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ENSURING AVAILABILITY AND SUSTAINABLE MANAGEMENT OF WATER AND SANITATION FOR ALL

Measuring the hydraulic functionality of PPP-managed water supply infrastructure in Madagascar

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This paper presents results from an on-going study that is aimed at developing continuous, objective tools for evaluating the performance of water system functionality. An additional goal of this study is to explore external factors that influence sustainability in order to better understand the effectiveness of PPP managed water systems. Pressure transducers were installed in water system storage tanks to continuously measure water levels and allow determination of supply/demand flows, and functionality in terms of water delivery was assessed using tank level thresholds and service provision levels of access. Both systems studied exhibited high functionality despite different contextual factors, and metered data was used to verify consumption estimates. The objective of this paper is to demonstrate the use of monitoring tools such as this to better inform planning, needed to achieve universal access.

Defining functionality and sustainability

New and innovative monitoring tools are needed to achieve universal and equitable access to safe and affordable drinking water for all (SDG Target 6.1). Many different technologies and management schemes show potential to contribute towards achieving sustainable, universal water access, but evidence is needed to determine what works and avoid wasted investment (Davis 2014). Sustainability is a common goal of rural water supply projects and numerous tools have been created to measure it (Schweitzer, Grayson, and Lockwood 2014). In the water sector, a number of different definitions of sustainability exist, depending on the significance and the relevance of factors determined to contribute most to post-construction sustainability, which can vary depending on the context (Harvey & Reed 2003, Lockwood 2003).

   The research associated with this paper continues the development of a methodology to provide continuous, objective measurement of water system functionality in gravity-driven piped water systems, and investigates factors influencing system sustainability, here defined as long-term functionality (Ermilio et al, 2014/2015). The results shown include two public-private partnership (PPP) managed water systems in Madagascar where pressure transducers were installed in storage tanks to continuously monitor water levels and to analyse supply/demand flowrates. System functionality was then assessed using the duration that water levels were above or below selected thresholds and service access levels. Sustainability can then be assessed by whether the water system continues to function above selected thresholds and access levels over time. Beyond water delivery, the overall study also includes measuring functionality in terms of water quality and quantification of sustainability factors at the service provider, regional, and national levels.

   Preliminary findings presented here are part of a wider study currently in progress to improve water system planning and implementation using the PPP approach. In a PPP, the municipality collaborates with a partner, in this case Catholic Relief Services (CRS), to delegate water system management to an enterprise through an open bidding process. Through a formal contractual arrangement, the enterprise provides different options for customers to connect into the system, and meters are installed with payment schemes that reflect the level of service provided. Private connections allow for the optimal level of service where household connect directly into the system and pay the most per unit volume of water used. Social connections are shared amongst many households and provide an intermediate level of service where customers pay a lower rate, and public connections provide a basic level of service with the lowest unit

volume cost. Service options for customers include private, social, and public connection types, allowing users to access different service levels according to their ability to pay. Meters installed on the connections allow the enterprise to charge users according to how much water they use (CRS 2013). The PPP approach has received acclaim for its potential to increase the sustainability of piped water systems in rural towns when compared with the dominant approach of community-management (Annis & Razafinjato, 2012).

Contextual background

The overall research for this study includes ten project sites which have been constructed with USAID Rano HP and Ranon'ala funding. The two systems being reported in this paper are: Anivorano Est and Mananara Nord (Anivorano and Mananara). Both are on Madagascar's east coast and are struck annually by tropical storms from January through March. Rainfall continues all year round, and annual precipitation can reach over 4m. Anivorano is inland along a dirt road 17 km from a major paved roadway that runs along the coast north towards Madagascar's commercial center Toamasina. The gravity-flow water system in Anivorano was rehabilitated in 2010 and a PPP was established at the end of 2011 in which the municipality selected a newly created enterprise as manager. The system began with 53 private and 82 social connections. By 2015, 26 new private connections and one social connection had been added. The water system served an estimated 1,900[1] people in 2015, approximately 35% of the town's 5,500[2] inhabitants. Anivorano has a rectangular buried tank with a cross-sectional area 41.0 m^2, height 1.7m, and volume 69.7 m^3.

Mananara is a coastal town, 240 km north of Toamasina. While less than an hour away by plane, Mananara is several traveling by vehicle over a mostly unpaved road from Toamasina. The gravity-flow system in Mananara was rehabilitated in 2012 and a well-established enterprise with existing assets and investments in construction has been managing the system since 2013. In just two years the system grew from 210 private and 9 social connections to 591 private, 34 social connections and 1 public connection (also referred to as a monoblock). The Mananara system served an estimated 4,430[1] out of the town's 16,530[2] people in 2015, representing about 27% coverage. Mananara and has a cylindrical tank with a cross sectional area of 50.3 m^2, height 3.8 m, and volume 191.1 m^3.

