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Performance of a Watergy Audit on the Submersible Pumps of the Talamban Raw Water System in Cebu City

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ABSTRACT

As part of its efforts to promote awareness of energy-efficiency in water-production and distribution companies in the Philippines, the Alliance to Save Energy (ASE) partnered with two provincial public water utility companies, one of which was the Metropolitan Cebu Water District in Cebu City. With the application of a methodology developed by the ASE and the Energy Research Institute (TERI) of India, a Watergy audit was performed on the submersible pumps of production wells within a selected raw water system of the MCWD, situated in the town of Talamban, Cebu City. The results of the audit led to the identification of opportunities for improvement of the pumps' performance and the formulation of recommended feasible measures toward attaining energy-efficiency.

Key terms: Energy Efficiency, Watergy, Specific Energy Consumption (SEC)

1. INTRODUCTION

The Alliance to Save Energy (ASE), a US-based coalition of prominent business, government, environmental, and consumer leaders, was geared to "'promote the efficient and clean use of energy worldwide to benefit consumers, the environment, the economy and national security."' This body's International Program aims to help save energy around the world through six programs: Education and Outreach, Policy Reform, Development and Capacity Building of Non-Government Organizations (NGO's), Energy Efficient Industry Partnerships, Policy Reform, Sustainable Cities Initiative and the Municipal Water Efficiency Program. The latter two programs focus on capacity building at the municipal level and creating strong links among the public, private and NGO sectors toward energy efficiency at this level.

One of the endeavors of the ASE under this program focused on municipal water supply systems. Pumping and treating water for urban and industrial use accounted for between 2% to 3% of the world's total energy consumption. This area poses opportunities for energy-efficiency

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activities which may lead to roughly 25% reduction in energy consumption. However, in studies done by this body, relatively little attention has been given to reducing energy use in municipal water systems. It was on this aspect that the ASE launched its water-energy efficiency program which they labeled as Watergy. This program was meant to present energy-efficiency measures leading to benefits such as monetary savings and subsequent environmental protection due to reduced energy consumption.

In some cities of developed nations such as the United States, Canada, Sweden and Australia, efforts were made by their respective water managers to save energy in their facilities. These accomplishments were noted by the ASE and served as models for developing their methodology for Watergy. This Alliance has also worked with developing countries in identifying opportunities in energy savings and the problems in achieving these. The Philippines was one of those countries covered by the ASE.

Watergy activities were piloted in two facilities in the Philippines. The first was in Iloilo City in the province of Iloilo. This was done by the ASE in partnership with the Metro Iloilo Water District (MIWD). On hand to perform the Watergy audit was The Energy Research Institute of India (TERI), the Energy Management Association of the Philippines (ENMAP) - a non-government organization focused on energy, and members of the Department of Mechanical Engineering and the Department of Electrical and Electronics Engineering of the University of the Philippines College of Engineering (UP-COE). The role of TERI was to perform an energy audit of the MIWD water treatment and pumping facilities, formulate and present ways to achieve energy-efficiency, and train and certify personnel from the MIWD as well as the participants from the ENMAP and the UPCOE on the methodology.

The other Philippine facility was the Metropolitan Cebu Water District (MCWD) in the province of Cebu. For this facility, the ASE contracted the ENMAP and the UPCOE to replicate the Watergy audit and capacity building activities done at the MIWD.

Entering full operation in 1970's, the MCWD, to date, services four major cities and four municipalities in the Metro Cebu region. At the time of the audit, the MCWD, in its annual report, recorded as having supplied a total of 51.95 million cubic meters of potable water with an average daily production of 142,300 cubic meters to serve 92,484 registered water concessionaires. This comprised about 45% of Metro Cebu's total demand. It sourced much of its water from 101 groundwater wells in operation at that time; in addition, it operates a dam, a desalination facility, and ten reservoirs among others. 97% of the water extracted and treated by the MCWD was groundwater; hence, its operations thrived on its groundwater wells. Table I shows the localities with corresponding number of groundwater wells operating under the franchise.

Since the time to perform the Watergy activity was one week, it was decided that a Watergy audit would be done on a selected number of wells by the ENMAP-UPCOE team to be assisted by personnel of the MCWD. Training of the MCWD personnel was to be done during performance of the Watergy audit and during presentation of all audit findings and energy-efficiency recommendations. It was intended that this activity would be replicated by the MCWD for the remainder of its groundwater stations. The Talamban wellfields were selected for the audit since this area was the most proximate to the main office of the MCWD, which served as the headquarters of the Watergy audit team. Likewise, Talamban accounted for 16% to 17% of the annual production of the MCWD, according to its records.

There are two water distribution systems in Talamban. Seven wells in the Talamban raw water system supply water to a 5,000 m^3 reservoir, whereas two others are direct supply wells.

