AN ENERGY ASSESSMENT OF THE WATER PUMPING SYSTEMS AT THE GIGIRI PUMPING STATION

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DECLARATION

I. Student’s Declaration

I declare that this is my original work and has not been submitted to any university or any learning institution for examination or any academic achievement.

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Signature: ……………………………………………………

Date: ……………………………………………………………

II. Supervisors’ Declaration

I confirm that the above student carried out this project work under our supervision for the entire period of the project.

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Date: ……………………………………………………………

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Date: ……………………………………………………………

DEDICATION

I dedicate this project to my God and heavenly father, my entire family and my great country.

ABSTRACT

The current energy situation in the country is characterized by high demand for energy and escalating costs. As a result, peak electricity demand has risen to 1,107 megawatts (MW) against an effective supply of 1,135 MW, leaving a reserve margin of 4% against the desired 15% necessary for grid system stability [1]. Since energy demand is growing faster than the energy supply growth, it has become necessary for the country to manage its existing energy supply efficiently in order to prevent the imminent collapse of the country's electric supply system.

Municipal water pumping is an energy-intensive process. The cost per unit of electricity has continued to rise at the Nairobi City Water and Sewerage Company's Gigiri pumping station, with an increase of 54% from May 2010 to February 2012. The pumping station had a maximum electricity demand range of 1,314 kVA and 1,664 kVA during the period 2010-2011 and 2011-2012 respectively.

The Gigiri pumping station operates on a 24 hour schedule. There are four pumping units each comprising of an electric motor connected to a centrifugal pump, a capacitor, surge vessel, piping system and flow control accessories. The only source of energy at the pumping station is electricity.

The pumping station's average monthly electricity consumption was 882,753 kWh in the period 2010-2011 and 847,894 kWh in the period 2011-2012 with observed specific energy intensities of 0.667 kWh/m^3, and 0.629 kWh/m^3, respectively. The pumping station's average monthly flow discharge was 1,338,533 m^3 during the period 2010-2011 and 1,348,568 m^3 during the period 2011-2012.

The pumping station's average system efficiency stood at 49%, with the highest pumping system efficiency of 70% being attained when pump No.4 was running alone. The lowest pumping system efficiency of 34% was observed when running the parallel combination of the pumps No.1 and No.2.

The pump with the highest pump efficiency was No.4 with an efficiency of 74%. The lowest pump efficiency was recorded in the pump No.1 with an efficiency of 46%.

Areas in the pumping system that were identified for potential energy cost savings included: Efficient single pump operation in place of inefficient and mismatched parallel pump operation – with potential annual energy savings of KES 4,904,254 with an immediate and at no cost savings benefit, the adjustment of the best efficiency point (BEP) of the Pump No.1 through an overhaul with potential annual energy savings of KES 7,220,495 with a payback period of approximately 1.5 years and recovery of cooling water losses from the pump bearings with potential annual water and energy cost savings of KES 1,110,798 with a payback period of approximately 1 month.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

KAM – Kenya Association of Manufacturers

MW – Megawatt

kW – Kilowatt

HI – Hydraulic Institute (US)

NCWSC – Nairobi City Water and Sewerage Company

KVA – Kilo volt-amperes

kWh – Kilo watt-hour

MWh – Mega watt-hour

KES – Kenya Shilling

USD – US Dollars

BEP – Best Efficiency Point

MLD – Million litres per day

AWSB – Athi Water Services Board

ASME – American Society of Mechanical Engineering

ANSI – American National Standards Institute

BEE – Bureau of Energy Efficiency (India)

LCC – Life cycle costing

HVAC – Heating, Ventilation & Air Conditioning

TDH – Total dynamic head

m^3 – Cubic meter/ 1,000 Litres

AC – Alternating Current

kV – Kilo-volts

DOE – Department of Energy (United States)

NEMA – National Electric Motors Manufacturers Association

VFD – Variable frequency drives

EPACT – Energy Policy Act of 1992

PSAT – Pumping System Assessment Tool

PSM – Pump Systems Matter

KEBS – Kenya Bureau of Standards

KPLC – Kenya Power and Lighting Company

HV – High Voltage

LV – Low voltage

CHAPTER 1: INTRODUCTION

1.1 Background

Pumping systems are used throughout the world to transport water and other fluids and in the operation of most industrial processes. Commercial and residential buildings also rely on pumps for heating and cooling, fire protection and other functions. Pumping systems account for nearly 25% of the energy consumed by electric motors, and for nearly 20% to 60% of the total electricity usage in many industrial, water, and wastewater treatment facilities. [2]

Municipalities are spending large amounts of their revenue on purchasing energy for providing local public services such as street lighting and water supply. Water pumping being a 24 hour operation tends to be a more energy intensive process. Through effective energy management practices and periodic energy audits, much energy savings can be realized in pumping systems.

Municipal energy efficiency saves on much needed funds and is capable of stretching tight budgets, giving citizens improved access to electricity and water services. Energy efficiency in municipal water supply systems can save water and energy while reducing costs and improving services at the same time.

For financial managers of local public services, efficiency in the provision of energy and water is one of the few cost-effective options available for meeting growing demands for vital services such as electricity, water and wastewater treatment and supply.

The economics of industrial production, the limitations of global energy supply and the realities of environmental conservation are currently challenges that we face as we industrialize. As energy costs increase, pump manufacturers are increasingly making equipment more energy efficient. Traditional methods of specifying and purchasing piping, valves, fittings, pumps and drivers often result in lowest first cost, but often produce subsequent unnecessary, expensive energy consumption and higher maintenance costs.

A municipal water pumping system that incorporates the energy, reliability and economic benefits of optimum pumping systems can reduce costs, gain pumping efficiency and improvement opportunities and can have confidence to move ahead with essential capital upgrades necessary for water services provision. [3]These measures will play a role in meeting the challenges of rising energy prices, population increase leading to an increased demand for water in the city.

To successfully invest in energy efficiency, an assessment of the water pumping system is necessary. It is paramount to establish the energy balance in the system, which is comparing the energy input into the system against the energy transferred into the fluid. This will involve analyzing flow, pressure and electrical readings as well as analyzing the pumping stations energy bill and demand profiles.

1.2 The NCWSC Gigiri Pumping Station

The pumping station that was assessed is the Gigiri pumping station. It is located in Gigiri about 12 km from the Nairobi city centre and is behind the United States embassy and the United Nations complex.

This pumping station is the largest among the various pump houses within the NCWSC. This is also the largest municipal water pumping station in East Africa. At a glance, the pumping station delivers on average 48 million liters per day (MLD) or 1.4 million cubic meters per month to the Kabete reservoir, while consuming about 900 MWh of electricity every month. The static head, which is defined as the height difference between the Gigiri pumping station and the Kabete reservoir is 136 meters. The length of the pipeline is 9,300 meters while the water pipe diameter is 0.7 meters.

The pumping station is run by an Operations and Maintenance Engineer supported by 20 technical staff comprising electrical technicians, mechanical technicians and artisans.

1.3 The Pumping station process

The Nairobi City Water and Sewerage Company (NCWSC) is the municipal entity responsible for supplying water to the city of Nairobi and its environs – and cater for approximately 4 million residents. The water is sourced from Sasumua and Ndakaini dams. Raw water from Ndakaini dam is piped to the Ngethu treatment works and thereafter flows by gravity to the Gigiri pumping station where it is pumped to boost supply to the high level areas in the East and West of the city via the Kabete reservoir. The Gigiri reservoir also serves the city center and surrounding areas by gravity. Figure 1-1 shows a schematic of the pump configuration at the station.

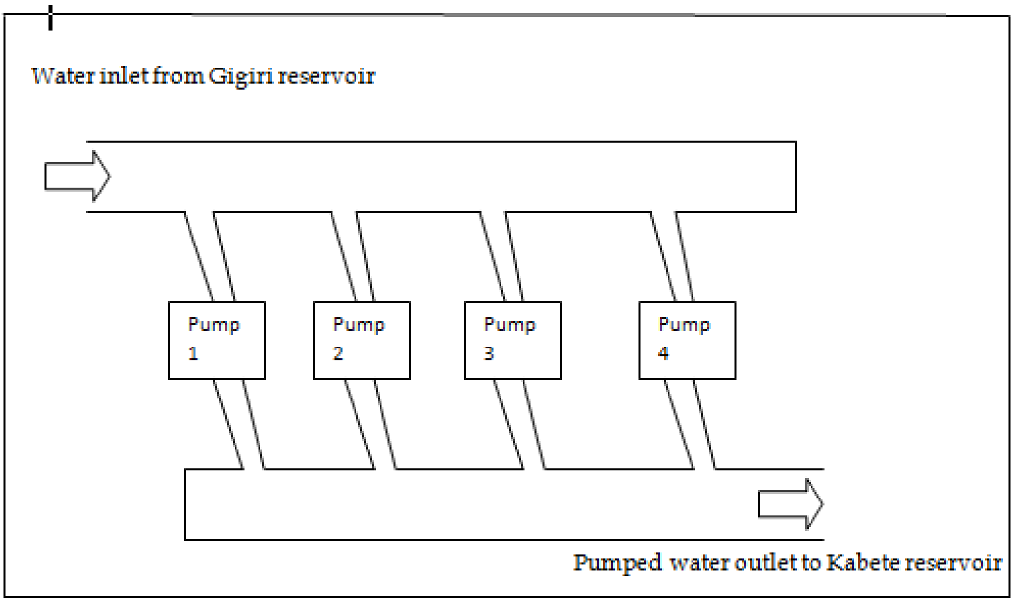

Fig 1-1: Pumping station schematic. (Source: NCWSC Gigiri Station Manual)

The water pumping system at the NCWSC Gigiri plant consists of a 66 kV substation with a transformer, two underground reservoir tanks with a capacity of 45,000 cubic meters each, a pump house consisting of 4 heavy duty motors each connected to a centrifugal pump by a propeller shaft, flow instrumentation, accessories and a motor control panel.

The Gigiri pumping station is a high energy intensity facility with high inductive motor loads. The station runs on a 24 hour basis throughout the year and was commissioned in 1985.

According to the NCWSC, current water demand for the city of Nairobi stands at 540,000 cubic meters per day and is expected to rise to 800,000 cubic meters per day by the year 2020. However, only 400,000 cubic meters is delivered to the city due to constraints on the distribution system. The Gigiri reservoir in total discharges 250,000 cubic meters of water per day to the city.

1.4 Problem Statement

Municipalities like the NCWSC are spending large amounts of their revenue on purchasing energy for providing local public services such as street lighting and water supply, and with a projected increase in population and water demand, energy costs are bound to further increase.

Over the years little attention has been given on energy management issues – but in the wake of the recent energy crisis, the cost and non-availability of electricity has been on the rise.

Initial analysis of the pumping station energy bills show that in June 2009, the fuel cost component was 4.68 KES per kWh compared to June 2011 which was 7.15 KES per kWh of electricity. This has led to the increase of the price of water for every 1,000 Liters consumed after transferring this cost to the consumer. This is not sustainable in the long term since water is a basic need that should be accessible to all at the lowest cost.

The Gigiri pumping station was observed not to have an organized system in place to adequately check, measure and record power, flow and pressure readings that are crucial for evaluating the energy performance of a pumping system.

Furthermore, a recent energy audit of water service providers countrywide by the Kenya Association of Manufacturers (KAM) did not cover crucial aspects of pump and system efficiencies. [4]

Energy efficiency in water pumping systems saves on running costs, hence giving city residents' better access at the lowest cost to this basic service. The study therefore is aimed at determining the current efficiency levels and operating conditions of the water pumping systems at the Gigiri pumping station to reduce the energy costs. The study will then analyze the historical data and measurements taken to identify energy saving opportunities within the facility.

1.3 Objectives of the Study

The general objective of this assessment is to establish energy cost savings opportunities at the NCWSC Gigiri pumping station.

The specific objectives are:

(i) To survey and establish the existing operating conditions of the main pumping system components i.e. the Motors and centrifugal pumps.

(ii) To establish the energy consumption patterns for the past 2 years and determine the flow-power relationship.

(iii) Using collected data to identify energy cost saving opportunities.

(iv) Perform energy economics analysis of identified opportunities.

CHAPTER 2: LITERATURE REVIEW

Pumping systems are critically important in many commercial operations. In industrial applications such as power and in municipal water pumping systems, pumps directly support production processes and run as often or even longer than any other equipment at the facility. The amount of energy consumed by many long-running pumping systems often results in a substantial addition to a plant's annual operating costs. About 27% of all the energy consumed by motor driven equipment in manufacturing facilities is used to operate pumps [5]. As a result, pumping systems are a high priority target in efforts to reduce energy consumption in motor driven systems.

Pumping system characteristics and needs range widely, but they can be classified in general as either closed-loop or open-loop systems. A closed loop system recirculates fluid around a path with common beginning and end points. An open loop system has an input and an output, as fluid is transferred from one point to another. Pumps that serve closed loop systems, such as a cooling water system, typically do not have to contend with static head loads unless there are vented tanks at different elevations. In closed loop systems, the frictional losses of system piping and equipment are the predominant pump load. In contrast, open loop systems often require pumps to overcome static head requirements as a result of elevation and tank pressurization needs.

According to the American Society of Mechanical Engineers (ASME) [6], an assessment of a pumping system should consider the interaction between the pump and the other system components but not the pump alone. This is because the system components play a big role in determining the operating conditions, pump efficiency, overall system efficiency and energy consumption.

Pump speed control includes both mechanical and electrical methods of matching the speed of the pump to the flow/pressure demands of the system. Adjustable speed drives (ASD's), multiple-speed pumps and multiple pump configurations are usually the most efficient flow control options, especially in systems that are dominated by friction head. This is because the amount of fluid energy added by the pumps is determined directly from the system demand. Pump speed control is especially appropriate for systems in which friction head predominates. At the Boise paper manufacturers in the United States [7], the bleach plant which had depended on a 150 horsepower pump for process requirements could not match with the production demand and hence caused huge production bottlenecks. An assessment found that the pumping system's pump was inadequate for peak demand which led to cavitation in the piping. The assessment recommended splitting the system by dedicating a 50 horsepower pump to low head applications while using the existing pump for the high head ones. Both pumps were also retrofitted with variable speed drives (VSD's). These changes yielded approximate annual energy and energy cost savings of 498,000 Kwh's and USD 15,157 respectively. There was also a reduction in the frequency of replacement of the pump bearings and check valves, resulting in savings of about USD 2,500 in annual maintenance cost savings.

In some cases, pumping system energy is used quite efficiently while in others it is not. Facility operators are often very familiar with the controllability, reliability and availability of pumping system equipment, but many might not be as aware of the system efficiency issues hence there are good reasons to increase awareness. For instance, there is a strong correlation between the reliability of pumps and their efficiency; i.e. pumps that operate close to their best efficiency point tend to perform more reliably and with greater availability [8].