Methodology

System functionality with respect to water delivery is evaluated using tank water levels and the flowrates into and out of the tank. Water level measurements are achieved through the installation of pressure transducers in storage tanks that continuously measure pressure at selected time intervals (Figure 1). Water levels are extracted from pressure readings, and the change in water level is multiplied by the cross sectional area of the tank and divided by the time step to calculate the flow of water through the tank.

The supply flowrate into the tank is determined by assuming that there is no outflow, or zero demand during certain periods. Figure 1 shows the water levels for a one-week period in January and demonstrates how the slope of the water levels can be used to estimate supply flowrate. For example, during this week, the water levels in the Mananara storage tank increase regularly during the evening hours. The rate at which the tank fills can provide for an approximation of the supply flowrate entering the system. Given the same circumstances, outflow from the tank can also be approximated by investigating the slope of the water level as the tank empties. In order to fully investigate demand flowrates however, the supply flowrate has to be included in a mass balance calculation where demand flowrate is equal to the change in water level, multiplied by the cross-sectional area, divided by the time step and then added to the estimated inflow. The lower portion of Figure 1 shows the calculated supply and demand flowrates for the one-week period corresponding to the water levels. The supply flowrate is approximated as being constant for each day and is based on the slope of the increasing water level during that period. The demand flowrate curve is variable throughout the day and is calibrated to zero using the supply flowrate.

From the estimate of demand flow, the total volume of water consumed can be calculated, and then divided by the number of users to estimate per-capita daily consumption. These estimates are then compared to per capita consumption data using household meters for validation. The system is evaluated using different service levels and optimal access with minimum threshold values for volume of water collected of 5, 20, 50, and 100 liters per capita per day (WHO, 2011).

Functionality using tank water levels is then evaluated with respect to the percentage of time that the tank water level is below or above selected thresholds (Figure 2). Water level thresholds and selected durations included here are less than 25% (tank empty), and greater than 75% (tank full), and are reported as a

performance efficiency (1-PE25) during the selected timeframe being considered. Graphically the results are reported as a percentage of a 24 hour day when the water levels exceeded the full or empty criteria.

Results and discussion

Figure 1 shows the water level results for a one week period for the town of Mananara. The maximum water level during this period occurred on January 10th and 11th when the tank was overflowing for 5.5 hours and 3.75 hours respectively. During the one-week period, the water tank was full for 35% of the time, and was empty for 8.9% of the time (as defined by the 75% and 25% thresholds). Using the performance efficiency analysis (1-PE25) the overall performance of the system was 91.1% for the one-week period shown. Figure 2 shows the monthly summaries for the performance evaluation analysis for both the Mananara and Anivorano locations and shows that the system performance varies significantly during the respective periods. In Mananara, the lowest performing periods (72.7%) was during the month of January when the tank experiences significant fluctuations in water levels for an extended period of time. In Anivorano, system performance was also variable with water shortages during the month of March when the system rarely exceeded the tank full criteria with a system performance of 77.8%.