Locality	Number of Groundwater Wells
Wellfields:	**Total: 67**
Talamban	9
Consolacion	8
Tisa-Pardo	8
Jaclupan	15
Mactan	5
Liloan	16
Mananga	4
Compostela	2
Direct Supply Wells:	**Total: 34**
Lahug-Guadalupe	15
Banilad-Talamban	7
Central Cebu City	5
Canduman-Cabangcalan	4
Ayala	1
Pardo	2

Table I. Breakdown of Cebu localities and corresponding number of groundwater wells operated by the MCWD

All seven wells supplying the reservoir were to be evaluated by the audit team. Each well is serviced by an electrically-powered submersible pump that is controlled via an electrical control panel. These control panels tap into the public utility lines. Focus of the discussion in this paper will be on the application of the Watergy audit methodology on these pumps.

2. METHODOLOGY

The methodology of performing a Watergy audit was outlined in the training materials supplied by ASE and TERI to participants in the MIWD audit and which is based on a document published by the ASE. The same procedure was applied in the MCWD case. This methodology is part of a four-step approach to energy conservation. The first step, intended for top management of the facility, concerns adoption of energy management and conservation. Step 2 describes an approach to identifying energy conservation opportunities through determining and recording energy consumption patterns, identifying areas or sections in the establishment that have significant influence to the said energy consumption patterns, searching for and identifying the possibilities of recovering losses and performance of an energy audit. The third step deals with action plan preparation and implementation, using details obtained from the second step. The last step is on sustaining the efforts toward energy conservation. Details of the energy audit steps are described in the same set of training materials and are enumerated below.

Data collection - In order to establish baseline figures for eventual development of energy-saving methods, the following data need to be collected from the records of the facility being audited:

- Capacity details, including network line diagrams, pipe sizes, elevations, population served and amount of water produced and consumed daily
- Specifications of energy consuming equipment such as performance ratings of pumps, motors and other major equipment
- Energy consumption figures and capacity utilization, based on meter readings indicated in the electrical bills assigned to the facility.
- Operating schedules assigned to each station and the number of hours of operation logged.
- Specific energy consumption (SEC),defined as the amount of energy consumed to process one million liters of water: in order to calculate this quantity, the energy consumption and total volume delivered within a given period are needed.

Observation, measurement and trials - These cover the following:

- Observation of present operating practices and parameters
- Study of records of operations
- Review of metering and monitoring facilities
- Measurement of performance and energy-related parameters for all energy sources and utilities using portable or on-site instrumentation - in the case of pumps, the parameters are the actual flow, the pump head and electrical power consumption
- Review of current maintenance practices
- Discussions with personnel and supervisors directly linked to operations

Data Analysis and Findings - From measurements taken in the previous step, the following are then determined:

- Current operating loads
- System operating efficiency
- Actual SEC and comparison with optimum achievable values
- Estimation of energy and water balances and corresponding losses
- Current system operational settings

It is from this step where measures toward system improvement would be identified. The equations used in data analysis are found in Appendix A.
Implementation of some measures and evaluation of same by trials - Whenever there are corrective measures in operational procedures or system settings that may be immediately implemented, these are done and data are collected. This may involve additional trial runs.
Techno-economic evaluation of measures - In this step, the identified ways of improvement of the system for energy efficiency are laid down and assuming proper implementation of these measures, the following projections are estimated:

- Energy and other related savings
- Cost savings from implementation of measures
- Required investments to implement measures
- Payback periods/rates of return

Detailed report preparation and presentation to concerned personnel and management - The report contains all information obtained from the preceding five steps.

3. ANALYSIS AND INTERPRETATION OF DATA AND RESULTS OF ANALYSIS

The following are the initial data supplied by the MCWD from their records for the establishment of baseline conditions.

Figure 1 below is a schematic line diagram of the seven pumping stations that feed the reservoir of the Talamban raw water system. The labels shown were assigned to these stations by the MCWD. The pipe sizes and materials are also indicated in the diagram.

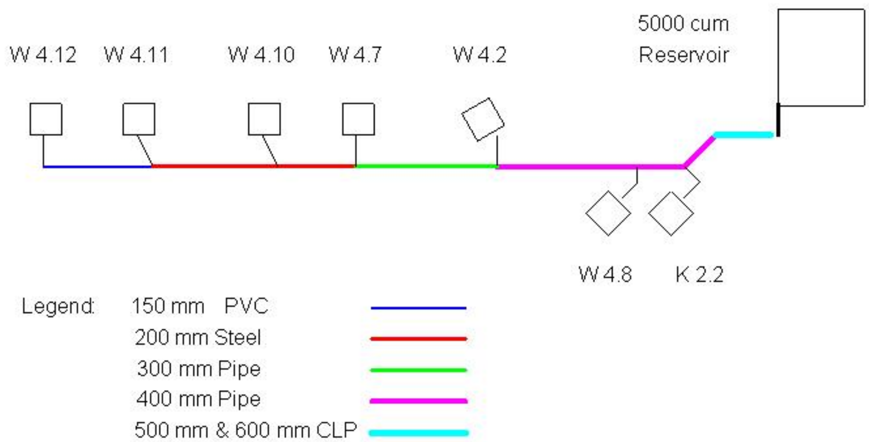

Figure 1. Schematic line diagram of the seven well stations linked to the reservoir of the Talamban raw water system in Cebu City

The elevations and distances between stations of the reservoir and the seven pumps are shown in Table II, using W-4.12 as the base location, as seen in this network's line diagram. In the same table are the measured discharge pressures of the pumps.

