pumping scheme only needs to encompasses these facilities in the model, because the water drains by gravity from R-12 to the rest of the system / storage tanks. With the total system demand placed on R-12, the pumping for the whole transmission can be captured with just these elements in the model. The network elements shown to the left of R-12 were only activated for looking at other pumping scenarios.

2.2. Model Calibration

Once the model was constructed, a calibration was performed by calculating a demand pattern for a specific day (September 9, 2015) using R-12 level data and pumping rates from a different day, and based on the storage tank geometry, calculating the net volume used and hourly demand. Tank and pumping data for the same day were not available; however, the general operating strategy, pumping rates, and pumping times rarely change from day to day. Therefore, the diurnal demand pattern for a given day can be calculated using pumping rates from a different day for the purpose of this study, which is to identify and compare alternatives for reducing GHG emissions and energy consumption. Since pumping energy is being evaluated for each of the scenarios as a key criterion, the model needed to be calibrated for both hydraulics and energy. Therefore, pump operating points and wire-to-wire efficiency [3] were calculated from field data collected from the pump control system. The field data included pump flow/pressure/elevations, and corresponding voltage and current readings for calculating wire-to-water efficiency. Although the pumping conditions do not vary significantly based on how the system is operated (pumps are turned on at 11pm, turned off at 6pm the next day, and pump clear well levels are kept relatively constant), the average values for a 24-hour period were calculated to define the pump operating point and corresponding wire-to-water efficiency. Table 1 summarizes the pumping conditions defined in the model for each pumping station. As can be seen from Table 1, the pumping efficiency for each of the pumping stations a considerably low. This is mainly due to the age of the pumps/motors.

Table 1 - Summary of current pump operation and efficiency (per pump)

Pumping station	Pump flow (lps)	Pump head (m)	Wire-to-wire efficiency (%)
Piñipampa	211	24	48
EB2	417	150	69
EB3	410	205	69

2.3. Scenario analysis / comparison

Three basic scenarios were constructed in the model using the software scenario management tools and were compared. The three scenarios included: 1) existing conditions; 2) replacing existing pumps/motors with efficient pumps/motors; and 3) reconfiguring the EB-3 pumping scheme so that only the water needed to meet R-12 service area demands are pumped to R-12, and the remainder is bypassed around R-12 to feed the rest of the system directly through a new pipeline (P-35 in Fig. 2). Since R-12 is at a significantly higher elevation than the rest of the system, this measure was considered to reduce the pumping head required for delivering the majority of the system's water. Child scenarios of each the above three scenarios were considered to see the effects of reducing water loss in the distribution system. Specifically, a six percent water loss reduction child scenario was developed for each scenario to evaluate the projected reduction by the end of 2018 (end of WaCCliM project) based upon SEDACUSO's ongoing water loss reduction program.

3. Results and discussion

3.1. Model Calibration

Once the demand patterns, pump performance, and pumping times for the calibration day were input, the model was executed. Pumping rates, tank levels, and pressures were then compared to historical data and were found to be within an acceptable margin of error. Fig. 3 shows a comparison of the measured and modeled R-12 water level levels, which is a good indicator of how well the model is capturing the system conditions and dynamics in terms of demands and pumping. Slight differences can be seen in the tank level values and time of peaks; however, the shape of the curves closely resemble each other. Therefore, for the purposes of this study, the fit of the model to the data was considered to be more than adequate.

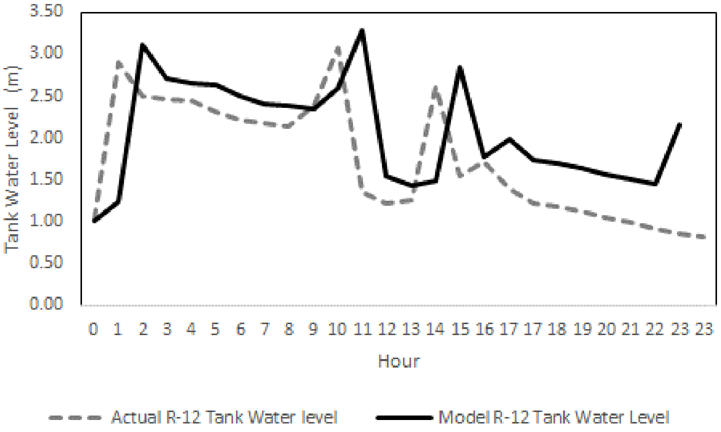

Fig. 3. Model calibration results, comparison of field and model R-12 storage tanks water levels