The motor power required to generate the head and flow conditions in a pumping system is slightly higher. This is mainly because of the motor and pump inefficiencies. The efficiency of a pump is measured by dividing the fluid power by the pump shaft power, which is for the case for directly coupled pump/motor combinations. Pumps have varying efficiency levels. The operating point of centrifugal pumps at which their efficiency is highest is known as the best efficiency point (BEP). Operating a pump at or near its BEP not only minimizes energy costs, but also decreases loads on the pump and maintenance requirements. Systems with high annual operating hours incur high operating and maintenance costs relative to initial equipment purchase costs. Inefficiencies in high run-time and oversized systems can add significantly to the annual operating costs. Chevron, the largest oil refiner in the United States came up with a project to downsize the pumps in its diesel hydro treater (DHT) in an attempt to save energy. As a result of the pumps being grossly oversized, they were operating at 40% below the best efficiency (BEP) point and resulting in low hydraulic efficiency and excessive vibrations. The measures put in place involved the installation of variable speed drives (VSD's) on the feed and product pumps, replacing the internal vanes of the secondary feed pump and changing the operating procedures for the main back-up pumps. This resulted in reduced energy consumption by 1 million kWh per month translating to annual savings of about USD 700,000 annually and hence eliminated demand charges on the DHT's operations. Improved equipment reliability and process control was also achieved. [9]

A systems approach can be effective in assessing system performance, solving operating problems and finding improvement opportunities. In this approach, both the demand and supply sides of the system and how they interact are analyzed. This shifts focus from the performance of individual systems to that of the systems as a whole. For example, although a pump might be operating efficiently, it could be generating more flow than the system requires. The General motor corporation (GMC) in the United States was due for major renovations at the Pontiac operations complex and had to relocate the facility's water booster pumping system. Using a systems approach and careful analysis, a highly efficient pumping system appropriate for the current plant requirements was developed. Because of a sizeable decrease in the workforce and production at this facility, the demand for water had significantly decreased. Hence in relocating the pumping system, GMC was able to replace the 5 original 60-100 horsepower pumps with three 15 horsepower pumps whose speed could be adjusted to meet plant requirements. As a result, GMC reduced pumping system energy consumption by 80% i.e. 225,100 kWh per annum, saving an annual US $ 11,255 in pumping costs. [10]

A study done by the United States Department of Energy (DOE), show that almost 67% of the potential energy savings for motor driven systems involve optimization and assessment [11]. As a result a program has been developed that is computer based known as the Pumping System Assessment Tool (PSAT), and is used to identify opportunities to improve pumping system efficiency. PSAT software can be used to estimate the efficiency of a system based on specific inputs. The software program is supported by fundamental electrical, mechanical and fluid power relationships, as well as typical performance characteristics from industry standards and databases. The field measurements taken of fluid and electrical parameters will constitute the input values.

PSAT estimates the efficiency of an existing motor and pump using field measurements and nameplate information. It also estimates achievable efficiencies if the motor and pump were optimally selected to meet specified flow and head requirements. The software will then combine the two results and determines potential power savings. PSAT then estimates the potential cost and energy savings based on user specified utility rates and operating times. An energy assessment was conducted by the United States department of Energy (DOE) on the pumping system of a fiberglass manufacturing company called Owens Corning Corporation [12]. The application of PSAT revealed three energy saving opportunities that had little or no capital costs and short term payback periods. These included the performing of regular evaluations of pump efficiencies and making use of the most efficient pumps, the repositioning of the tank discharge lines as well as the re-evaluation of flow rates to reduce excessive flows. The combined annual energy savings for these measures was estimated at USD 122, 000.

The United States department of Energy (DOE) has also developed a motor database software known as the MotorMaster+ [13]. The program consists of an extensive database of motors constructed using data supplied by motor manufacturers, including a comprehensive list of parameters such as motor rated power, efficiency, power factor, speed, full-load current, enclosure style, NEMA (National Electric motors Manufacturers Association) design type, rated voltage and price.

After the database was filtered to ensure a homogeneous and representative motor population, the database was used to develop the algorithms used in PSAT. The database was first limited to include only 460 Volts NEMA design B motors, which is the design type used on most pumps. The database was next sorted and classed according to rated power and number of poles and filtered to exclude inconsistent entries. After categorization of the motor population by size, speed and efficiency class, the average performance characteristics (current, power factor and efficiency versus load) were established. From these average values, the curve fits of these performance characteristics were created.

According to the DOE, the performance of motors can vary within a given power, speed and efficiency class. However, in comparison to other uncertainties surrounding pumping system field measurements, the variability in motor data is relatively small. Many interdependencies in motor performance characteristics also exist. E.g. the efficiency and current are functions of motor size, number of poles (speed), load and voltage.

The MotorMaster+ program allows motor efficiency to be estimated based on the motor's size, speed and either motor input power or current measurement. If power is measured, PSAT will determine the shaft power and efficiency that is consistent with the specified motor size and speed. If current is measured, power is estimated from current versus load profiles in PSAT. A full set of motor characteristics (shaft power, current, power factor and electrical power) can be established regardless of whether current or power is measured. Although the motor characteristics used in PSAT were derived for 460 Volts motors, the user can select from other nominal voltages i.e. 230, 2300, 4160 and 6,900 Volts. The current data is linearly adjusted for nominal voltage. Most motors used on pump systems are the NEMA design B.

The Hydraulic Institute (HI) has published a standard [14] that provides guidance on achievable efficiencies. The standard addresses the effects of general pump style, capacity, specific speed and variability in achievable efficiency from other factors such as surface roughness and internal clearances. The HI standard explains through a series of steps, from reading a graph to determination of efficiency at an optimum specific speed for the selected pump style and flow rate. The PSAT software uses curve fits of the graphical data included in the HI standard to estimate achievable efficiency.

From the input data, PSAT first estimates the existing shaft power from the motor data measurements. It will then calculate fluid power from the specified flow rate, head and specific gravity. From this point, the motor input power, the shaft power and the fluid power are known, together with the existing motor and pump efficiencies. If the fraction of time the pump is operated and the electricity cost rate are given, then the PSAT will also determine annual energy use and energy costs.

The Gigiri pumping station experiences a lot of water leakage particularly at the water pump and bearing interfaces, where uncontrolled leakage of water during pumping at the mechanical seals was visible. There was also water leaks noted at the pump input shaft bearings which are water cooled. The cooling water enters the bearing from the discharge pipe, and then exits to the drainage system. It is worth noting that this water flows all the time irrespective of whether the pump is running or not hence presenting a case of excessive water leakage and water loss. The relationship between leaks, water loss, and energy costs has also been explored in past research. According to a study done by Jordan Harrison in his research titled: Connecting the Drops: The Potential for Energy Conservation in Ontario's Municipal Water Sector[15], he gives a brief that through computer simulation, he concludes that leaks substantially increase energy costs for both pipe segments and distribution networks. He goes on to mention that non-revenue water in Ontario averages 12% of the total water that goes through the system. This is in contrast to the Nairobi Water Company's 60% of non-revenue water that goes through the system [16].

Leaks increase the energy consumption of a system by creating extra demand and thus, requiring extra pumping. Leaks represent a fraction of energy that has gone into the water that cannot reach the end point. The extra demand that a leak imposes means that the pump must bring water from the source to the leak, water that is energized through pressure and velocity. If this water escapes from a leak in an underground water main, it is now useless and an opportunity cost is paid in terms of energy that could be applied to a more useful purpose. In the presence of leaks, pumps must work harder to maintain the same level of service.

An energy assessment done on a municipal pumping system in Ahmedabad, India by the UN-HABITAT sustainable urban energy planning program – SUEP [17], revealed that capacitors on water pump motors reduced power consumption by 12.6%, resulting in financial savings of over USD 50,000 a year. The city also replaced its steel water pipes with bigger diameter poly vinyl chloride pipes, which reduced friction in the pipes and improved energy efficiency. These changes reduced energy consumption by an estimated 1.7 million kWh each year and saving USD 100,000.

A similar assessment was done by the UN-HABITAT-SUEP program in the Metropolitan system of water in Mexico City that has a population of 628,000 residents. The project achieved savings mainly from supply side strategies which were the optimization of electromechanical efficiency resulting in savings of 153,254 kWh per month with a payback period of 1.7 years, and leak detection and water conservation resulting in savings of 35,500 kWh per month. The baseline energy intensity taken at the beginning of the program was 0.48 kWh/m^3. Over the period of the assessment, the energy intensity had been reduced to 0.39 kWh/m^3 resulting in USD 394,000 savings for the utility.

An energy assessment done at the Accra – Tema water supply system in Ghana [18] consisting of the Weija water works, Accra booster station, Tema booster station and the Kpong water works revealed two energy saving opportunities after analysis of the pumping and electrical systems. The first was increasing the rated flow to the required pump flow rate at a cost of USD 250,000 leading to annual energy savings of 977,500 kWh and giving a payback of 3.8 years. The second energy saving measure involved increasing the power factor from 0.88 to above the minimum of 0.90. The capacitor bank was replaced at a cost of USD 18,000 leading to energy savings of 5,189 kWh and giving a payback of 0.63 years.

An energy audit for Municipal Water Service providers in Kenya was carried out by an industry lobby group in 29 municipalities this year, and the results revealed accrued energy saving measures worth KES 103,839,464 in savings to the companies which would be realized by investing KES 120,220,302 in energy saving projects.[19] The energy audit showed that electricity was the main source of energy, and the overall average results showed that 8% of the current energy consumption could be saved by carrying out projects with an average payback of 1.16 years as shown in figure 2-1.

Table 2-1: Average energy consumption and savings in 29 water service providers. (Source: KAM report on energy audit for water service providers in Kenya)

	Energy usage kWh	Specific energy usage kWh/M3	Average PF	Total energy cost KES	Total energy savings kWh	% Energy savings	Total cost savings KES	% Cost savings	Total investment KES	Payback period years
Total	60,579,636			964,736,629	4,655,760		103,839,464		120,220,302	
Average	2,163,558	0.56	0.89	34,454,880	166,277	8%	3,708,552	10.8%	4,293,582	1.16

The energy audit also showed that the expected percentage energy cost savings of each water company were not necessarily related to the size of the water company. The Mombasa Water Company with an annual water production of 22,280,860 cubic meters revealed an energy cost saving of 1%, while the smallest water company sampled which was Meru Water Company with an annual water production of 166,486 cubic meters realized a 20% energy cost savings. There was no relationship between the annual water production and projected energy savings.

From the energy audit 20 energy saving opportunities were identified and were summarized in various ways. The most common opportunities were lighting improvements, power factor correction, operational improvements and the use of energy saving motors. This is shown in figure 2-1.

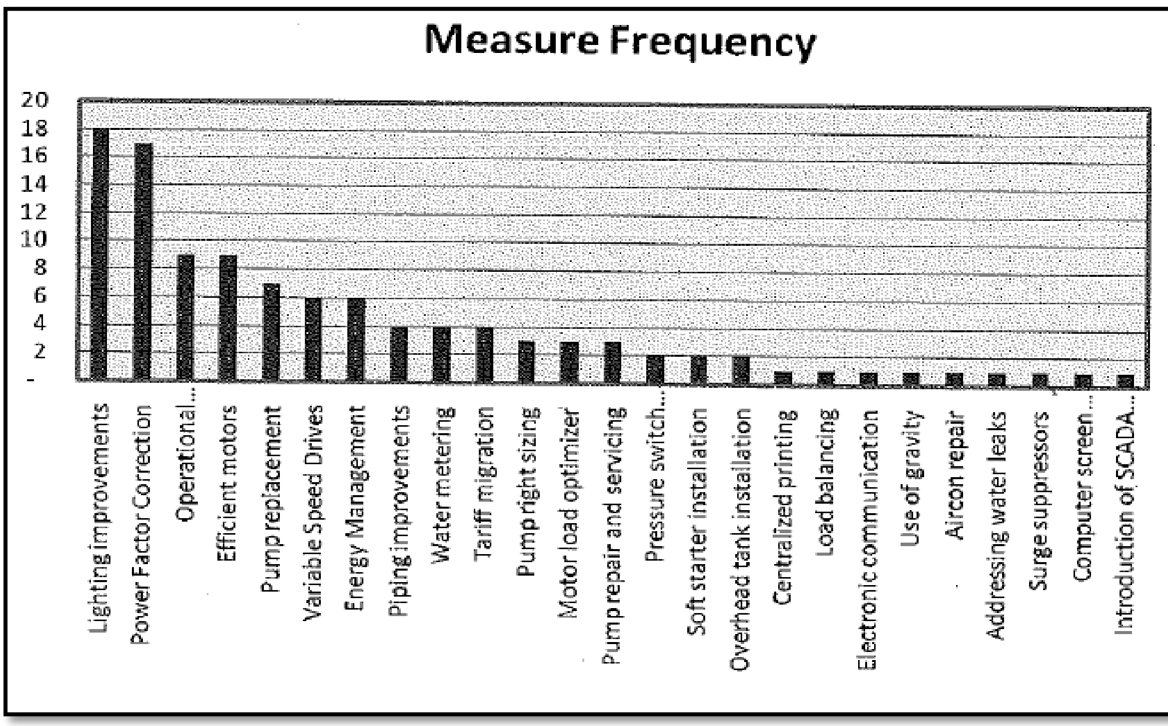

Fig 2-1: Measures/ Opportunities by frequency of occurrence. (Source: KAM)

From the energy audit, the biggest gains in energy saved came from correct pump sizing, efficient motors, pump replacements, developing energy management systems, lighting and piping improvements. This is shown in figure 2-2.

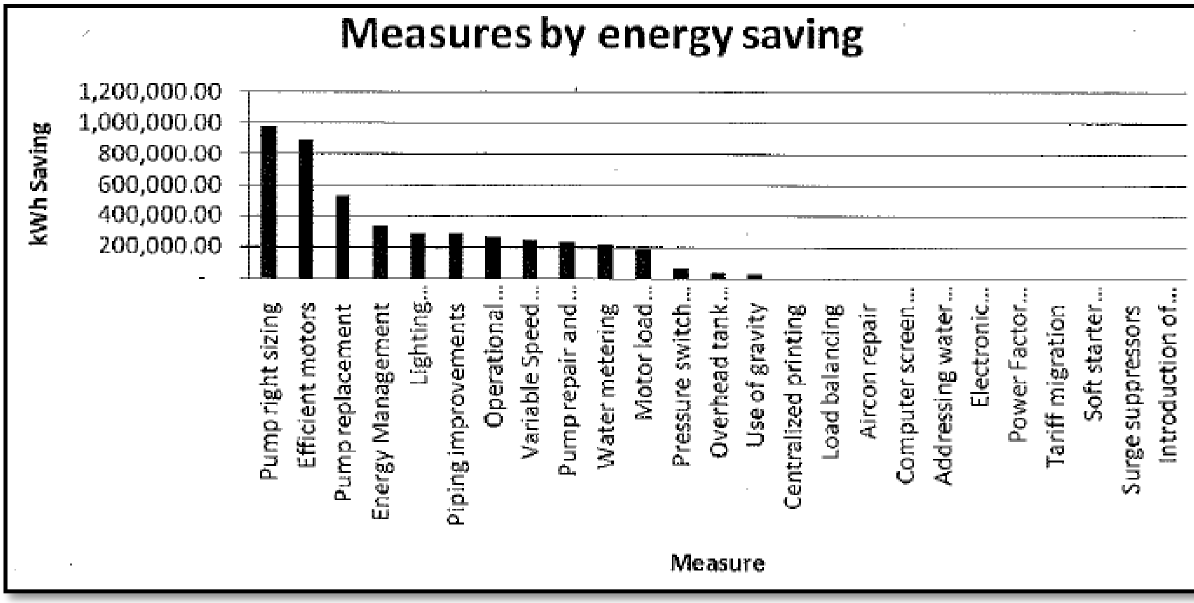

Fig 2-2: Measures/ Opportunities by amount of energy saved. (Source: KAM)

From the energy audit, the most expensive energy saving opportunity in terms of investment is the use of energy efficient motors, lighting improvements, water metering, pump replacement then use of variable speed drives (VSD's). This is shown in figure 2-3.