All of the submersible pumps in this particular system were old model single-speed units that went through several modifications in the past such that their characteristic curves deviated from those supplied by the manufacturers of the original models. *Hence, these pumps' ratings were based on curves supplied by MCWD resulting from evaluation of these pumps at its test facility.* These pumps' rated flow, head and efficiencies at the time of audit are shown in Table III.

Electrical energy consumption and costs of Talamban for the year prior to the Watergy audit were obtained from electric bills of the MCWD. Placed alongside these was the water production of the same network over the same period of time (Each pump operated for 22 hours daily) . The monthly SEC is then calculated from these two data. The trend in SEC of Talamban is shown in Figure 2. Based on calculations, the average monthly SEC of the Talamban system is 422 kW-hr/ML. By multiplying the cost per kW-hr to the SEC, the energy cost to pump 1 million liters would be determined.

In Table IV are the calculated heads for the pumps in the network. These values are obtained from the pump water level (data supplied by MCWD), the dynamic head through the pipeline

PUMP STATION NO.	GROUND ELEVATION, m	DISTANCE BETWEEN STATIONS, m	PRESSURE, psig
W-4.12	35.89	0.0	77.75
W-4.11	30.34	300.0	81.00
W-4.10	29.67	140.0	76.00
W-4.7	30.46	115.0	71.00
W-4.2	34.30	260.0	54.00
W-4.8	42.72	230.8	50.00
K-2.2	47.34	26.5	22.00
Reservoir Inlet	65.00	114.5	
TOTAL		**1186.8**	

Table II. Elevations, distances between stations and pump pressures of the Talamban raw water system

Pump Station	Rated Flow, m^3/hr	Rated Head, m	Rated Pump Efficiency, %
K-2.2	33.55	69.0	83.0
W-4.2	163.64	89.5	72.5
W-4.7	91.84	107.0	82.0
W-4.8	215.57	77.0	71.0
W-4.10	138.46	90.5	84.0
W-4.11	207.13	84.5	72.0
W-4.12	94.24	91.0	82.0

Table III. Rated flows, heads and efficiencies of the submersible pumps of the Talamban raw water system (based on MCWD pump test facility data)

and the pressure head, obtained from pressure gage readings.

Pumping station	K2.2	W4.2	W4.7	W4.8	W4.10	W4.11	W4.12
Pump H2O level, m	38.00	30.00	30.00	38.00	30.67	28.36	35.60
Pressure reading, psig	38.00	54.00	71.00	50.00	76.00	81.00	77.50
Pressure head, m	26.74	37.99	49.95	35.18	53.47	56.99	54.53
Static head, m	73.54	67.99	79.95	73.18	84.14	85.35	90.13
Dynamic head, m	0.00*	1.55	0.90	3.82	1.40	2.52	0.57
Total head, m	73.54	69.54	80.86	76.99	84.54	87.87	90.69

*Pipe sizes of this station are small such that the dynamic head developed are negligible.

Table IV. Heads developed at the pumping stations based on pump water levels, pressure gage readings and dynamic heads using pipe sizes and fittings

It is expected that the pumps contribute the largest share of the Talamban SEC. Table V

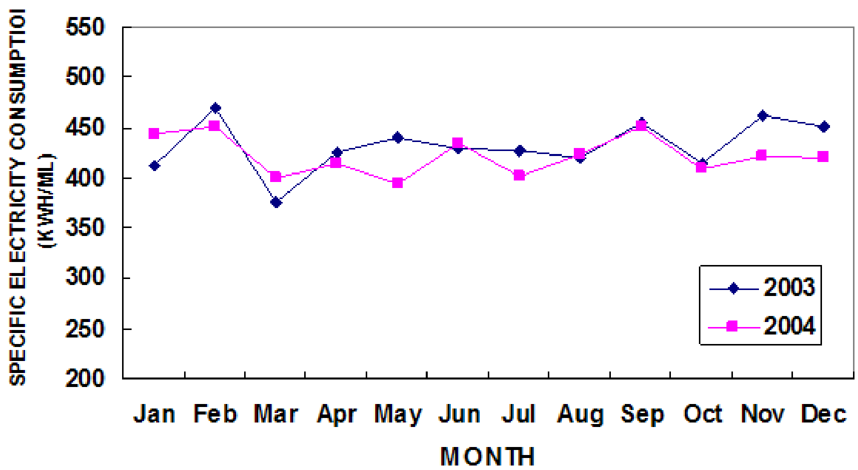

Figure 2. Specific Energy Consumption (SEC) of the Talamban raw water system

contains the results of analysis of data taken from readings done.

It must be noted that readings were done at the well sites and that the time when measurements were done was within the noontime, where loads were expectedly high.