  Table 1 shows daily summaries for Anivorano and Mananara for comparative purposes. A review of the results shows that both systems are functioning well, but that the Anivorano system provides significantly lower volumes of water per capita. It can also be seen that supply, demand, and system performance fluctuate on a daily basis which further justifies the need for continuous monitoring of water delivery services in order to achieve SDG Target 6.1. In Anivorano there are less days and shorter durations when tank water levels were below lower thresholds, and more days and longer durations when they were above higher thresholds. The system in Mananara exhibited decreased functionality in January, when more days and longer durations were below lower thresholds, and less days and shorter durations were above higher thresholds. The low functionality of the Anivorano system in March and the Mananara system in January may have been due to the effects of seasonal hurricanes that annually hit the east coast of Madagascar from January to March. For example, a tropical storm struck Madagascar on 16-Jan 2015, which could partially explain the lower performance of the Mananara system during that timeframe.
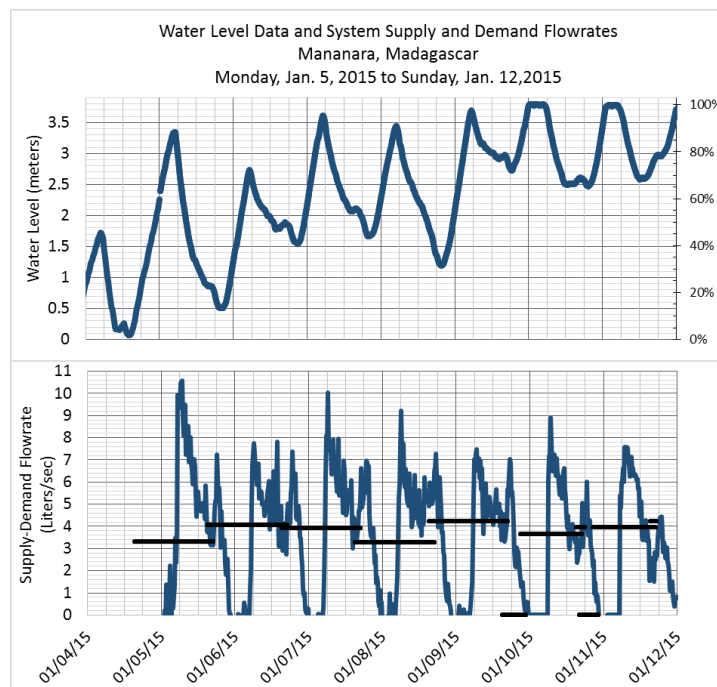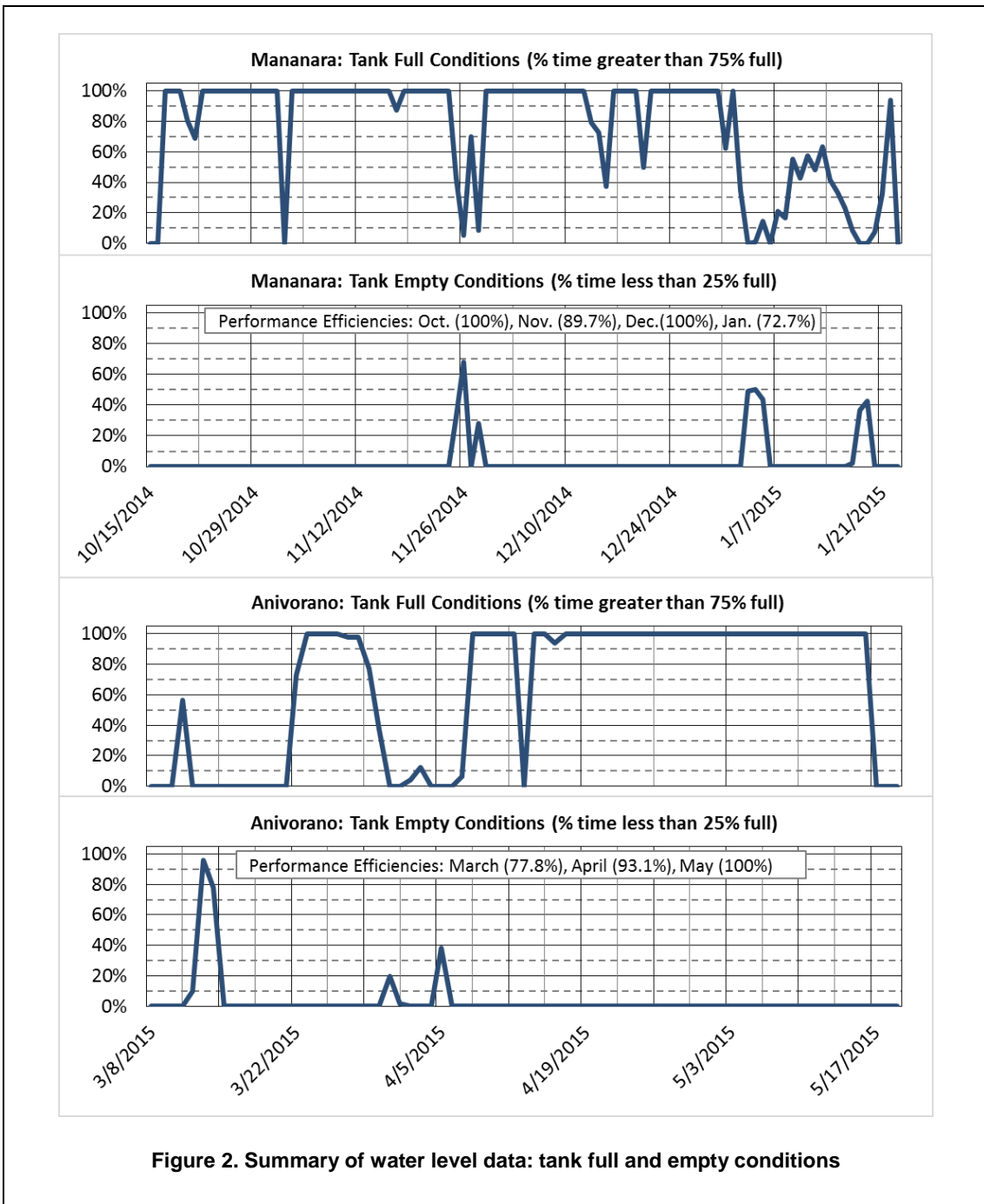