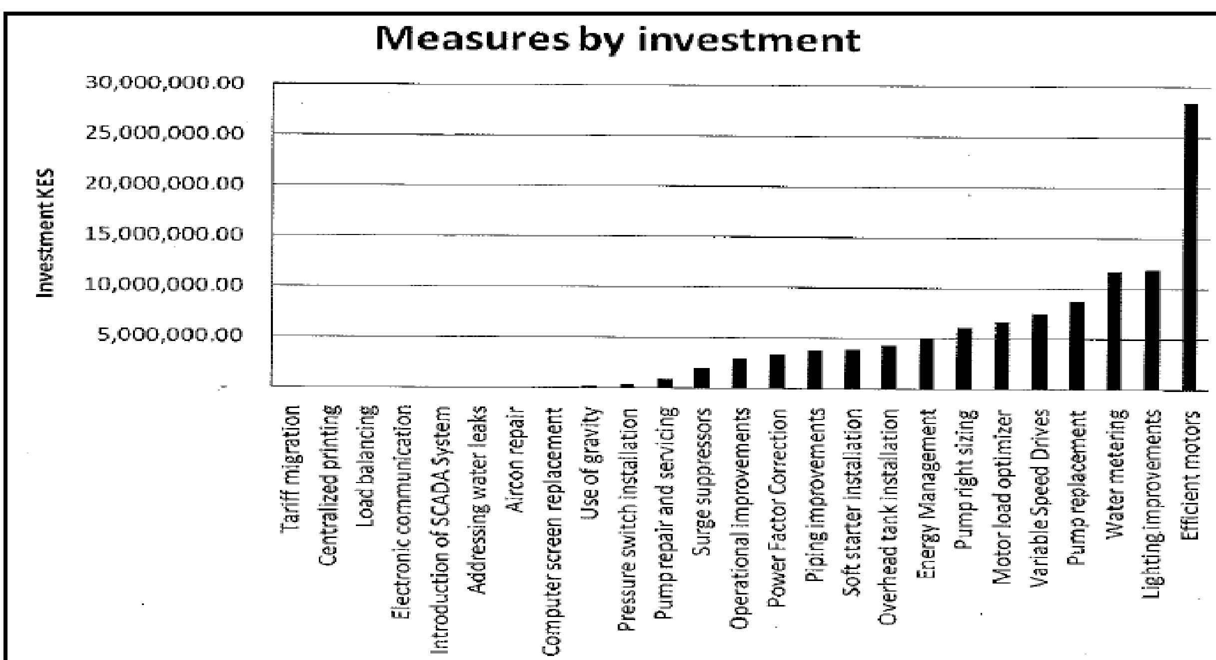

Fig 2-3: Measures/ Opportunities by amount of investment required. (Source: KAM)

CHAPTER 3: METHODOLOGY AND PUMPING OPERATIONS

3.1 Introduction

In this chapter, the methodology used in the assessment is described as well as the existing pumping station equipment and accessories.

3.2 Methodology

3.2.1 ASME EA-2-2009 – Energy Assessment for Pumping Systems

The energy assessment of the Gigiri pumping station was based on this standard. While EA-2-2009 provides requirements to be performed during the assessment of the pumping system, it does not provide direction on the various activities required to carry out the actual assessment.

The ASME/ANSI EA-2-2009 – Energy Assessment for Pumping Systems (EA-2-2009) provides:

(i) Methods to organize and conduct the assessment.
(ii) Recommendations to analyze the assessment data.
(iii) Suggestions for the content and a format for the assessment's final report.

EA-2-2009 describes three different levels of pump system assessment. Table 3-1 below provides an overview of the activities required, or to be considered, for each assessment level. As the assessment level increases, additional amounts of time, resources, data gathering and analysis, and other activities are required.

Table 3-1: Assessment Levels. Source (ASME Energy standard guide 2010)

Activity	Assessment Level		
	1	2	3
Prescreening opportunities	Required	N/A	N/A
Walk through	Optional	Required	Required
Identify systems with potential saving opportunities	Required	Required	Required

Evaluate systems with potential saving opportunities	Optional	Required	Required
Snapshot type measurement of flow, head and power data	Optional	Required	N/A
Measurement/data logging of systems with flow conditions that vary over time*	N/A	N/A	Required
* Verify and use data from plant historical information where applicable			

The primary objectives of the Level 1 assessment are to prescreen the pump systems in a facility and to determine which systems have the greatest opportunity for energy savings. Those systems with the greatest opportunity would then be assessed with the activities of a Level 2 or Level 3 assessment and analyzed further. Utilizing simple worksheets, most basic information can be gathered for further analysis.

The primary objective of a Level 2 assessment is to gather operational data for existing pumping systems or with portable measuring devices, such as flow meters, pressure sensors, and power sensors. That collected data is for a defined period of time and is representative of normal operation. The information from a Level 2 assessment was used to determine an estimate of the potential energy savings of the system. The assessment done at the Gigiri pumping station was a level 2 assessment.

A Level 3 assessment will be performed on pumping systems that have a high operating variation over an extended period of time. The assessment will measure the system conditions over a period of time that allows ample data to be collected to allow for a thorough analysis. As with a Level 2 assessment, the data can come from existing pumping systems or temporary monitoring equipment that has extended data logging capabilities.

Undergoing a Level 2 or Level 3 assessment requires additional information to analyze the efficiency of the pump system. As the focus is on system efficiency, the assessment team determined the boundaries and the demand of each pump system. More specific information that is required about the components within the system boundary includes:

(i) Pump information.
(ii) Driver information (the driver is typically an electric motor in pumping stations).
(iii) Fluid properties information.
(iv) Physical system data – layout, static head, control method.

Quantitative data that requires sensors, instrumentation, or other measurement tools includes

(i) Electrical data – motor voltage, current or power.
(ii) Flow and pressure of the fluid in the system.
(iii) Operating load profile.

The standard does not make any recommendations as to software tools for the analysis of pump system performance. However, it emphasizes the need for a thorough understanding of system requirements before applying any type of software or other analysis tool. EA-2-2009 states that there are two methods to identify the energy savings potential:

(i) Measure or estimate the existing pump system performance and compare it to an optimal performance.
(ii) Measure of estimate of the losses in the existing pump system.

3.2.3 Assessment Organization and Execution:

a) To determine the operating conditions of the pumping station, the following procedure was used:

(i) A walk through of the pumping station was done in order to pre-screen for the high energy consumption areas, which were identified as the pump motors.

(ii) Research on equipment manuals for pump and motor data, pump accessory equipment, drawings and pump data sheets. Some of this information was obtained from the maintenance head office in Industrial area while other information was found in archived documents in the pumping station.

(iii) Observed the start-up and shut-down sequences of the pump motors.

(iv) Interviews were done with the pumping station staff to verify on the actual operating procedures on the ground.

b) To determine pump and system efficiency for pumps No.1, No.2 and No.4 together with their combinations, the following procedures were used:

(i) Instantaneous electrical measurements – Motor voltage, current, power factor using voltmeter, ammeter and power factor meter.

(ii) Instantaneous flow measurements using ultrasonic flow meter.

(iii) Instantaneous pressure measurements using pressure gauges at the pump suction and discharge sides.

(iv) The total dynamic head (TDH) was determined using the piping system diagrams, and the friction losses arising from the pipeline, valves and fitting were calculated.

c) To determine the energy consumption patterns for the past two years, the following procedures were used:

(i) Analysis of historical power bill readings for the period 2010-2011 and 2011-2012.

(ii) Calculated historical power readings sub-metered from motor ammeter, voltmeter and power factor meter for the period 2010-2011 and 2011-2012.

(iii) Annual pump running hours were calculated for the period 2010-2011 and 2011-2012.

(iv) Annual pump water discharge outputs were calculated for the period 2010-2011 and 2011-2012.

d) When evaluating the energy cost saving opportunities in the pumping station the following methods were used:

(i) Cost savings were calculated based on energy savings alone. (Cost Savings = Units of Energy saved × cost of Unit of Energy).

(ii) The simple payback method was used to calculate the payback period of the investment that would be deployed to achieve the energy cost saving measure. (Payback = Cost of Investment ÷ Cost Savings).

3.2.4 Pumping Station Operating Conditions

3.2.4.1 Pumps

The pumping station at Gigiri uses four vertical centrifugal pumps. The first two pumps were installed during the first phase when the construction of the pumping station was done in 1985. The pumps were designated as pumps No.1 and No.2. The contractors and the installed pumps and accessories were all from China. Unfortunately over the years the pump manuals and pump curve charts were misplaced and as a result no nameplate information was available during the assessment of pumps No.1 and No.2. The pumps are located in a basement below the electric motors.

In 1998 there was a second phase of expansion of the Gigiri pumping station where two additional pumps were added in parallel to the existing pumps No. 1 & 2. The new pumps were designated as pumps No.3 and No.4. The second phase expansion was done by a local contractor and much of the pump information was readily available during the assessment.

During the pump efficiency tests, pumping operations had to be interrupted for a period of 2 hours to facilitate the installation of the pressure gauges and the ultrasonic flow meters, with authority from the Technical Director of NCWSC since the Gigiri –

Kabete line is critical and provides water to the higher altitude areas of Nairobi city. Test readings of power, flow and pressure were taken when each pump was running alone, and when the pumps were running in parallel combinations. Unfortunately, by the time authorization for the field tests came through, the pump No.3 had broken down and was out of service. However, since the pumps No.3 and No.4 were identical and were installed at the same time, the information derived from pump No.4 was a good representation of pump No.3. The pump is shown in fig 3-1.

Fig 3-1: Pump No.4 Vertical Centrifugal pump as assembled with components. Source (NCWSC)

<u>3.2.4.2 Electric Motors</u>

Pumps No.1 and No.2 are each driven by a 4 pole electric motor with rated nominal output of 850 kW. Pumps No.3 and No.4 are each driven by a 4 pole electric motor with rated nominal output of 709 kW. All motors are designed for operation at 3,300 V supply voltage and equipped with 6 winding temperature sensors and one 400 W 110 V anti-condensation space heater.

The nameplate and motor are shown in figure 3-2 and fig 3-3 respectively.

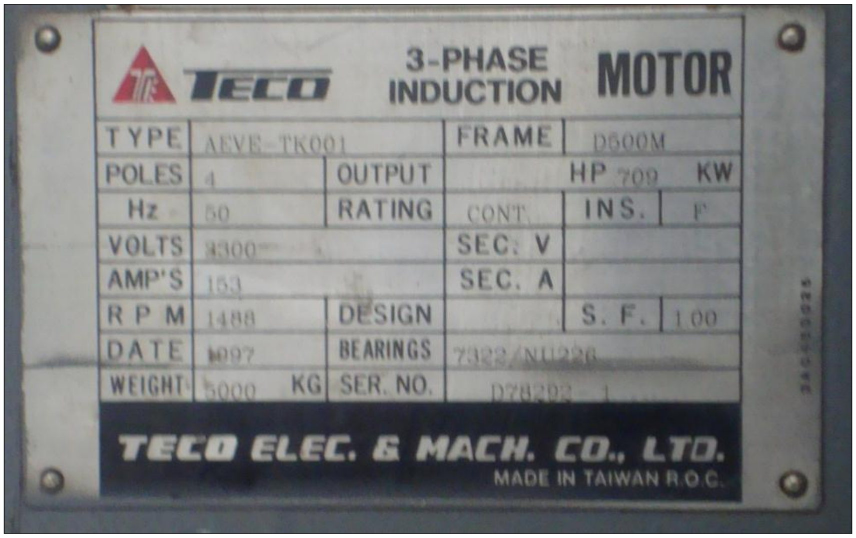

Fig 3-2: Motor Nameplate. Source (NCWSC)

Fig 3-3: Vertical Electrical Motors for Pumps No. 3 and 4. Source (NCWSC)

3.2.4.3 Flow Meters

Flow meters used in Gigiri pumping station are of the Ultrasonic type, where movements of ultrasonic sound waves through flowing water particles are converted to digital signals that indicate the flow rate in the pipeline.

The main advantages of Ultrasonic flow meters are that they are non-invasive of the pipe work and are very accurate. The flow meter permanently installed in the pipeline is of the Maddalena™ model while the flow meter used for the field testing is of the Micronics™ model. The test flow meter was calibrated at the KEBS volume laboratory.

During the field testing, the probes of the flow meter were placed 1 meter apart along the pipe and fastened with a chain and a couplant was added between the probe and the pipe. Readings were then taken after the pumps were switched on and 50 average values in liters per second taken over a period of 20 minutes for each pump and for all pump combinations. These values were then averaged to arrive at the flow rate. During normal pumping operations, hourly readings of flow and reservoir levels are recorded in an excel worksheet throughout the year.

Test set-up and pumping station flow meter are shown in figure 3-4.

Fig 3-4: Pumping station flow meter (DN 700) and flow test set-up (Inset).Source (NCWSC & KEBS)

3.2.4.4 Main Meter & Sub-meter

The main digital electricity meter was installed by the Kenya Power company and is used for billing the pumping station's energy consumption. KPLC meters are located at the transformer sub-station. Analogue sub-meters were installed by the contractors and are positioned at the pump control switchboard for operational use.

Model of the main meter is from ABB™ while that of sub-meter is from GEC-Alsthom™.

During normal pumping operations, hourly readings of current, voltage and power factor are recorded in a log book throughout the year.

Main meter and sub-meter are shown in figure 3-5.

Fig 3-5: Main meter (Left) and sub-meter (Right). Source (NCWSC)

3.2.4.5 Pipework, Valves and Fittings

All the pumps receive feed water through an individual feeder pipe DN400 (400 mm nominal diameter) into a manifold of DN1000 which is connected to the main transmission line of DN700.

Individual pipes are equipped with the following accessories:

(i) 1 piece suction end manual valve (DN400).
(ii) 1 piece non-return valve (DN400).
(iii) 1 piece delivery end motorized actuator valve (DN400).
(iv) 2 piece flexible coupling.

The manifold of the DN1000 is equipped with a main shut-off butterfly valve.

Sample pipework and valves are shown in figure 3-6.

Fig 3-6: Steel pipes ready for lining and suction valve. Source (NCWSC)

__3.2.4.6 HV and LV Switchboards__

HV (High voltage) and LV (Low voltage) switchboards, which are located at the control panel, contain the power supply controls and all electric equipment necessary to start, stop and control pumping operations.

The control panel is shown in figure 3-7.

Fig 3-7: HV and LV switchboards. Source (NCWSC)

__3.2.4.7 Transformer__

The Transformer at the Gigiri pumping station is located at a sub-station within the reservoir compound and is a step-down transformer. The transformer is fed from a 66 kV 3-phase dedicated power line from the regional Karura sub-station.

Within the Gigiri sub-station, power to the pumps is stepped down to 3.3 kV and are laid via underground cables to the pump's control panel within which there are common bus bars for tapping power to the various pumps.

The transformer was manufactured by ABB™ and Evertech™ transformers.

Transformer and sub-station is shown in figure 3-8.

Fig 3-8: Sub-station 66 kV transformer and 3.3 kV bus bar terminating point. Source (NCWSC)

3.2.4.8 Capacitor Banks

Each of the four pump motors has a capacitor connected to it for power factor correction. Capacitors are located between the pumps and the control panel.

Capacitors for pumps No.1 and 2 each have a capacitance of 90 kVar, while pumps No.3 and 4 have a capacitance of 300 kVar each.

Capacitor banks are shown in figure 3-9.

Fig 3-9: Capacitor banks for pumps No.1and 2 (left) and No.3 and 4 (right). Source (NCWSC)

3.2.4.9 Surge Vessel & Air Compressor

The Gigiri – Kabete pipeline has a surge vessel located 10 meters away from the discharge point. Its purpose is to control potentially harmful surge pressures from damaging the piping when the pumps are switched off and the non-return valve closes. This action produces water hammer when the water column along the 9,300 meter pipeline flows back and slams the non-return valve, causing the surge pressures.

The surge vessel is supported by two air compressors to maintain the air gap in the surge vessel at required levels.

The surge vessel has a working pressure of 2.25 MPa (Megapascals), a design pressure of 2.5 MPa and a test pressure of 3.13 MPa.

Surge vessel and air compressors are shown in figure 3-10.

Fig 3-10: Surge Vessel and Air compressors. Source (NCWSC)

<u>3.2.4.10 Propeller Shaft</u>

The propeller shaft transmits the turning force from the electric motor to the centrifugal pump located in the basement below the motor.