PUMPING STATION	Input Power, kW	Pump Discharge (m^3/hr)	Head developed, m	SEC (kWh/ML)	Measured Pump Efficiency, %
K-2.2	8.80	17.04	73.54	516.43	45.0
W-4.2	51.80	158.60	69.54	326.61	67.0
W-4.7	43.13	122.60	80.86	351.92	73.0
W-4.8	76.80	214.00	76.99	358.90	73.0
W-4.10	53.23	151.40	85.54	351.62	78.0
W-4.11	84.63	207.26	87.87	408.30	69.0
W-4.12	35.53	85.55	90.69	415.34	70.0

Table V. Measured parameters of the pumps at the Talamban raw water system

As seen in Table V, the SEC's of four of the pumps (W-4.2, W-4.7, W-4.8, and W-4.10) were below the Talamban average, whereas one pump (K-2.2) registered the highest SEC (516.43 kW-hr/ML) as well as the lowest efficiency (45%). It is also worth mentioning that the pump at W-4.2 operated away from its best efficiency point, yet it also registered the lowest SEC in the group. This will be explained in the subsequent portions.

The average SEC of these pumps is 390 kW-hr/ML, which is 92.3% of the average SEC of the entire Talamban raw water system SEC (note that there were two direct supply wells in Talamban which were outside of the reservoir system which account for a significant portion of the remainder of the Talamban SEC).

Table VI is a comparison between each pump's rated flow and head at its best efficiency point and its measured flow, head and calculated efficiency.

Well: K-2.2	Flow, m^3/hr	Head, m	Pump efficiency, %
Rated	33.55	69.00	83.0
Actual, as measured	17.04	73.54	45.0
Well: W-4.2	**Flow, m^3/hr**	**Head, m**	**Pump efficiency, %**
Rated	163.64	89.50	72.5
Actual, as measured	158.60	69.54	67.0
Well: W-4.7	**Flow, m^3/hr**	**Head, m**	**Pump efficiency, %**
Rated	91.84	107.0	82.0
Actual, as measured	122.60	80.86	73.0
Well: W-4.8	**Flow, m^3/hr**	**Head, m**	**Pump efficiency, %**
Rated	215.57	77.0	71.0
Actual, as measured	214.00	76.99	73.0
Well: W-4.10	**Flow, m^3/hr**	**Head, m**	**Pump efficiency, %**
Rated	138.46	90.5	84.0
Actual, as measured	151.40	85.54	78.0
Well: W-4.11	**Flow, m^3/hr**	**Head, m**	**Pump efficiency, %**
Rated	207.13	84.50	72.0
Actual, as measured	207.26	87.87	69.0
Well: W-4.12	**Flow, m^3/hr**	**Head, m**	**Pump efficiency, %**
Rated	94.24	91.00	82.0
Actual, as measured	85.55	90.69	70.0

Table VI. Comparisons between rated and measured flow, head and efficiency of each pump of the Talamban raw water system

As shown in Table VI, the pump at W-4.8 has the most satisfactory performance since its measured flow and head are closest to the rated capacity at this pump's best efficiency point (bep), which implies that the pump matches the system, as is the correct practice. Furthermore, this pump had an SEC below the Talamban system average. In the same table, the pump at K-2.2 has the lowest efficiency, at nearly half of its rated value. The other pumps were all operating at efficiencies away from their respective bep's. In the case of W-4.2, which had the lowest SEC among the pumps, its computed efficiency indicated that it was operating away from its bep. It should be noted that the measured flow was close to the rated flow, but there is a 20 m difference between the rated and the operating heads, thus implying that a wrong-sized pump could have been installed in that well.

To further illustrate the differences between best and worst operation, the plots of the system operating points versus the performance curves of the pumps at W-4.8 and K-2.2, respectively, are shown in Figure 3. Similar plots for all the pumps are contained in Appendix B.