The energy efficiency that was calculated using field data for each of the three pumping stations was checked to see if the energy calculated for the year in the model was within an acceptable margin of error. Based upon 2013 energy bills for the Vilcanota system, and normalizing the total volume delivered for the year to the 2013 volume, the energy model results were only within an eight percent difference of the actual kilowatt hours (kWh) metered. Therefore, the calibrated model provides a sound basis from which comparisons can be made between baseline (existing) conditions and various scenarios to evaluate potential energy / GHG reductions. It should be noted; however, that the relative differences between scenarios should be evaluated more closely than the exact numbers, since a number of assumptions are made that can impact the exact kWh numbers. For example, pumping station clear well levels were not available for the given pumping data; therefore, slightly different levels than the assumed can have a minor impact on the energy values calculated. Nonetheless, the calibration was successful and the results provide more than adequate confidence in the model for the purpose of this study.

3.2. Scenario analysis / comparison

Table 2 provides a summary of the scenario analysis results. For each scenario, you can see significant savings as a result of reducing water loss (Scenarios 1A, 2A, and 3A). This shows the impact each drop of water has on the pumping energy. So whether it is reducing water loss, conserving water, reusing water, or harvesting rainwater, the results help emphasize that water efficiency is essential for providing a secure and sustainable water supply for Cusco given its high elevation above sea level. Scenario 2, replacing the existing pumps with efficient pumps (increasing wire-to-water efficiency to 80%) has a large impact, but not as large as Scenario 3. In Scenario 3, the pumps are also replaced with efficient pumps, but we also see the benefits of splitting the pumps between R-12 and the other storage tanks, as opposed to pumping the total system demand to R-12, the highest tank. This in turn cuts down on the overall pumping time because the storage volume in R-12 can supply the R-12 zone, which allows the newly R-12 designated EB-3 pumps to shut down for a good part of the day, in addition to the five hours they are already shut off as part of their energy tariff restrictions. Similarly, the other set of new EB-3 pumps pumping directly to the rest of the system can also reduce pumping time, because they only have to satisfy the remaining tanks and are also able to shut down utilizing some of the storage capacity of the tanks. When the EB-3 pumps shut down, the other stations also shut down as they are in-line, which also adds to the energy savings. Therefore, nearly 40 percent of the energy costs can be saved by reconfiguring the pumping in Scenario 3 combined with reducing water loss by six percent. However, the new pipeline required to pump directly to the other storage tanks was determined to be not feasible. Therefore, Scenario 2 and reducing water loss is where the focus is now being placed by SEDACUSCO.

Table 2 - Summary of scenario analysis results

Scenario	kWh/yr	USD/yr savings	% savings	kgCO2e/yr	% GHG reduction
1 – Baseline / existing	16,008,718	NA	NA	3,602,003	NA
1A - existing + 6% WL reduction	12,674,589	202,677	20.8	2,851,791	20.8
2 - Replace pumps	13,358,343	161,112	16.6	3,005,611	16.6
2A - Replace pumps + 6% WL reduction	10,576,970	330,188	33.9	2,379,818	33.9
3 - Reconfigure EB3	11,803,954	255,601	26.3	2,655,923	26.3
3A - Reconfigure EB3 + 6% WL reduction	9,962,018	367,570	37.8	2,241,438	37.8

4. Conclusions

As part of the WaCCliM project, water distribution hydraulic modelling software was used to simulate various scenarios (water loss reduction, pump replacement, and system reconfiguration) and their energy impacts on SEDACUSCO’s Vilcanota drinking water transmission system. Results showed that pumping efficiency has a big impact on the transmission system pumping energy. Together with the model results, a holistic view on the total urban water cycle has also helped to identify that a combined effort to conserve water at the end user level, reduce water loss, reuse water, and rainwater harvesting will ultimately make the biggest impact on the system’s energy consumption and GHG emissions, and lead to the most sustainable and resilient urban water management for SEDACUSCO and the City. This was apparent through the water loss reduction scenarios. As a result, SEDACUSCO is now evaluating various water efficiency strategies as part of their climate change mitigation and adaptation plan, which water utilities in Peru are required to prepare. Along with incorporating various system updates, the water distribution system model will be used to evaluate various scenarios integrating water loss reduction, water conservation, water reuse, and rainwater harvesting at various planning horizons (i.e. 5, 10, 20, 40 years) and verify whether the new pumps proposed under Scenario 2 will still be operating near their best efficiency points. SEDACUSCO has demonstrated industry leadership in carrying out this study, and is now one step closer to realizing a more integrated and sustainable management of their urban water systems. This study has also demonstrated that water distribution system models can play an invaluable role in water utility climate change mitigation and adaptation planning.

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