Because of the large distance between the motor and pump – about 8 meters, a center bearing has been installed to transmit the shaft power using two propeller shafts in series. The propeller shaft was manufactured by Hardy Spicer Drivelines™.

The propeller shaft assembly is shown in figure 3-11 and figure 3-12.

Fig 3-11: Propeller shaft on center bearing (left) and on motor output universal joint (right). Source (NCWSC)

Fig 3-12: Propeller shaft universal joint on centrifugal pump input. (Author pointing at shaft universal joint) Source (NCWSC)

CHAPTER 4: HISTORICAL AND MEASURED DATA ANALYSIS

4.1 Introduction

In this chapter, historical data as well as snapshot measurement data for the year periods 2010-2011 and 2011-2012 are analyzed and discussed.

4.2 Total Electricity Consumption and Flow Rate at the Pumping Station

Flow rate data were taken from an ultrasonic flow meter installed at the Kabete reservoir where the pipeline ends. The flow meter was installed in the end of February 2010.

Tables 4-1 and 4-2 show the total energy and flow data for the period 2010-2011 & 2011-2012, with electrical consumption in kilowatt—hours (kWh) and corresponding flow rate in cubic meters (m^3).

Table 4-1: Electrical Energy and Flow Data 2010-2011

Electrical Energy Data					
Year	Month	Flow (m^3)	Electrical Consumption (kWh)	Cumulative (m^3)	Cumulative (kWh)
2010-2011	Mar	1,375,954	909,200	1,375,954	909,200
	Apr	1,333,430	850,353	2,709,384	1,759,553
	May	1,442,477	866,370	4,151,861	2,625,924
	Jun	1,419,951	897,242	5,571,812	3,523,165
	Jul	1,364,389	888,974	6,936,201	4,412,139
	Aug	1,424,071	889,496	8,360,272	5,301,635
	Sep	1,253,697	861,000	9,613,969	6,162,636
	Oct	1,400,358	916,571	11,014,327	7,079,207
	Nov	965,561	870,974	11,979,888	7,950,181
	Dec	1,401,995	893,721	13,381,883	8,843,902
	Jan	1,383,245	922,063	14,765,128	9,765,965
	Feb	1,297,271	827,077	16,062,399	10,593,042
Totals		16,062,399	10,593,042		

Table 4-2: Electrical Energy and Flow Data 2011-2012

Electrical Energy Data					
Year	Month	Flow (m^3)	Electrical Consumption (kWh)	Cumulative (m^3)	Cumulative (kWh)
2011-2012	Mar	1,323,019	840,820	1,323,019	840,820
	Apr	1,246,631	775,666	2,569,650	1,616,486
	May	1,387,799	866,271	3,957,449	2,482,757
	Jun	1,301,839	832,555	5,259,288	3,315,312
	Jul	1,388,302	893,653	6,647,590	4,208,964
	Aug	1,379,665	880,226	8,027,255	5,089,190
	Sep	1,402,083	867,276	9,429,338	5,956,466
	Oct	1,419,142	880,762	10,848,480	6,837,228
	Nov	1,397,950	871,669	12,246,430	7,708,897
	Dec	1,323,280	806,630	13,569,710	8,515,527
	Jan	1,307,964	843,319	14,877,674	9,358,846
	Feb	1,305,142	815,880	16,182,816	10,174,726
Totals		16,182,816	10,174,726		

Electricity use was measured in two ways: From the incoming KPLC digital meter at the transformer substation which is the billed consumption and from the pump control panel where hourly readings of current, voltage and power factor were measured from analogue meters.

Tables 4-3 and 4-4 show the comparison between the billed electricity consumption done by KPLC and the sub-metered energy consumption for the period 2010-2011 & 2011-2012.

Table 4-3: Billed versus measured electricity consumption for 2010-2011.

Year	Month	Billed Electrical Consumption (kWh)	Measured Electrical Consumption (kWh)	Billed - Measured Variance ± (kWh)
2010-2011	Mar-10	895,932	909,200	-13,268
	Apr-10	858,846	850,353	8493
	May-10	841,350	866,370	-25,020
	Jun-10	971,442	897,242	74,200
	Jul-10	789,990	888,974	-99,074
	Aug-10	866,634	889,496	-22,862
	Sep-10	873,630	861,000	12,630

	Oct-10	854,214	916,571	-62357
	Nov-10	881,100	870,974	10,126
	Dec-10	910,110	893,721	16,389
	Jan-11	817,554	922,063	-104,509
	Feb-11	885,000	827,077	57,923
				147,329

Table 4-4: Billed versus measured electricity consumption for 2011-2012.

Year	Month	Billed Electrical Consumption (kWh)	Measured Electrical Consumption (kWh)	Billed - Measured Variance ± (kWh)
2011-2012	Mar-11	810,155	840,820	-30,665
	Apr-11	641,700	775,666	-133,966
	May-11	764,664	866,271	-101,607
	Jun-11	892,092	832,555	59,537
	Jul-11	160,698	893,653	-732,955
	Aug-11	602,316	880,226	-277,910
	Sep-11	891,720	867,276	24,444
	Oct-11	841,026	880,762	-39,736
	Nov-11	895,590	871,669	23,921
	Dec-11	782,850	806,630	-23,780
	Jan-12	808,056	843,319	-35,263
	Feb-12	866,046	815,880	50,166
				1,217,814

From tables 4-3 and 4-4, there was observed to be a large variation between the billed consumption and the measured consumption. The period 2010-2011 had the total measured consumption exceeding the billed consumption by 147,329 kWh, while a similar period for 2011-2012 had the total measured consumption exceeding the billed consumption by a massive 1,217,814 kWh.

The variation between the billed and measured electricity consumption were inexplicably large. It was noted that in the months of July and August 2011, there was a large discrepancy between the billed and the measured consumption. It was possible that the accuracy of the control panel meter was low or erratic, mainly because the meter was of the dial analog type and very aged in service.

4.3 Individual Pump Motor Energy Consumption and Running Hours

Table 4-5 shows the monthly individual pump motor energy consumption for the period 2010-2011 and 2011-2012.

Table 4-5: Individual pump motor energy consumption

Individual Pump Motor Energy Usage					
Year	Month	Energy Used Pump 1 (kWh)	Energy Used Pump 2 (kWh)	Energy Used Pump 3 (kWh)	Energy Used Pump 4 (kWh)
2010-2011	Mar-10	331,648	298,138	279,415	0
	Apr-10	283,607	239,271	242,714	84,760
	May-10	270,703	128,951	240,234	226,482
	Jun-10	326,009	0	292,854	278,379
	Jul-10	311,479	0	294,933	282,562
	Aug-10	252,582	138,593	243,910	254,411
	Sep-10	235,481	211,403	205,507	208,610
	Oct-10	323,361	286,655	28,615	277,940
	Nov-10	326,071	280,831	0	264,072
	Dec-10	325,302	288,925	0	279,494
	Jan-11	334,923	300,447	0	286,693
	Feb-11	301,867	268,708	0	256,502
Totals		**3,623,032**	**2,441,921**	**1,828,184**	**2,699,904**
2011-2012	Mar-11	315,134	273,459	0	252,228
	Apr-11	244,569	229,324	108,715	193,058
	May-11	241,992	223,960	193,300	207,019
	Jun-11	234,584	224,059	175,944	197,968
	Jul-11	233,905	238,356	216,231	205,161
	Aug-11	228,413	256,847	202,830	192,136
	Sep-11	249,387	247,994	210,384	159,511
	Oct-11	268,411	238,780	187,716	185,855
	Nov-11	266,268	229,953	164,872	210,577
	Dec-11	227,405	228,509	158,346	192,369
	Jan-12	246,594	234,120	147,744	214,861
	Feb-12	294,909	255,686	0	265,284
Totals		**3,051,572**	**2,881,047**	**1,766,081**	**2,476,027**

Table 4-6 shows the monthly individual pump running hours for the period 2010-2011 and 2011 -2012, along with their percentage of running time annually.

Table 4-6: Individual pump motor running hours

Individual Pump Motor Running Hours					
Year	Month	Running Hours Pump 1	Running Hours Pump 2	Running Hours Pump 3	Running Hours Pump 4
2010-2011	Mar-10	499	489	482	0
	Apr-10	421	383	423	151
	May-10	410	199	415	422
	Jun-10	480	0	480	480
	Jul-10	477	0	485	492
	Aug-10	361	232	413	435
	Sep-10	344	360	344	360
	Oct-10	480	482	48	478
	Nov-10	480	470	0	452
	Dec-10	487	485	0	479
	Jan-11	498	492	0	492
	Feb-11	448	440	0	436
Totals		**5,385**	**4,032**	**3,090**	**4,677**
% Run time		**61**	**46**	**35**	**53**
2011-2012	Mar-11	462	443	0	426
	Apr-11	351	364	194	324
	May-11	348	357	327	341
	Jun-11	335	355	298	326
	Jul-11	361	364	361	345
	Aug-11	361	366	347	325
	Sep-11	395	365	360	282
	Oct-11	378	380	318	305
	Nov-11	383	366	278	347
	Dec-11	322	361	267	315
	Jan-12	357	379	250	355
	Feb-12	432	426	0	446
Totals		**4,485**	**4,526**	**3,000**	**4,137**
% Run time		**51**	**52**	**34**	**47**

From tables 4-5 and 4-6, it is seen that individual pump motor energy consumption is consistently proportional to the duration of time the pump motor was running during the year period. This observation is in tandem with the expectation. In the period 2011-2012, the pump motor No.1 consumed the highest energy but ran for a slightly shorter duration than the pump motor No.2 by 41 running hours.

4.4 Combination Pump Motor Energy Consumption and Running Hours

Table 4-7 shows the monthly combination pump motor energy consumption for the period 2010-2011 and 2011-2012.

Table 4-7: Combination motor energy consumption

Combination Pump Motor Energy Usage							
Year	Month	Energy Used Pump1&2 (kWh)	Energy Used Pump1&3 (kWh)	Energy Used Pump1&4 (kWh)	Energy Used Pump2&3 (kWh)	Energy Used Pump2&4 (kWh)	Energy Used Pump3&4 (kWh)
2010-2011	Mar-10	322,728	301,630	0	283,877	0	0
	Apr-10	158,739	307,335	27,087	193,324	148,516	0
	May-10	10,127	355,620	118,711	34,482	205,213	116,322
	Jun-10	0	309,432	302,194	0	0	285,616
	Jul-10	0	316,573	297,374	0	0	293,115
	Aug-10	0	339,938	125,914	29,543	254,888	146,411
	Sep-10	0	440,988	0	0	416,463	0
	Oct-10	263,944	60,967	268,768	0	309,078	0
	Nov-10	304,351	0	289,016	0	286,748	0
	Dec-10	316,296	0	305,669	0	276,531	0
	Jan-11	318,574	0	310,173	0	292,282	0
	Feb-11	286,667	0	276,499	0	261,322	0
Totals		**1,981,426**	**2,432,483**	**2,321,404**	**541,227**	**2,451,041**	**841,465**
2011-2012	Mar-11	303,989	0	288,533	0	265,387	0
	Apr-11	128,933	266,374	83,595	19,092	337,312	0
	May-11	25,127	419,836	20,094	5,458	428,510	0
	Jun-11	49,863	398,949	25,635	22,368	409,009	0
	Jul-11	12,827	450,136	0	12,827	443,517	0
	Aug-11	37,167	419,738	8,132	19,096	440,611	0
	Sep-11	108,975	370,356	40,835	75,088	318,929	26,501
	Oct-11	98,028	425,956	25,019	41,175	378,761	0
	Nov-11	92,683	365,351	64,576	18,405	372,459	4,821
	Dec-11	80,628	398,681	37,007	35,244	415,673	4,798
	Jan-12	86,596	338,766	71,354	16,577	399,380	0
	Feb-12	264,671	0	298,898	0	268,940	0
Totals		**1,289,487**	**3,854,143**	**963,678**	**265,331**	**4,478,489**	**36,120**

Table 4-8 shows the monthly combination pump running hours for the period 2010-2011 and 2011 -2012, along with their percentage of running time annually.

Table 4-8: Combination pump motor running hours

Combination Pump Motor Running Hours							
Year	Month	Running Hours Pump1&2 (kWh)	Running Hours Pump1&3 (kWh)	Running Hours Pump1&4 (kWh)	Running Hours Pump2&3 (kWh)	Running Hours Pump2&4 (kWh)	Running Hours Pump3&4 (kWh)
2010-2011	Mar-10	256	238	0	236	0	0
	Apr-10	122	246	22	162	126	0
	May-10	8	286	100	31	173	108
	Jun-10	0	240	240	0	0	240
	Jul-10	0	251	243	0	0	248
	Aug-10	0	265	98	25	215	124
	Sep-10	0	344	0	0	354	0
	Oct-10	208	48	214	0	263	0
	Nov-10	238	0	229	0	240	0
	Dec-10	250	0	244	0	235	0
	Jan-11	248	0	247	0	245	0
	Feb-11	223	0	219	0	218	0
Totals		**1553**	**1918**	**1856**	**454**	**2069**	**720**
% Run time		**18**	**22**	**21**	**5**	**24**	**8**
2011-2012	Mar-11	215	0	215	0	211	0
	Apr-11	62	194	57	0	267	0
	May-11	0	323	0	4	341	0
	Jun-11	0	294	4	4	322	0
	Jul-11	0	361	0	0	345	0
	Aug-11	0	347	0	0	325	0
	Sep-11	54	297	25	37	231	26
	Oct-11	16	302	0	16	305	0
	Nov-11	32	274	47	0	296	4
	Dec-11	0	263	0	0	311	4
	Jan-12	41	248	40	2	315	0
	Feb-12	194	0	230	0	216	0
Totals		**614**	**2903**	**618**	**63**	**3485**	**34**
% Run time		**7**	**33**	**7**	**1**	**40**	**0.5**

From tables 4-7 and 4-8, it is seen that the combination pump motor energy consumption is consistently proportional to the duration the pump motor was running during the year period. This observation is in tandem with the expectation.

4.5 Energy Performance and Trending Indices of Pumping Operations

In this section, the graphical representation for energy consumption, trending and analyses are shown.

4.5.1 Electricity Consumption and Flow

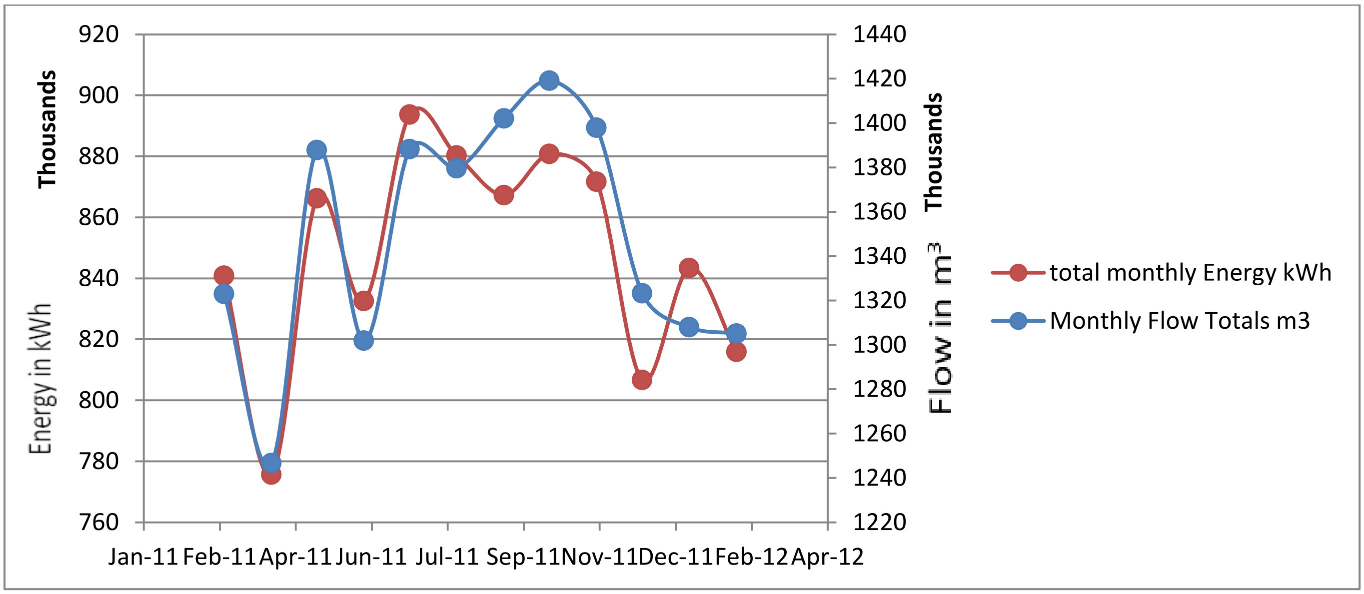

Figure 4-1: Electricity Consumption and Flow for period 2011-2012

In figure 4-1, electricity consumption is proportional to the flow output of the pumping station for the 2011-2012 period. This trend met the expectation. The higher the flow output, the higher the electricity consumption.