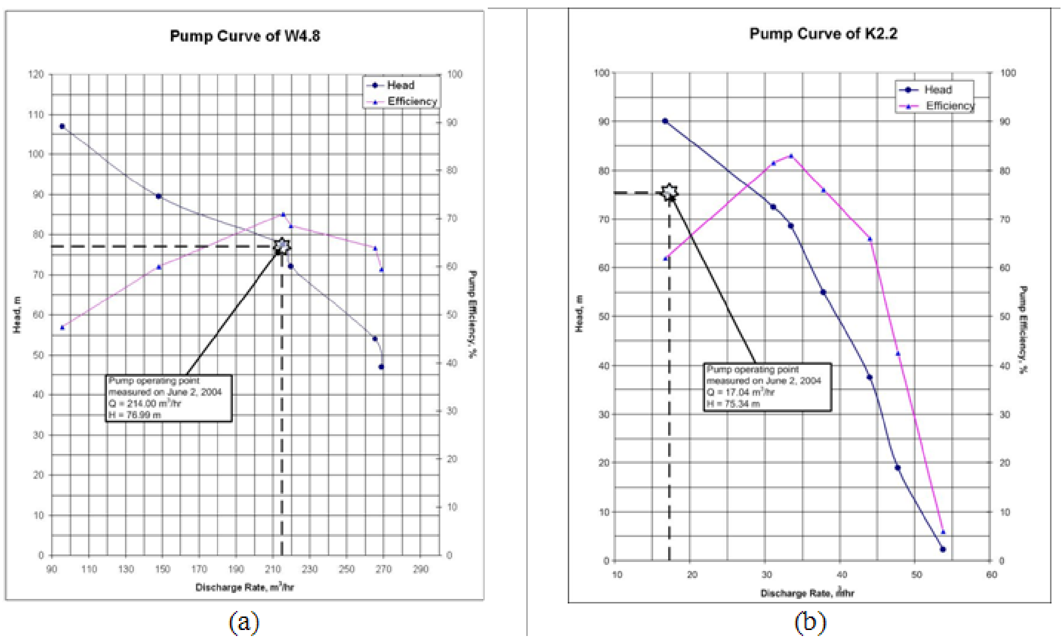

Figure 3. (a) A plot of the system operating point on the performance curve of the pump at W-4.8 (b) A plot of the system operating point on the performance curve of the pump at K-2.2

Deviations of measured pump operation from rated performance provide opportunities for system improvement leading to achieving energy efficiency. These opportunities range anywhere from maintenance to equipment issues. For each installation, all possible solutions were identified and classified, in this case, under cost level of investment. Citing the pump at K-2.2 as an example, all possible solutions regarding the pump were identified; the following summarized recommendations for improvement in pump performance are shown in Table VII.

A complete listing of improvement measures of all pumps covered is found in Appendix C.

Decisions on which measures to adapt would be made based on projected energy and cost savings and payback period. For example, if the system operating point is to be maintained, then replacing the existing pump with one that matches the system would be an option. Pump performance curves in manufacturer's catalogues may be used as reference for selection of the replacement unit. One such set of curves is shown in Figure 4. Referring to this figure, for the given head, the pump would have a discharge of approximately 19.4 m^3/hr and its efficiency is 74%. A 5.5 kW motor, with a rated efficiency of 79% for the specified load, is supplied with the proposed pump.

Pump: K-2.2	**No-Cost**	**Low-Cost**	**Medium-Cost**	**Major-Cost**
Issue: Measured operating point deviates well away from pump's best efficiency point	• Check the pump screen, casing and pipeline for blockages and remove these, then retest the pump for flow and head • Inspect the well for groundwater quality	• Check pump impellers and repair • Inspect and modify or replace pump discharge lines	• Modify or replace pump impellers	• Replace the pump with a unit that matches the system at pump bep

Table VII. Recommended measures for the improvement of pump performance at K-2.2

A comparison between the current pump at K2.2 and the proposed replacement, working under the same head, is shown in Table VIII.

Pump at K-2.2
Head: 73.54

Parameters	**Current Pump (measured values)**	**Proposed Pump (projected values)**
Flow rate, m^3/hr	17.04	19.40
Hydraulic Power, kW	3.41	3.89
Pump Efficiency	0.45	0.74
Motor Efficiency	0.86	0.79
Power Input, kW	8.80	6.64
SEC, kW-hr/ML	516.43	342.27
Daily production (22 hrs/day), ML/day	0.37	0.43
Daily energy consumption, kW-hr/day	191.08	147.18
Daily energy savings, kW-hr/day		43.90
Yearly energy savings, kW-hr/yr		16,034.48

Table VIII. Comparison between current pump at K-2.2 and the proposed replacement of the same pump showing potential energy savings

The savings in power costs could be determined from the results in Table VII. Payback period could be calculated by dividing the price of a new unit with the yearly cost savings. The same approach would be used to determine the feasibility of the other measures to improve efficiencies of all pumps.

4. CONCLUSIONS

Of the pumps tested for energy efficiency, W-4.8 had the best results, W-4.7 and W-4.10 were also satisfactory and K-2.2 presented the farthest deviation from its rated values and therefore, was the installation that required the most work to be done in order to improve performance.