Figure 1. Mananara tank water levels and supply-demand flowrates

Figure 2. Summary of water level data: tank full and empty conditions

Whereas, households that have private connections would normally imply an optimal level of service, the reliability of that service and the volume of water being delivered also needs to be considered. At the same time, households with a shared connection (social) would normally be classified as an intermediate to basic level and would typically depend on the distance and time spent collecting water. Estimated per-capita consumption for Anivorano indicate that the system is currently providing a basic level of service, particularly when considering the volume of water collected (11.4 to 29.5 L/p/d) and the reliability of the service (60.4% to 100%). Estimated and metered per-capita consumption for Mananara indicate a volume of water collected between 63.1 and 77.8 L/p/d. The preference for private connections means that most of the population likely obtains water at the household level. Further considering the volume and reliability of the service in Mananara suggests that this system is providing close to optimal service levels. At the same time,

because of the potential for intermittent supply (based on results from November and January) it can be argued that this system is providing an intermediate/optimal level of service.

Table 1. Flow, Consumption and performance analysis							
Anivorano	**30-Mar**	**31-Mar**	**1-Apr**	**2-Apr**	**3-Apr**	**4-Apr**	**5-Apr**
Day of the Week	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.
Supply Flow (L/s)	0.31	0.34	0.30	0.83	0.48	0.37	0.33
Total Consumption (m^3)	40.7	49.3	21.6	56.1	44.8	48.1	41.8
Per-Capita Consumption (L/p/d)	21.5	26.0	11.4	29.5	23.4	25.3	22.0
Performance Efficiency (1-PE25)	100%	79.2%	97.9%	100%	100%	100%	60.4%
Mananara	**5-Jan**	**6-Jan**	**7-Jan**	**8-Jan**	**9-Jan**	**10-Jan**	**11-Jan**
Day of the Week	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.
Supply Flow (L/s)	3.33	4.08	3.95	3.30	4.23	3.65	3.95
Total Consumption (m^3)	344	306	334	295	278	258	268
Per-Capita Consumption (L/p/d)	77.8	69.1	75.6	66.6	63.1	75.9	73.5
Performance Efficiency (1-PE25)	56.3%	100%	100%	100%	100%	100%	100%

Table 2. Transducer estimated and metered water consumption		
	Anivorano	**Mananara[3]**
Average per-capita consumption (L/p/d) – Water Level Data	23	72
Average per-capita consumption (L/p/d) – Household Meter Data	21	86

Limitations and sustainability considerations

There are several limitations to this approach for measuring functionality for selected sites. First, water level data used here was not corrected for barometric pressure. Pressure transducers measured total pressure, hydrostatic plus barometric, and a fixed pressure offset was applied upon installation to make the transducers record approximate water depth. While calculation of supply and demand flows over several time steps may diminish errors caused by variations in barometric pressure, depth measurements can fluctuate by as much as 20 cm in a few hours at these sites due to barometric pressure and this could have affected consumption calculations. Additionally, the criteria used to estimate consumption using transducer data requires that water levels decrease below the tank's overflow for a significant period of time, in order to complete the supply and demand analysis. As a result, a continuous estimate of daily consumption may not always be feasible and comparison between sites will depend on overlapping time periods. Finally, in order to fully evaluate performance, measurements of water quality will be needed. Preliminary results (not reported here) do indicate that water quality could have a significant impacted on functionality. Both of the system studied during this phase of the research did include water quality analysis however, the results are too inconclusive to report on at this time. Anivorano regularly chlorinates the supply which could improve its overall performance and Mananara was not chlorinating during a visit in July 2015. Water quality sampling and analysis from the system in Mananara does suggest the presence of thermotolerant coliform which could place the system in a high risk category.

Lastly, only a qualitative assessment of sustainability is currently possible for the two sites. While details are omitted here due to the potential inclusion of sensitive information, the overall research plan includes

quantification of the different factors affecting system sustainability. The research team plans to use a hybrid of the USAID/Rotary International WASH Sustainability Index Tool and the STEEP tool (Ermilio, 2014) to assess sustainability. Continuous, objective measurement of water system functionality has the potential to improve water service delivery. Collected information informs local service providers, national governments and external organizations who are interested in monitoring progress towards achieving universal, sustainable water access. The work outline in this paper intends to report back local management, and Catholic Relief Services Madagascar to improve PPP water system planning and implementation.

Acknowledgements

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Note/s

1. The number of beneficiaries has been rounded up and is based on the average number of users per private (6.5) and social (16.7) connection in Anivorano from 2011-2012 data.
2. Population estimates in 2015 were obtained from pre-project feasibility studies
3. Total water consumption in m^3 for the Mananara system in January 2015 was estimated using the monthly revenue of 11,824,820 Ar ($3,704.60) and assuming a price of 1,000 Ar ($.31) / m^3.

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