In figure 4-2, the electricity consumption partially follows the flow output of the pumping station for the 2010-2011 period. There were wide variations in the months of April, September and February.

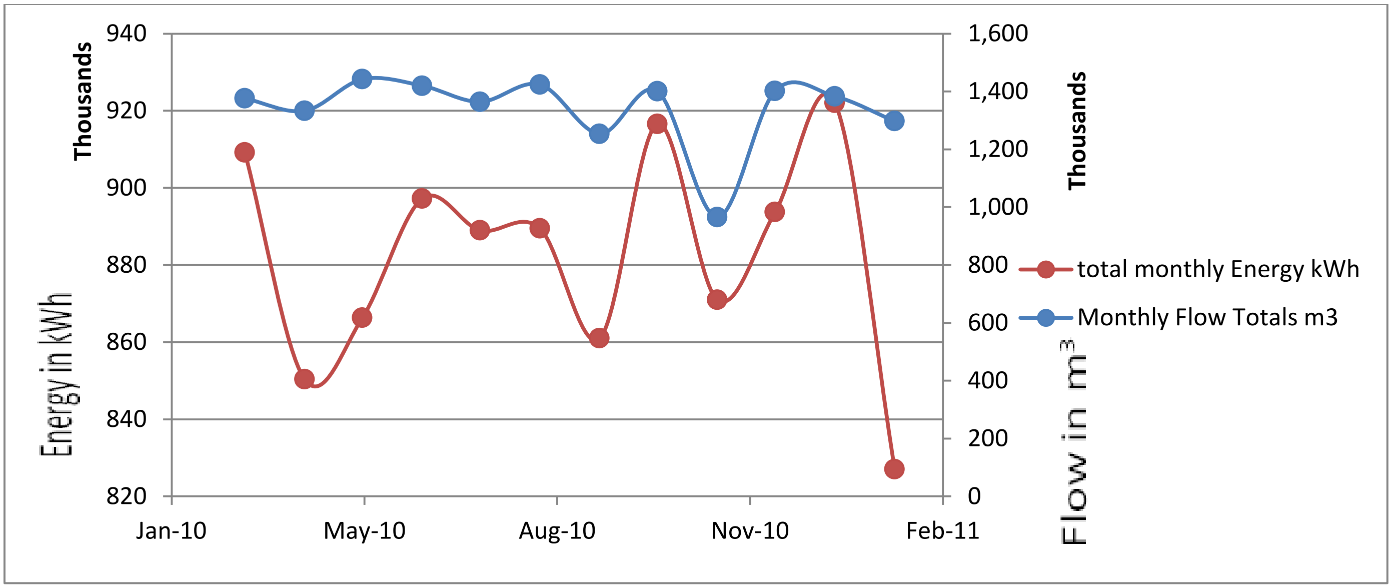

Figure 4-2: Electricity Consumption and Flow for period 2010-2011

Figure 4-3 shows the cumulative energy versus flow graph for the period 2010-2011.

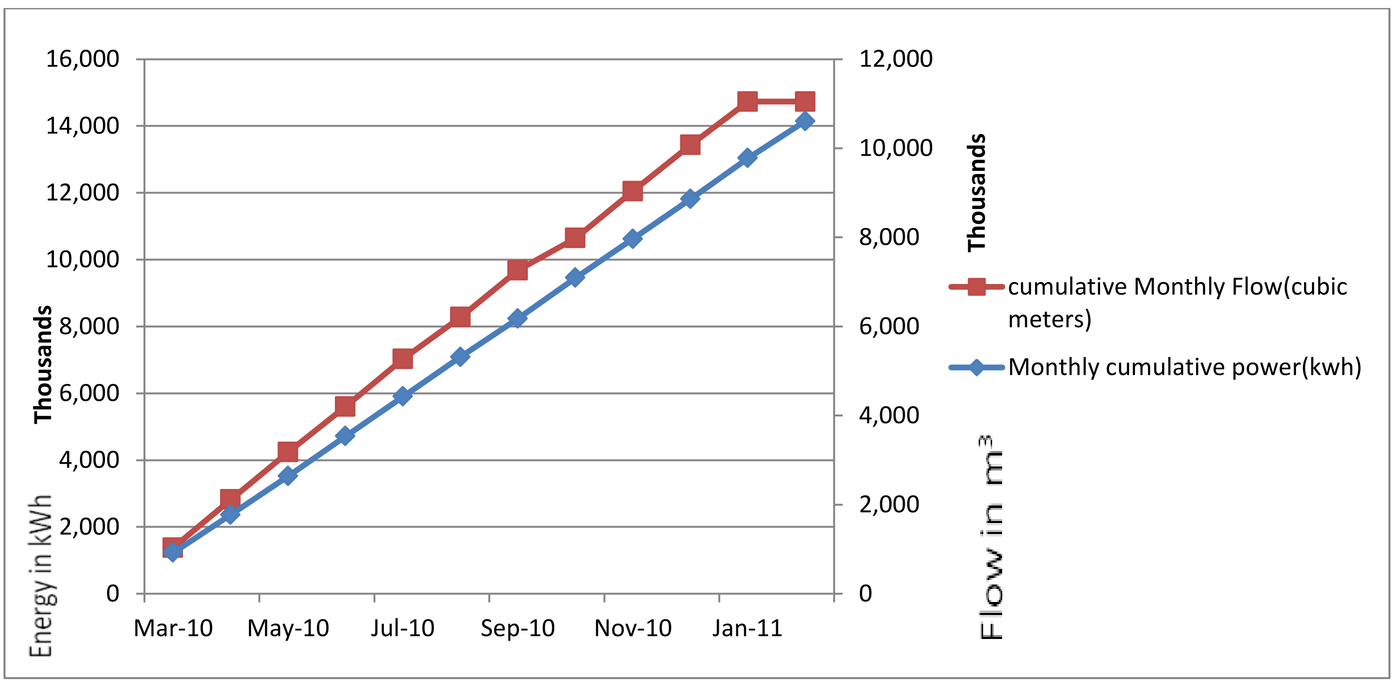

Figure 4-3: Electricity Consumption and Flow for period 2010-2011

The cumulative graph for the monthly electricity consumption versus flow output indicates an abnormal trend with the lines diverging. This trend was inconsistent with the expectation for the cumulative electricity consumption and flow output values, which were generally expected to be parallel.

Figure 4-4 shows the relationship between flow output and electricity consumption for the period 2010-2011.

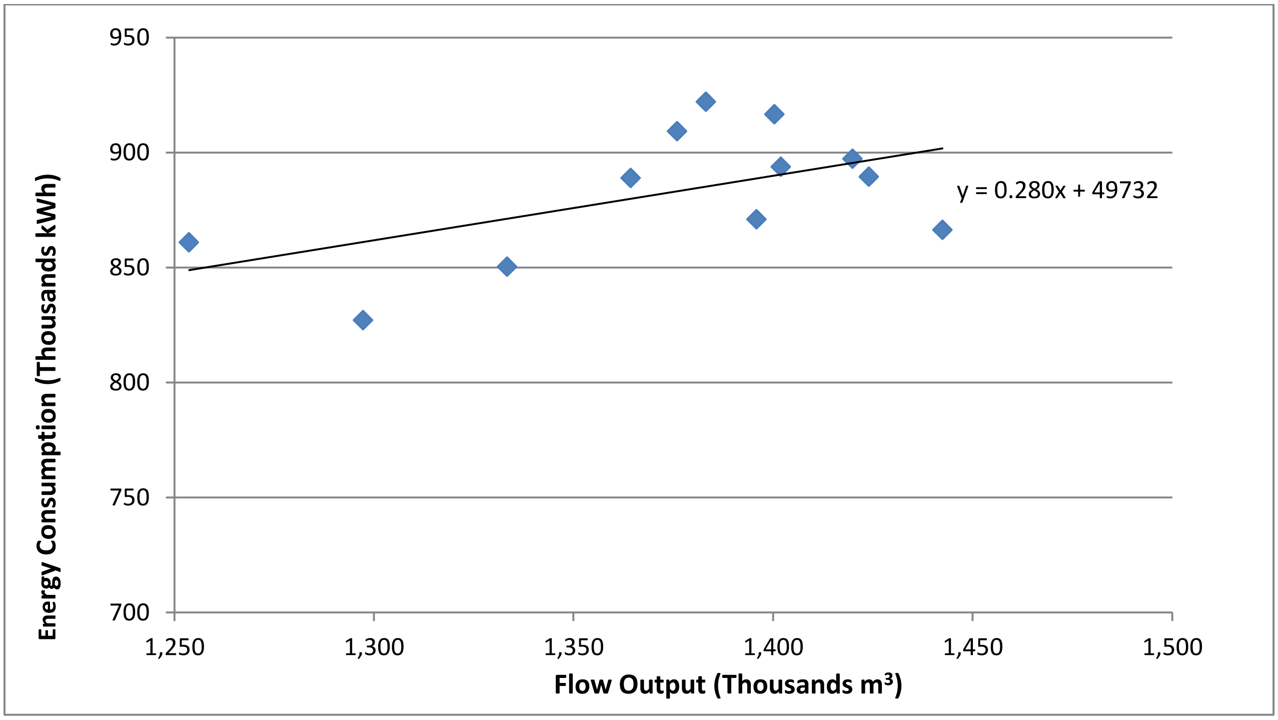

Figure 4-4: Relationship between Electricity Consumption and Flow - 2010-2011

For the period 2010-2011, figure 4-4 indicates that the slope is positive. The electricity consumption increases with an increase in flow output. As a result of the narrow flow output range, the extrapolation of the Y – axis shows that there is energy consumption of 49,732 kWh at zero flow output. The energy intensity of 0.280 kWh/m^3 is also much lower compared to the period average of 0.667 kWh/m^3.

This is mainly because of energy consumption of auxiliary equipment and lighting which function even when the pumps are not in operation. This equipment consists of flow instrumentation, motor cooling fans and the Surge-tank compressor. The lighting for the facility compound and control house is done using fluorescent tubes and sodium vapor lamps.

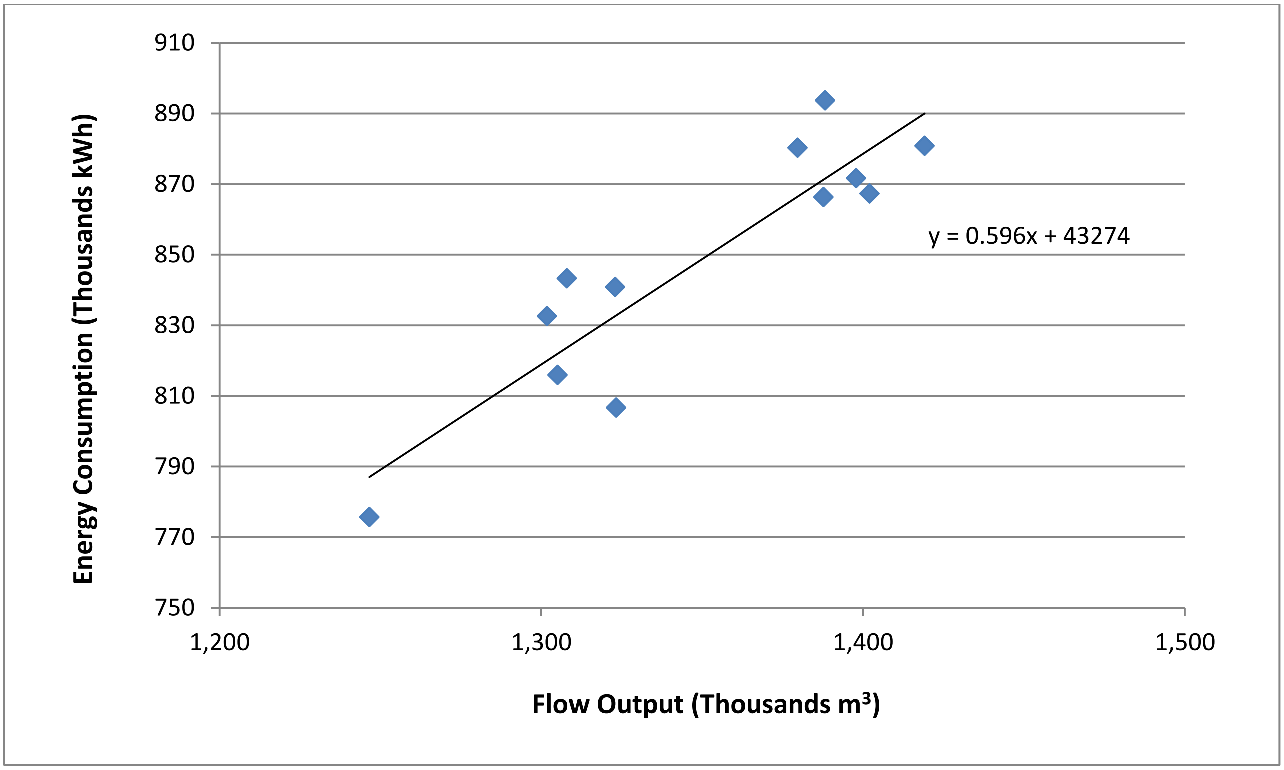

Figure 4-5: Relationship between Electricity Consumption and Flow - 2011-2012

For the period 2011-2012, figure 4-5 indicates that the slope is positive. The electricity consumption increases with an increase in flow output. The energy intensity of 0.596 kWh/m^3 is slightly less than the period energy intensity of 0.629 kWh/m^3. The Y – intercept energy consumption at zero flow was 43,274 kWh.

4.6 Electrical Energy Intensity of Pumping Operations – Specific Energy

Table 4-9 shows the energy intensities and the corresponding flow output for the period 2010-2011 and 2011-2012.

Table 4-9: Intensity and Flow output figures for periods 2010-2011 and 2011-2012

Year	Month	Flow (m^3)	Electrical Consumption (kWh)	Energy Intensity (kWh / m^3)
2010-2011	Mar-10	1,375,954	909,200	0.661
	Apr-10	1,333,430	850,353	0.638
	May-10	1,442,477	866,370	0.601
	Jun-10	1,419,951	897,242	0.632
	Jul-10	1,364,389	888,974	0.652
	Aug-10	1,424,071	889,496	0.625
	Sep-10	1,253,697	861,000	0.687
	Oct-10	1,400,358	916,571	0.655
	Nov-10	965,561	870,974	0.902
	Dec-10	1,401,995	893,721	0.637
	Jan-11	1,383,245	922,063	0.667
	Feb-11	1,297,271	827,077	0.638
			Average Energy Intensity	**0.667**
2011-2012	Mar-11	1,323,019	840,820	0.636
	Apr-11	1,246,631	775,666	0.622
	May-11	1,387,799	866,271	0.624
	Jun-11	1,301,839	832,555	0.640
	Jul-11	1,388,302	893,653	0.644
	Aug-11	1,379,665	880,226	0.638
	Sep-11	1,402,083	867,276	0.619
	Oct-11	1,419,142	880,762	0.621
	Nov-11	1,397,950	871,669	0.624
	Dec-11	1,323,280	806,630	0.610
	Jan-12	1,307,964	843,319	0.645
	Feb-12	1,305,142	815,880	0.625
			Average Energy Intensity	**0.629**

Figure 4-6 shows the relationship between the flow output and Specific energy for the period 2010-2011.