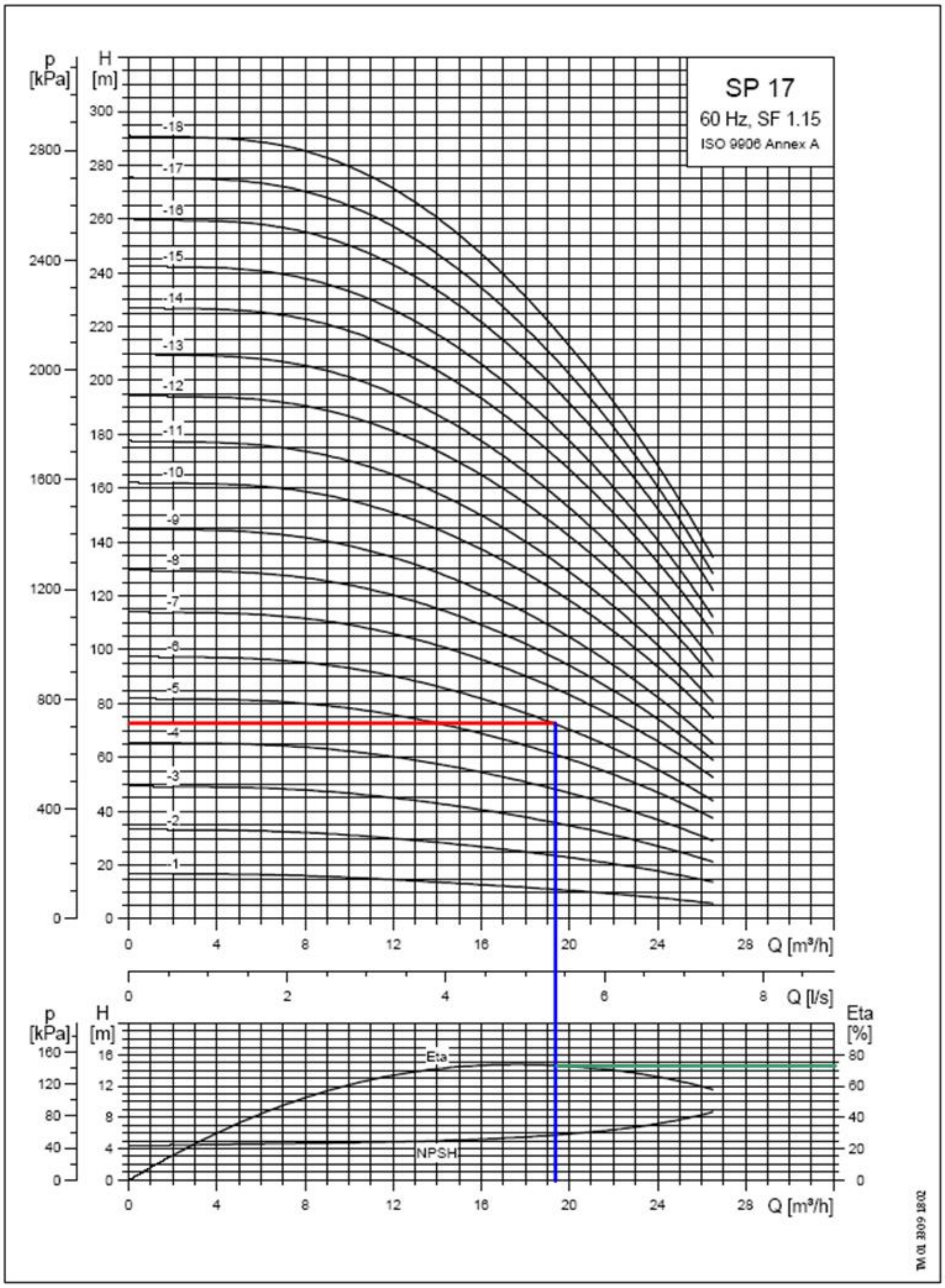

Figure 4. Pump curve of proposed replacement of unit at K-2.2 (from the Grundfos Data Booklet, www.grundfos.com)

The other stations also showed slight deviations from their respective rated performances and therefore require some light to moderate changes to bring these back to rated capacities. On the whole, with the exception of W-4.8, replacing the pumps with those that would match their respective loads could lead to more desirable energy efficiencies.

On the side, application of the Watergy audit methodology has resulted in ready identification issues of pump performance and the formulation of strategies in pump performance improvement toward attaining energy efficiency. The simplicity of the method makes it potentially attractive for the targeted local water utilities in assessing their systems' performance and developing ways of improving them. It enables the practitioner to produce and present data in a guided manner suitable for the intended readers. Furthermore, the approach is flexible such that it could serve as a framework for energy audit procedures for other facilities outside of water production and distribution.

Although highly significant savings in energy would be realized by improving performance of the pumps presented here, by no means are these the only equipment that have an effect on energy use. Opportunities in energy improvement have also been uncovered at the electrical systems and these may be covered in a separate paper.

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APPENDIX

Appendix A

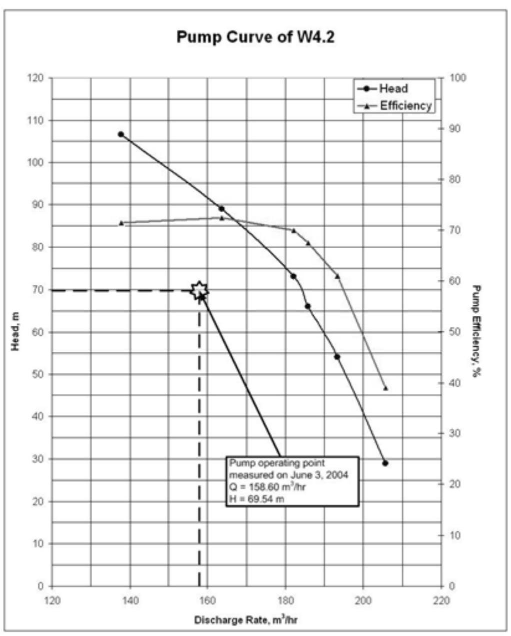
Equations used in the analysis of data collected during the audit