The graph indicates that the relation is strong, non-linear and with a negative slope. The energy intensity (kWh/m^3) generally reduces at higher flow output levels as seen in the figure below.

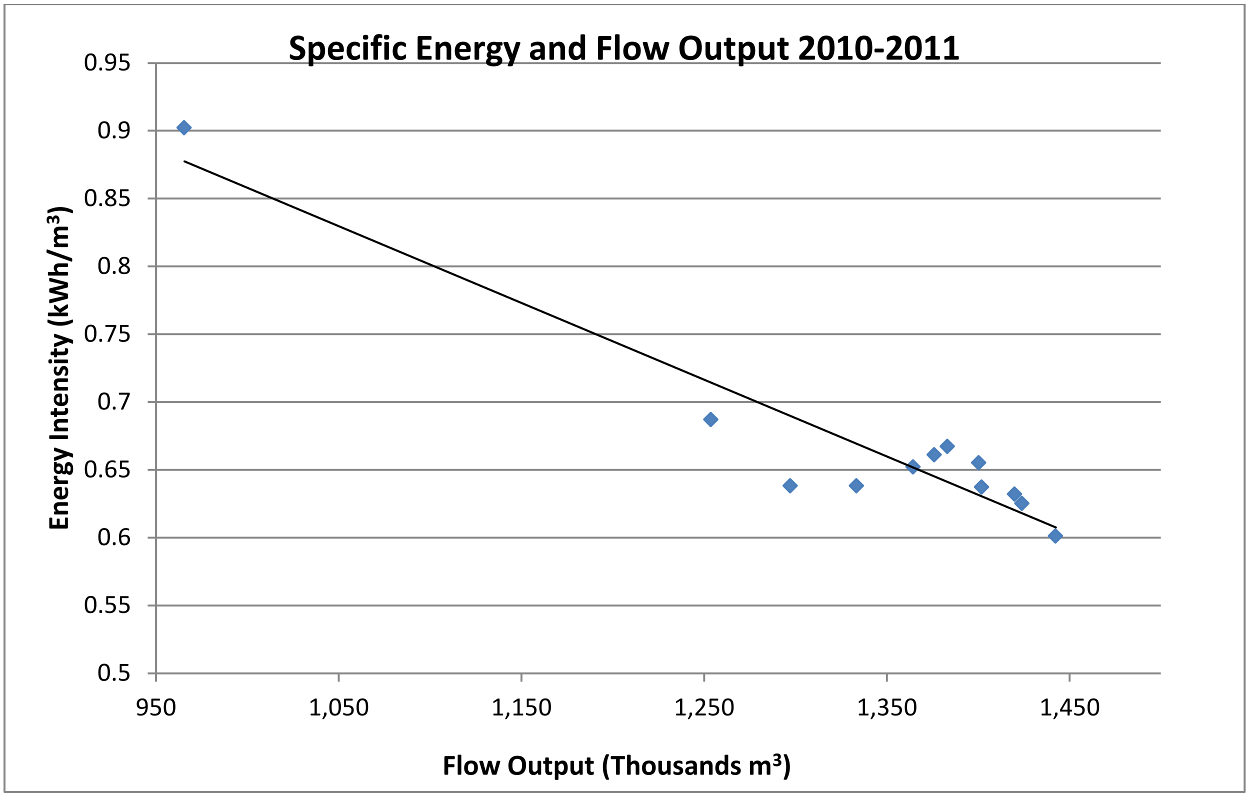

Figure 4-6: Specific Energy Consumption and Flow Output - 2010-2011

Figure 4-7 shows the relationship between flow output and Specific energy for the period 2011-2012.

The graph indicates that there is no relationship between flow output and specific energy as seen from the horizontal line. The energy intensity of approximately 0.630 kWh/m^3 from the graph remains constant for the entire range of flows.

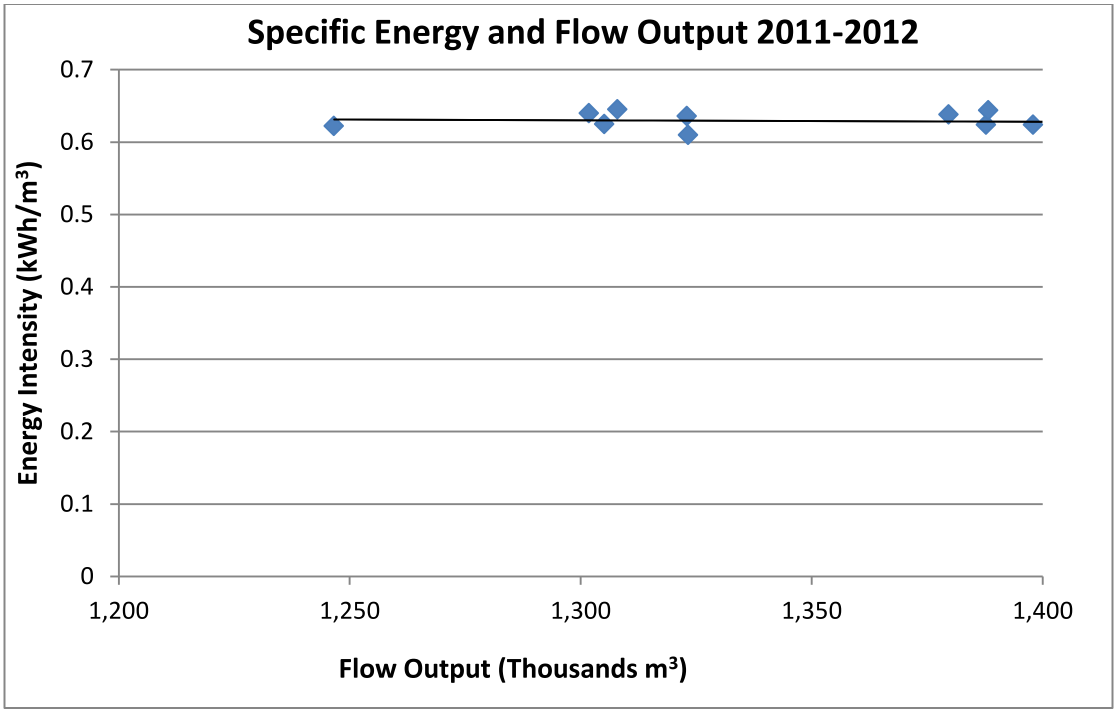

Figure 4-7: Specific Energy Consumption and Flow Output - 2011-2012

Table 4-10 shows the parallel pump combination annual specific energies for the period 2010-2011 and 2011-2012.

Table 4-10: Parallel Pump and Motor Energy Intensity 2010-2011 & 2011-2012

Combination Pump & Motor Energy Intensity						
Year	Specific Energy Pump1&2 (kWh/m³)	Specific Energy Pump1&3 (kWh/m³)	Specific Energy Pump1&4 (kWh/m³)	Specific Energy Pump2&3 (kWh/m³)	Specific Energy Pump2&4 (kWh/m³)	Specific Energy Pump3&4 (kWh/m³)
2010/2011	**0.726**	**0.665**	**0.611**	**0.467**	**0.554**	**0.568**
Totals Energy	1,981,426	2,432,483	2,321,404	541,227	2,451,041	841,465
Totals Flow	2,728,615	3,649,713	3,799,271	1,158,362	4,424,203	1,480,685
2011/2012	**1.224**	**0.600**	**1.022**	**0.901**	**0.589**	**0.639**
Totals Energy	1,289,487	3,854,143	963,678	265,331	4,478,489	36,120
Totals Flow	1,053,457	6,413,580	942,829	294,390	7,597,442	56,507

From table 4-10, it is seen that the pump combination with the highest energy intensity during both duration periods was the pump combination of pumps No.1 and No.2. The intensities reached were 0.726 (kWh/m^3) and 1.224 (kWh/m^3) respectively for the 2010-2011 and 2011-2012 periods.

4.7 Pump and Pumping System Efficiency

4.7.1 Pump Efficiency

Pump efficiency is defined as the ratio of the hydraulic pump output power of the pumped liquid to the mechanical pump shaft input power, and is expressed as a percentage. The equation is shown below:

$$\eta_P = \frac{P_W}{P_P} \times 100$$

$$P_W = \frac{Q \times H \times \rho}{367}$$

$$P_P = Current\ (I) \times Voltage\ (kV) \times 1.732\ \times cos\varphi\ \div \eta_M$$

$$P_D = \rho\ \times g\ \times H$$

Where;

H = Total head (m)

Q = Flow rate (m^3/h) – Flow measurements taken at discharge side of pump.

ρ = Density (kg/m^3)

P_P = Motor-pump shaft input power (kW)

P_D = Discharge pressure (N/m^2), P_S = Suction pressure (N/m^2)

P_W = Hydraulic pump output power (kW)

η_P = Pump Efficiency (%),η_M=Motor Efficiency (%)

g = gravitational acceleration (9.81 m/s^2), $cos\varphi$ = Power factor

Using the above equations, the pump efficiencies of pumps No.1, No.2 and No.4 were calculated. Pump No.3 was out of service during the field tests.

Motor efficiencies were calculated to be approximately 80% for motors No.1, 2 and 4.

4.7.1.1 Pump Efficiency Pump No.1

Flow rate Q of pump No.1 running = 1,019 m^3/h

Discharge Pressure P_D = 14 bar = 1,400,000 N/m^2

Suction Pressure P_S = 0.1 bar = 10,000 N/m^2

$$H = \frac{(P_D - P_S)}{\rho \times g} = \frac{(1{,}400{,}000 - 10{,}000)}{1000 \times 9.81} = 141.70 \text{ m}$$

Input power $P_P = 120 \times 3.55 \times 1.732 \times 0.93 \div 0.80 = \mathbf{857.73}\ \boldsymbol{kW}$

Hydraulic power $P_W = \frac{1{,}019 \times 141.7 \times 1000}{367} = \mathbf{393.44\ kW}$

Pump Efficiency $\eta_P = \frac{P_W}{P_P} = \frac{393.44}{857.73} = \mathbf{46}$ **%**

4.7.1.2 Pump Efficiency Pump No.2

Flow rate Q of pump No.2 running = 1,364 m^3/h

Discharge Pressure P_D = 14 bar = 1,400,000 N/m^2

Suction Pressure P_S = 0.1 bar = 10,000 N/m^2

$$H = \frac{(P_D - P_S)}{\rho \times g} = \frac{(1{,}400{,}000 - 10{,}000)}{1000 \times 9.81} = 141.70 \text{ m}$$

Input power $P_P = 110 \times 3.50 \times 1.732 \times 0.92 \div 0.80 = \mathbf{766.84}\ \boldsymbol{kW}$

Hydraulic power $P_W = \frac{1{,}364 \times 141.7 \times 1000}{367} = \mathbf{526.64\ kW}$

Pump Efficiency $\eta_P = \frac{P_W}{P_P} = \frac{526.64}{766.84} = \mathbf{69}$ **%**

4.7.1.3 Pump Efficiency Pump No.4

Flow rate Q of pump No.4 running = 1,502 m^3/h

Discharge Pressure P_D = 14 bar = 1,400,000 N/m^2

Suction Pressure P_S = 0.1 bar = 10,000 N/m^2

$$H = \frac{(P_D - P_S)}{\rho \times g} = \frac{(1{,}400{,}000 - 10{,}000)}{1000 \times 9.81} = 141.70 \text{ m}$$

Input power $P_P = 110 \times 3.55 \times 1.732 \times 0.93 \div 0.80 = \mathbf{786.25\ kW}$

Hydraulic power $P_W = \frac{1{,}502 \times 141.70 \times 1000}{367} = \mathbf{579.92\ kW}$

Pump Efficiency $\eta_P = \frac{P_W}{P_P} = \frac{579.92}{786.25} = \mathbf{74\ \%}$

4.7.2 Pump Characteristic Chart

A pump curve is a graphical representation describing the operation of a rotodynamic pump for a range of flows. A system curve represents the head required to move fluid through a piping system. The system curve has 2 components, which are the static head and friction head. The friction head losses are ignored in this scenario.

Intersection of the pump curve and system curve is the duty point of the pump. The duty point is the optimum flow and head condition at which a pump operates. Every pump has a point on the pump curve where its efficiency is highest; this point is known as the Best Efficiency Point (BEP). Operating a pump on or close to the BEP utilizes the least amount of energy and minimizes vibrations that can damage the pump impeller and bearings.

The pump curve for pump No.4 is shown in figure 4-8. From the test flow data of the pump, a system curve is superimposed on the pump curve to obtain the duty point. Flow rate pump No.4 is 1,502 m^3/ h.

From the pump curve, we see the system curve representing the pipeline intersecting at the point A. This point is the duty point of pump No.4 operating at Gigiri pumping station. A pump efficiency of 87.5% was attained when operating at the duty point A. Pump efficiency tests done indicate the efficiency of pump No.4 to be 74%. This difference can be attributed to adjustments to field operating conditions. Point B represents the duty point that was obtained during the pump factory tests.

The duty points A and B are located near the best efficiency point (BEP) with respect to the pump curve. The performance of pump No.4 is satisfactory.

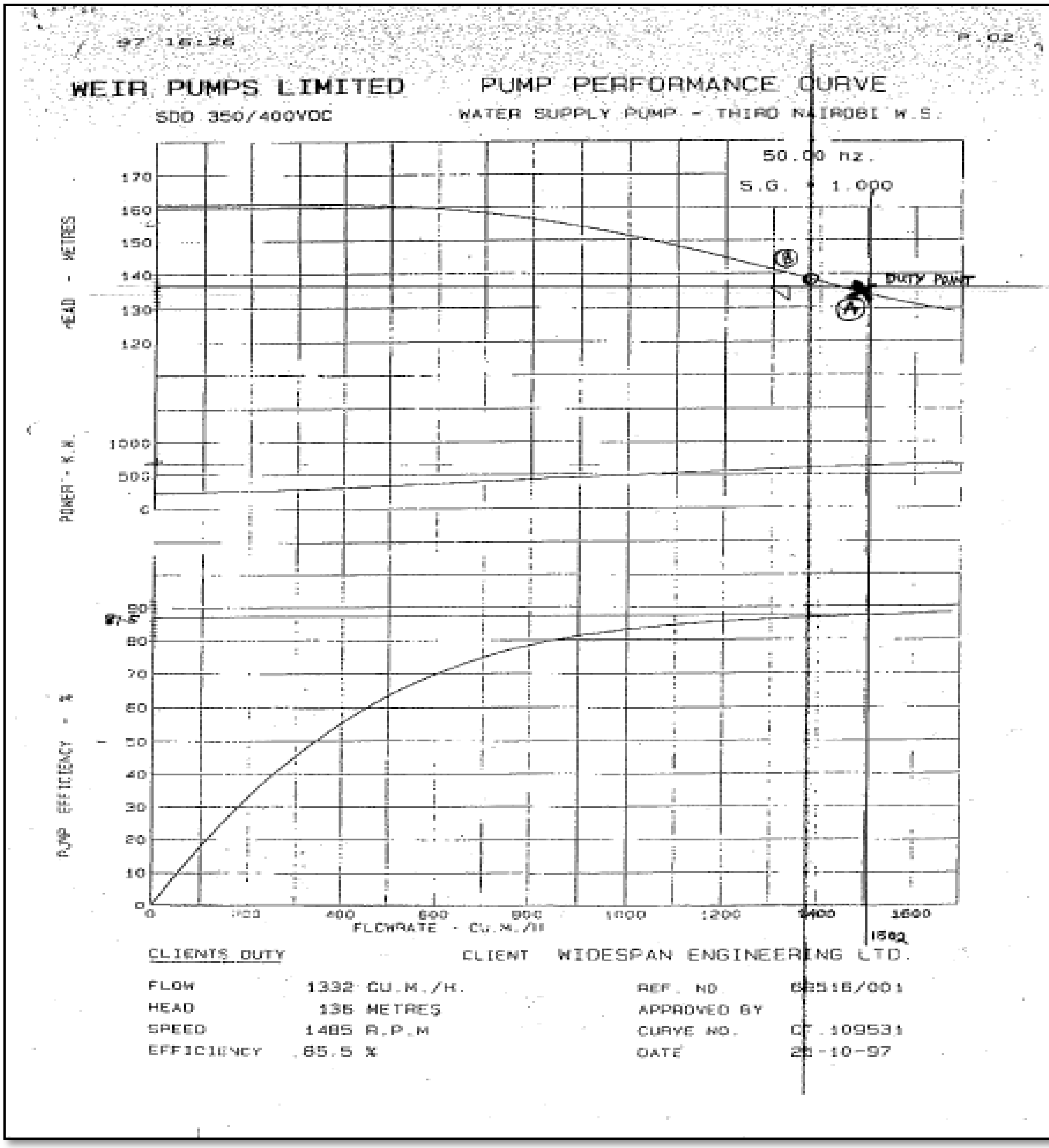

Fig 4-8: Pumping characteristic curve for pump No.4 with system curve.