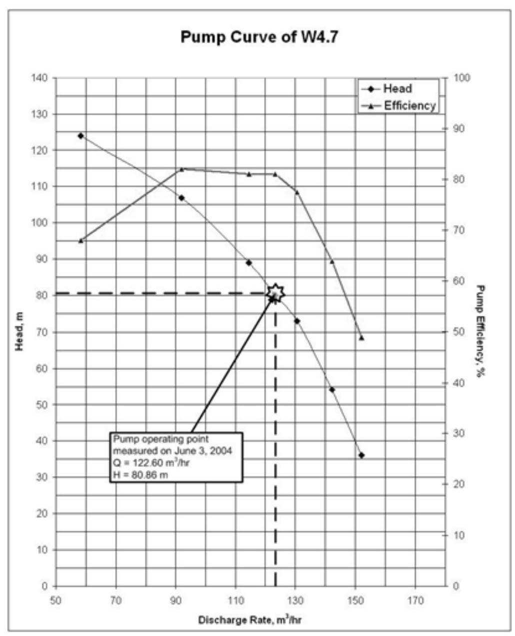
Pressure Head, m	$H_P = P_{gagereadinginpsig} \times 0.0704$
Hydraulic Power (kW)	$P_{water} = \frac{\rho g Q H}{1000}$
Pump + Motor efficiency	$e_{total} = \frac{Water\ Power}{Input\ Power\ (kW)}$
Pump efficiency	$e_{pump} = \frac{e_{total}}{e^{*}_{motor}}$
Specific energy consumption (SEC), kW-hr/ML	$SEC = \frac{Input\ Power\ (kW)}{Flow\ (m^3/hr)} \times 1000$

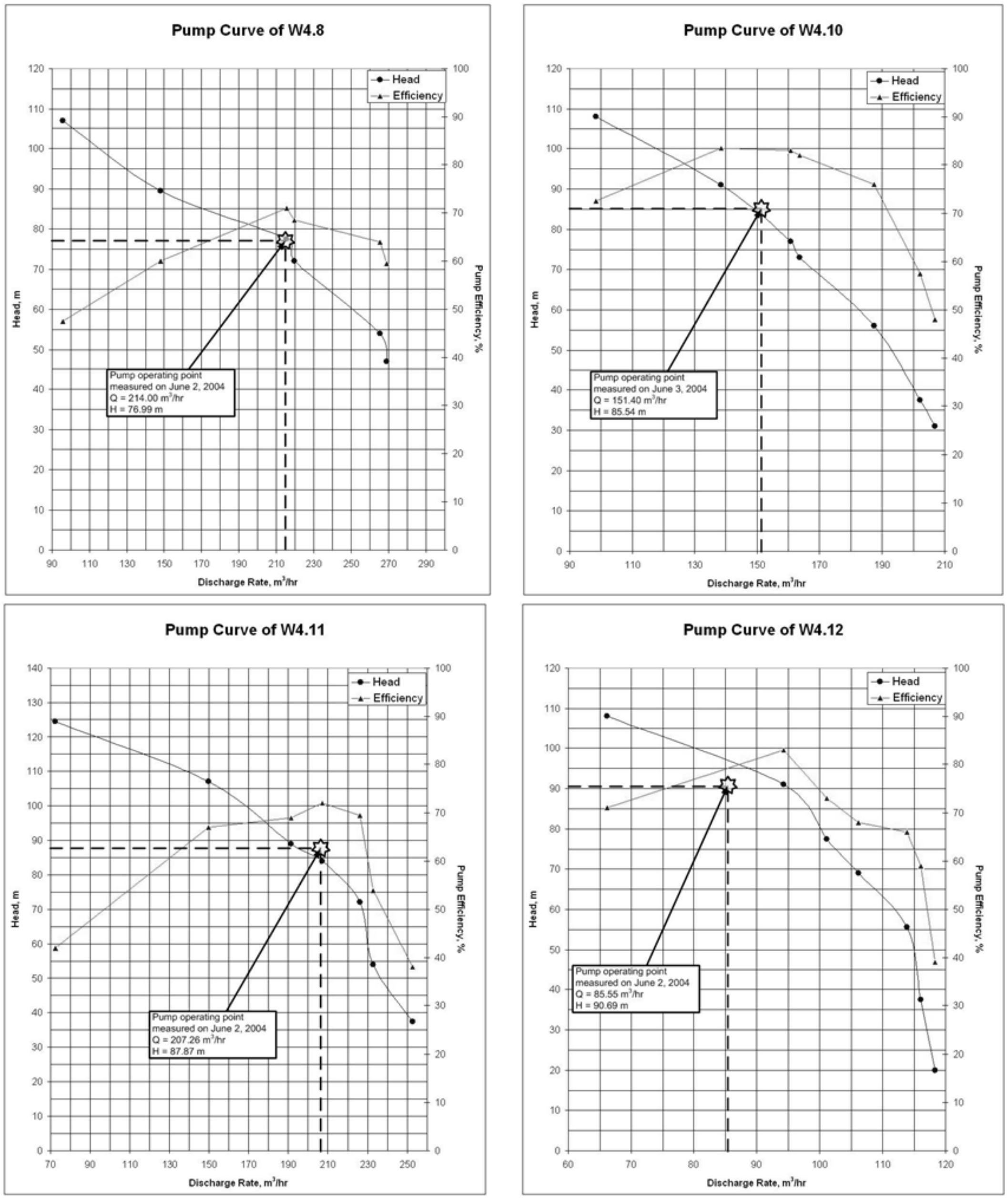
*motor efficiencies were based on test data supplied by MCWD