4.7.3 System Efficiency

Pumping system efficiency is defined as the minimum hydraulic power needed to fulfill the process or operational demands divided by the input power to the pump drive system. The minimum hydraulic power corresponds to the design /duty flow rate. Flow measurements were taken at the Kabete reservoir where the pipeline ends.

4.7.3.1 Estimation of Pipe, Valves and fitting Friction Losses for the Gigiri – Kabete Pipeline

Length of pipeline ≅ 9,300 m

Diameter of pipeline (Asphalted Cast Iron) = 700 mm

Relative roughness $r = \frac{e}{D}$

Where e = Pipe roughness co-efficient

D = Pipe diameter

From roughness co-efficient tables, e for Asphalted cast iron = 0.12 mm

Diameter D of pipe = 700 mm

$r = \frac{0.12}{700}$, $r = 1.71 \times 10^{-4}$

Required system volumetric flow rate, Q = 1,332 m^3/h = 0.37 m^3/s (Design flow rate)

Volumetric flow rate = Cross Sectional Area (A) × Velocity (u)

$$Q = A \times u$$

A = πr^2

A = 3.14 × $(0.35)^2$= 0.385 m^2

$$u = \frac{Q}{A} = (0.37) \div (0.385) = 0.96\ m/s$$

Reynolds number, $Re = \frac{uD}{\vartheta}$

Where u = Water velocity

D = Pipe diameter

ϑ = Kinetic viscosity of water = 1.003×10^{-6} m^2/s

$\mathrm{Re} = \frac{0.96 \times 0.7}{1.003 \times 10-6}$, $\mathrm{Re} = 0.669 \times 10^6$

From Moody Chart with $\mathrm{Re} = 0.669 \times 10^6$ and $r = 1.71 \times 10^{-4} = 0.00017 \approx 0.0002$;

We obtain friction co-efficient factor, $f = 3.75 \times 10^{-3}$

Darcy-Weisbach head loss equation;

Head loss due to friction; $H_f = \frac{f \times L \times u^2}{2 \times D \times g}$

$H_f = \frac{3.75 \times 10^{-3} \times 9{,}300 \times 0.96^2}{2 \times 0.7 \times 9.81}$

$H_f = 2.34\ m$

Losses due to valves and fittings along the pipeline, H_{LV} are defined as follows [21]:

$H_{LV} = K \times \frac{V^2}{2g}$

Where: K = Resistance coefficient, v = Flow velocity and g = Gravitation acceleration.

Within the pumping station and the pipeline, there are approximately 5 valves and 47 standard elbows for the pipe bends totaling 52 valves and fittings. All these have an average K value of 0.36 corresponding to the pipe diameter of 0.7m from resistance coefficient charts. Substituting in the equation gives;

$H_{LV} = 0.36 \times \frac{0.96^2}{2 \times 9.81} = 0.0169\ m$

Multiplying by 52 valves and fittings gives; $0.0169 \times 52 = 0.88$ m

From the above friction head loss calculations for the pipe, valves and fittings, it can be said that these losses are minor with respect to the static head of 136 meters and can hence be ignored.

4.7.3.2 System Efficiency with Pump No.1 Running

Single pump flow rate Q (Pump No. 1) = 985$m^3\ /h$

Hydraulic Power,Pw $= \frac{Q \times H \times \rho}{367} = \frac{985 \times 136 \times 1000}{367} = \mathbf{365.00\ kW}$

Input power P_P = 120 × 3.55 × 1.732 × 0.93 ÷ 0.80 $= \mathbf{857.72\ kW}$

System Efficiency (Pump No.1) $\eta_S = \frac{P_W}{P_P} \times 100 = \frac{365.00}{857.72} \times 100 = \mathbf{43}\ \%$

4.7.3.3 System Efficiency with Pump No.2 Running

Single pump flow rate Q (Pump No. 2) = 1,350$m^3\ /h$

Hydraulic Power,Pw $= \frac{Q \times H \times \rho}{367} = \frac{1{,}350 \times 136 \times 1000}{367} = \mathbf{500.30\ kW}$

Input power P_P = 110 × 3.50 × 1.732 × 0.92 ÷ 0.80 $= \mathbf{766.84\ kW}$

System Efficiency (Pump No.2) $\eta_S = \frac{P_W}{P_P} \times 100 = \frac{500.30}{766.84} \times 100 = \mathbf{65}\ \%$

4.7.3.4 System Efficiency with Pump No.4 Running

Single pump flow rate Q (Pump No. 4) = 1,490$m^3\ /h$

Hydraulic Power,Pw $= \frac{Q \times H \times \rho}{367} = \frac{1{,}490 \times 136 \times 1000}{367} = \mathbf{552.15\ kW}$

Input power P_P = 110 × 3.55 × 1.732 × 0.93 ÷ 0.80 $= \mathbf{786.25\ kW}$

System Efficiency (Pump No.4) $\eta_S = \frac{P_W}{P_P} \times 100 = \frac{552.15}{786.25} \times 100 = \mathbf{70}\ \%$

4.7.3.5 System Efficiency with Pumps No.1 & No.4 Running

Parallel pump flow rate Q (Pumps No. 1 & 4) = 1,553$m^3\ /h$

Hydraulic Power,Pw $= \frac{Q \times H \times \rho}{367} = \frac{1{,}553 \times 136 \times 1000}{367} = \mathbf{575.50\ kW}$

Input power (Pump No.1) $P_P = 120 \times 3.55 \times 1.732 \times 0.93 \div 0.80 = \mathbf{857.73\ kW}$

Input power (Pump No.4) $P_P = 110 \times 3.55 \times 1.732 \times 0.93 \div 0.80 = \mathbf{786.25\ kW}$

System Efficiency (Pump No.1 & 4) $\eta_S = \frac{P_W}{P_P} \times 100 = \frac{575.50}{857.73 + 786.25} \times 100 = \mathbf{35}\ \%$

4.7.3.6 System Efficiency with Pumps No.2 & No.4 Running

Parallel pump flow rate Q (Pumps No. 2 & 4) = $1{,}952 m^3 /h$

Hydraulic Power,Pw $= \frac{Q \times H \times \rho}{367} = \frac{1{,}952 \times 136 \times 1000}{367} = \mathbf{723.36\ kW}$

Input power (Pump No.2) $P_P = 110 \times 3.50 \times 1.732 \times 0.92 \div 0.80 = \mathbf{766.84\ kW}$

Input power (Pump No.4) $P_P = 110 \times 3.55 \times 1.732 \times 0.93 \div 0.80 = \mathbf{786.25\ kW}$

System Efficiency (Pump No.2 & 4) $\eta_S = \frac{P_W}{P_P} \times 100 = \frac{723.36}{766.84 + 786.25} \times 100 = \mathbf{47}\ \%$

4.7.3.7 System Efficiency with Pumps No.1 & No.2 Running

Parallel pump flow rate Q (Pumps No. 1 & 2) = $1{,}521 m^3 /h$

Hydraulic Power,Pw $= \frac{Q \times H \times \rho}{367} = \frac{1{,}521 \times 136 \times 1000}{367} = \mathbf{563.64\ kW}$

Input power (Pump No.2) $P_P = 110 \times 3.50 \times 1.732 \times 0.92 \div 0.80 = \mathbf{766.84\ kW}$

Input power (Pump No.1) $P_P = 120 \times 3.55 \times 1.732 \times 0.93 \div 0.80 = \mathbf{857.72\ kW}$

System Efficiency (Pump No.1 & 2) $\eta_S = \frac{P_W}{P_P} \times 100 = \frac{563.64}{766.84 + 857.72} \times 100 = \mathbf{34}\ \%$

4.7.4 Electrical Demand Variation

Figure 4-8 shows the electrical demand variation for the period 2010-2011 and 2011-2012. The highest demand attained in the pumping station was 1,664 kVA and the lowest demand was 1,314 kVA. The average demand for the period was 1,429 kVA. The maximum allowed demand for the pumping station is 4,900 kVA. During the entire 2 year period, power factor did not fall below the minimum of 0.90, which is the minimum specified by the Kenya power company. Below 0.9 power factor NCWSC incurs a penalty of 1% of the total bill for every 1% the power factor is below 0.9.

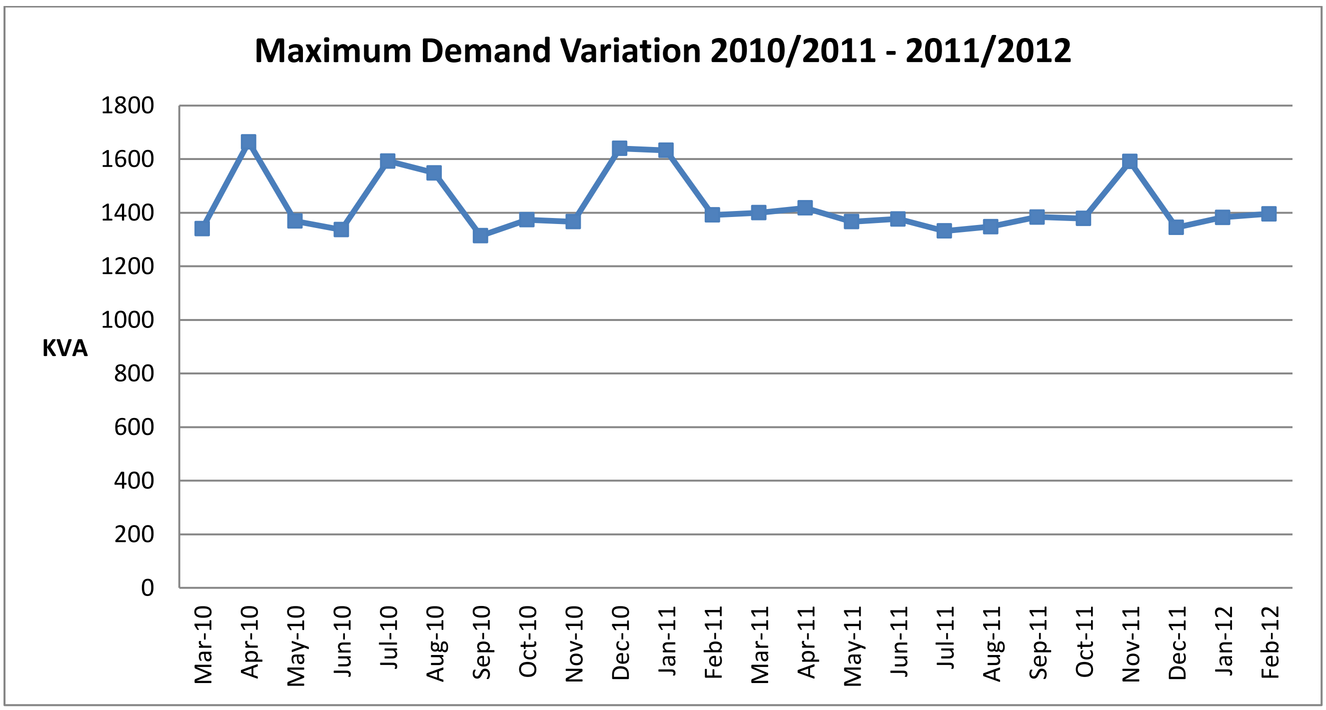

Fig 4-9: Pumping station electricity demand profile for period 2010-2011 and 2011-2012

CHAPTER 5: ENERGY COST SAVINGS OPPORTUNITIES

5.1 Introduction

In this chapter, the major energy costs saving opportunities are analyzed. These opportunities are found in the following areas:

(i) Configuration of pump operations.
(ii) Pump best efficiency point (BEP) adjustment for pump No.1.
(iii) Cooling water losses from pump bearings.

5.1.1 Life Cycle Costing (LCC) of Pumping System

The life cycle costs of a pump and system equipment is the total lifetime cost to purchase, install, operate, maintain and dispose-off the equipment.

The LCC system can be used as a comparison tool between possible pump selections for system design for new or existing installations. Pump initial cost and rated efficiency are often given top priority during the design phase, but constitute only a very small portion of total life cycle costs. [20]

Determining the LCC of a system involves using a methodology to identify and quantify all components of the LCC equation, which is shown below:

LCC = Cic + Cin + Ce + Co + Cm + Cs + Cenv + Cd

Where C, the cost element has many aspects:

Cic = Initial cost or purchase (e.g. the pump, pipe, auxiliaries)

Cin = Installation and commissioning costs (including training)

Ce = Energy costs (predicted for entire system, including controls)

Co = Operating costs (labor man-hours for normal system supervision)

Cm = Maintenance costs (e.g. parts, tools, labor man hours)

Cs = Downtime costs (loss of production)

Cenv = Environment costs (leakage losses and environmental hazards)

Cd = Decommissioning costs (disassembly and disposal)

The above elements should also include the administrative costs associated with loans, depreciation and taxes.

For the purpose of this assessment, the payback periods obtained are calculated on the basis of energy cost savings alone, whereas in reality the above mentioned costs interact with energy costs in various ways during actual pumping system operations.

5.2 Pump Configuration – Single Pump Operation

A sample summary of the pump field test results are shown in the table 5-1 below.

Table 5-1: Summary of field test results.

Pump /s	Annual Running Hours	Discharge Pressure (bars)	Flow Rate(m^3/h)		Specific Energy (kWh/m^3)	Pump Efficieny (%)	System Efficiency (%)
			Gigiri	Kabete			
2 & 4	2,069	Pump2: 15 Pump4: 16	1,998	1,952	0.554	-	47
1	5,385	Pump1: 14	1,019	985	0.779	46	43
1 & 4	1,856	Pump1: 15.5 Pump4: 16	1,576	1,553	0.611	-	35
4	4,677	Pump4: 14	1,502	1,490	0.441	74	70
1 & 2	1,553	Pump1: 15 Pump2: 15	1,540	1,521	0.726	-	34
2	4,032	Pump2: 14	1,364	1,350	0.473	69	65
							Avg=49%

The minimum design output requirement for the pumping system is 1,332 m^3/h. From table 5-1, it is seen that the single pump operation of pump No.4 can comfortably meet the system demand. Pump No.4 also has the lowest specific energy than pump No.2.