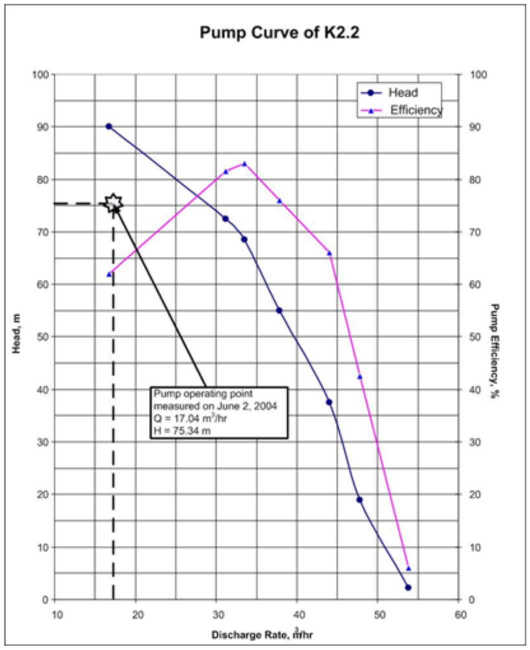
Appendix B

Characteristic Curves of Pumps of the Talamban Raw Water Distribution System (based on test data submitted by the Metropolitan Cebu Water District - MCWD)






Pump Curve of W4.8
Head
Efficiency
Pump operating point
measured on June 2, 2004
Q = 214.00 m³/hr
H = 76.99 m
Head, m
Pump Efficiency, %
Discharge Rate, m³/hr
Pump Curve of W4.10
Head
Efficiency
Pump operating point
measured on June 3, 2004
Q = 151.40 m³/hr
H = 85.54 m
Head, m
Pump Efficiency, %
Discharge Rate, m³/hr
Pump Curve of W4.11
Head
Efficiency
Pump operating point
measured on June 2, 2004
Q = 207.26 m³/hr
H = 87.87 m
Head, m
Pump Efficiency, %
Discharge Rate, m³/hr
Pump Curve of W4.12
Head
Efficiency
Pump operating point
measured on June 2, 2004
Q = 85.55 m³/hr
H = 90.69 m
Head, m
Pump Efficiency, %
Discharge Rate, m³/hr



Appendix C

Recommended Performance-Improvement Measures for Each Pump of the Talamban Raw Water System

Pump: K-2.2	**No-Cost**	**Low-Cost**	**Medium-Cost**	**Major-Cost**
Issue: Measured operating point deviates well away from pump's best efficiency point	• Check the pump screen, casing and pipeline for blockages and remove these, then retest the pump for flow and head • Inspect the well for groundwater quality	• Check pump impellers and repair • Inspect and modify or replace pump discharge lines	• Modify or replace pump impellers	• Replace the pump with a unit that matches the system at pump bep

Pump: W-4.2	**No-Cost**	**Low-Cost**	**Medium-Cost**	**Major-Cost**
Issue: Measured operating point deviates below the pump's performance curve/ actual head is lower than rated head at bep			• Modify or replace pump impellers to match pump with the system	• Replace the pump with a unit that matches the system at pump bep

Pumps: W-4.7, W-4.8, W-4.10	**No-Cost**	**Low-Cost**	**Medium-Cost**	**Major-Cost**
Issue: Pump operates within range of bep	• Regularly check the pump screen, casing and pipeline for blockages and remove these,			

Pump: W-4.11	**No-Cost**	**Low-Cost**	**Medium-Cost**	**Major-Cost**
Issue: Measured operating point slightly above pump performance curve/Improve on SEC	• Check the pump screen, casing and pipeline for blockages and remove these, then retest the pump for flow and head • Inspect the well for groundwater quality	• Check pump impellers and repair • Inspect and modify or replace pump discharge lines	• Modify or replace pump impellers	• Replace the pump with a unit that matches the system at pump bep

Pump: W-4.12	**No-Cost**	**Low-Cost**	**Medium-Cost**	**Major-Cost**
Issue: Measured operating point slightly below pump performance curve/Improve on SEC	• Check the pump screen, casing and pipeline for blockages and remove these, then retest the pump for flow and head • Inspect the well for groundwater quality	• Check pump impellers and repair • Inspect and modify or replace pump discharge lines	• Modify or replace pump impellers	• Replace the pump with a unit that matches the system at pump bep