There is a clear mismatch of pump combinations for parallel pumping operations using pumps No.2 and 4, and pumps No.1 and 4. The variation of discharge pressures indicates that the weaker pumps in the combination could be experiencing some throttling. This could lead to pump mechanical seal and impeller damage.

Running pump No.4 individually as a single pump operation presents an energy saving opportunity, especially when running in parallel with the low efficiency pump No.1. Running the pumps No.1 and No.4 in parallel is costly and inefficient. Specific energy of the pumps No.1 and No.2 when running in parallel is also higher than average.

The potential cost savings are illustrated below:

Annual Energy Consumption of parallel pump combination pumps No. 1 and 4 for period 2010-2011. (Table 4-7)

= 2,321,404kWh

Annual running hours of parallel pump combination pumps No. 1 and 4 for period 2010-2011. (Table 4-8)

= 1,856 Hours

Annual volume of water pumped by parallel pump combination pumps No. 1 and 4 for period 2010-2011. (Table 4-10)

= **3,799,271 Cubic meters or m^3**

Energy Consumption of Pump No.4 running alone for 1,856 hours is:

$$Power = Current \times Voltage \times \sqrt{3} \times Power\ factor \times Running\ hours$$

$P = 110 \times 3.55 \times 10^3 \times \sqrt{3} \times 0.93 \times 1{,}856$

Energy Consumption for Pump No.4 = **1,167,462 kWh**

Cost Savings = $2{,}321{,}404 - 1{,}167{,}462 = \mathbf{1,153,942\ kWh} \times 4.25\ KES\ (KPLC\ unit\ rate)$

Potential Annual Energy Cost Savings = $\boldsymbol{KES\ \ 4,904,254}$

This will be the cost saving in pumping the same volume of water that is 3,799,271m^3, which was pumped by the parallel pump combination of pumps No. 1 and 4.

Cost of Investment = No cost.

Payback period = Immediate savings benefit.

5.3 Pump best efficiency point (BEP) adjustment for pump No.1

In order to adjust the BEP for the pump No.1, the pump has to be overhauled to replace the mechanical components that could have worn out and affected the pumps operational performance.

This is likely as the pump No.1 is the oldest since first installation and runs for the longest time annually. A case in point would be a worn out impeller that is diminished in size resulting in decreased flow delivery. Another case would be faulty or worn out mechanical seals that lead to water pressure leaks hence decreasing flow.

To determine this energy saving opportunity, we target to have the pump No.1 increase its discharge from the current 985 m^3 /h to the pumping system's design flow rate of 1,332 m^3 /h after the pump overhaul.

Increase of flow discharge after overhaul = (1,332 – 985) m^3/h =347 m^3/h

From table 5-1, the specific energy intensity of pump No.1 = 0.779 kWh/m^3

From table 4-6, the annual pump running hours of pump No.1 = 5,385 Hours

Potential Annual Energy Savings =347× 0.779 × 5,385 = 1,455,635 kWh

Potential Annual Energy Cost Savings = 1,455,635 kWh × 4.25 KES ($KPLC\ unit\ cost$)

Potential Annual Energy Cost Savings = $\boldsymbol{KES}$ **6,186,449**

<u>Cost of Investment:</u>

Average costs of Vertical Centrifugal pump overhaul= $\boldsymbol{KES}$ **1,500,000**

(Source: NCWSC Staff)

<u>Simple Payback Calculation:</u>

= 1,500,000 (KES) ÷ 6,186,449 (KES/ Annum)

= 2.9 Months = **Approximately 3 Months.**

5.4 Cooling water losses from pump bearings.

The vertical centrifugal pumps at Gigiri pumping station have a cooling mechanism for their rotor bearings. Pumps No.1 and No.2 have their bearings cooled by tapping water under pressure from the pump casing using a half- inch pipe to the bearings to prevent over-heating. The bearing cooling jackets have an inlet and outlet port.

Once cooling takes place, the water exits into the storm drainage system. This was observed as loss of water resources, but also the water loss had energy implications. Cooling water that is treated is drawn under pressure from the pump to the bearings, and energy used in the process is lost when it goes to the drains. Cooling water was also observed to be flowing even when the pumps were off.

This presented an energy saving opportunity. The wasted water can be re-directed back to the reservoir or to the discharge side of the pump for onward pumping.

Flow tests revealed that 20 liters of water were lost per minute for each of the pumps No.1 and No.2.

If the water was re-directed to the discharge pipe section:

Total water loss per day = 20 Liters$\times$ 2 $Pumps$ $\times$ 60 $minutes$ $\times$ 24 $hours$ = 57,600 Liters.

Total Annual water loss = 57,600 $\times$ 365 days = 21,024,000 Liters = **21,024 m^3**

From table 4-9, average specific energy for period 2010 – 2011 = **0.667 kWh /m^3**

Potential Annual Energy Savings =21,024$\times$ 0.667 = **14,023 kWh**

Potential Annual Energy Cost Savings = 14,023 kWh $\times$ 4.25 KES ($KPLC\ unit\ cost$) (Source: Gigiri Energy bill)

Potential Annual Energy Cost Savings= $\boldsymbol{KES}$ **59,598**

If the water was re-directed back to the reservoir:

Total water loss per day = 20 Liters $\times$ 2 $Pumps$ $\times$ 60 $minutes$ $\times$ 24 $hours$ = 57,600 Liters.

Total Annual water loss = 57,600 $\times$ 365 days = 21,024,000 Liters = **21,024 m^3**

Unit cost of treated water per 1,000 Liters or per cubic meter = **KES 50.00**
(Source: NCWSC Tariffs)

Potential Annual Water Cost Savings = 21,024$\times$ 50 = **KES 1,051,200**

Cost of Investment:

Costs for installing half-inch piping from bearing outlet port to discharge side of pipe or to underground reservoir = $approx$ $\boldsymbol{KES}$ **5,000** (Source: NCWSC Staff)

Simple Payback Calculation:

If the water was re-directed to the discharge pipe section:

= 5,000 (KES) ÷ 59,598 (KES/ Annum)

= 1.06 Months = **Approximately 1 Month.**

If the water was re-directed back to the reservoir:

= 5,000 (KES) ÷ 1,051,200 (KES/ Annum)

= 0.05 Months = **Under 1 Month.**

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions were derived from the assessment of the pumping station:

- Individual and combination pump motor energy consumption were proportional to number of running hours of the pumps. For the individual pump energy consumption and running hours, it was observed that the pump No.1 consumed the highest energy and ran for the longest duration in both periods 2010-2011 and 2011-2012.
- Total energy consumption is proportional to the flow output of the pumping station. The average energy consumption and flow output was 882,753 kWh and 1,338,533 m^3 for the period 2010-2011 and 847,894 kWh and 1,348,568 m^3 for the period 2011-2012.
- The pumping operation is always done by two pumps running in parallel configuration and intermittently switched in different pump combinations using a start/ stop flow control mechanism. The pumping operation runs on a 24 hour basis.
- The pump combination of pumps No.1 and No.2 are the most expensive to run during pumping operations with specific energies of 0.726 kWh/m^3 for the period 2010-2011 and 1.224 kWh/m^3 for the period 2011-2012.
- The pump with the lowest pump efficiency was the pump No.1 with 46%. The most efficient pump was the pump No.4 with an efficiency of 74%. The highest system efficiency during parallel pump operation was attained by the pumps No.2 and No.4 at 47%, while the lowest system efficiency stood at 34% with pumps No.1 and No.2 in service.
- The following areas were identified for energy savings:
    I. Efficient single pump operation in place of inefficient and mismatched parallel pump operation – with potential annual energy savings of KES 4,904,254 with an immediate and at no cost savings benefit.

II. Pump No.1 BEP adjustment with potential annual energy savings of KES 6,186,449 with a payback period of approximately 3 months.

III. Cooling water losses from pump bearings, with potential annual water and energy cost savings of KES 1,110,798 with a payback period of approximately 1 month.

6.2 Recommendations

The following recommendations were arrived at for possible implementation and further studies:

- It is recommended that a further study be done during the overhaul of pump No.1 and No.2. These are the oldest pumps having been installed in 1985. This will investigate the condition of the impeller to find the cause of the low flow output resulting in the low pump efficiency. Studies are also recommended for the motors especially the actual speed in revolutions per minute.
- Due to the numerous routine maintenance requirements, it is recommended that a Computerized Maintenance Management System - CMMS be acquired to keep track of maintenance issues. This will aid in identifying more accurately energy related breakdowns and maintenance events.
- It is recommended that new digital energy meters are installed for the 3.3 kV high voltages for the motors and the 415 V medium voltages for the pump accessories. No meter exists for the pump accessories.
- Nomination of a technical staff member at the pumping station to spearhead energy management activities. Energy issues are largely overlooked as a result of lack of awareness and proper recording of operations data. Energy audits are recommended annually for the next 3 years and thereafter after every 2 years.
- The quality of the electrical power in use within the pumping station from the transformer sub-station to the motors is not within the scope of this assessment.

A further study is recommended to establish the power quality effects on energy efficiency.

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APPENDICES

APPENDIX - 1

Electricity Bill

Kenya Power

Contract No. / Account No: 0531886-02

SEWARAGE CO. LTD WATER AND NAIROBI CITY..
P.O. BOX 30656-00100
NAIROBI
NAIROBI GPO

Bill Number: 0531886-02-28/02/2012-1
Maximum Authorised Load (KVA): 5,300
Date of Issue: 28/02/2012
Date Due: 06/03/2012
Method of Charge Rp: CI4 (HIGH/LOW RATE, PF)
Deposit: KShs. 0.00
Supply Location: 91/126 GIGI CLOSE (OFF

CONSUMPTION DATA

Consumption Type	Meter Number	Previous Reading	Current Reading	Conversion Factor	Consumption
HIGH RATE (CI4)	18010632	7170822	7531238	1	360408
LOW RATE (CI4)	18010632	8934852	9500488	1	565636
DEMAND KVA (CI4)	10018832		1396	1	1396
DEMAND KW (CI4)	10018832		1276	1	1276

BILLING DETAILS

BILLING CONCEPT	AMOUNT
BALANCE BROUGHT FORWARD	10,717,888.20
FIXED CHARGE	4,200.00
HIGH RATE CONSUMPTION	1,531,734.00
LOW RATE CONSUMPTION	2,146,061.50
FUEL COST CHARGE 304.8 cents/kwh	4,804,409.44
FOREX ADJ. 131.8 cents/kwh	1,134,520.26
INFLATION ADJ. 21.8	196,530.12
ERC Levy 3.0 cents/kwh	25,081.38
REP Levy 5.00 %	184,034.77
MAXIMUM DEMAND KVA	237,320.00
POWER FACTOR SURCHARGE (Kwh)	0.00
VAT 12.00 %	1,215,811.83
20120215-PAYMENT	-10,717,888.20
Round Adjustment	0.08
	11,557,593.40

Consumption: 30/01/2012 - 28/02/2012 (Act) Power Factor: 0.91

The monthly bill is KShs. 11,557,593.30

v2.01 KLPCORP 20120229_15.28.00 575 9446 26

This electricity bill is payable before 06/03/2012.
Notice is hereby given that if this bill is not paid within fourteen days from 06/03/2012, i.e on 20/03/2012, your supply shall be liable to disconnection without any further notice to you.

Should the supply be disconnected, in addition to settling the outstanding amount, you will be required to pay the applicable Reconnection (RC) fee before reconnection. The RC fees are as follows: Sh588 for cut-out RC or Sh3,828 for pole RC or Sh13,920 for service line RC. The said RC fees are inclusive of an 16% VAT charge. In addition, you will also be required to top up your deposit to 2 times your average monthly bill

PAID
1 MAR 2012

All enquiries to Customer Service Eng. NAIROBI NORTH P.O. BOX 30099, NAIROBI TEL. 020-3201823

customercarenairobi@kplc.co.ke

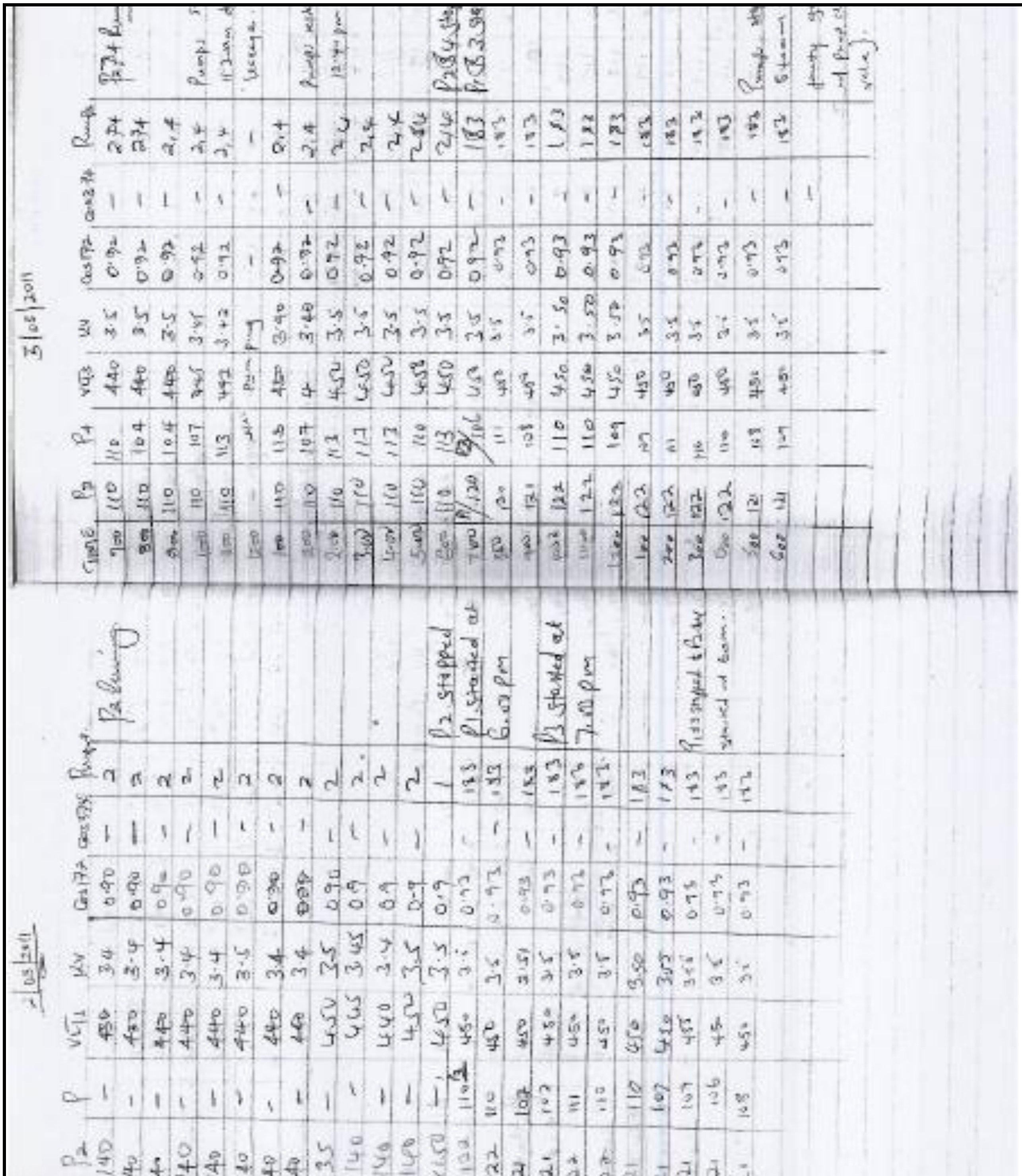
SEWARAGE CO. LTD WATER AND NAIROBI CITY. P.O. BOX 30656-00100 NAIROBI

06/03/2012 0531886-02-28/02/2012-1 KShs. 11,557,593.40

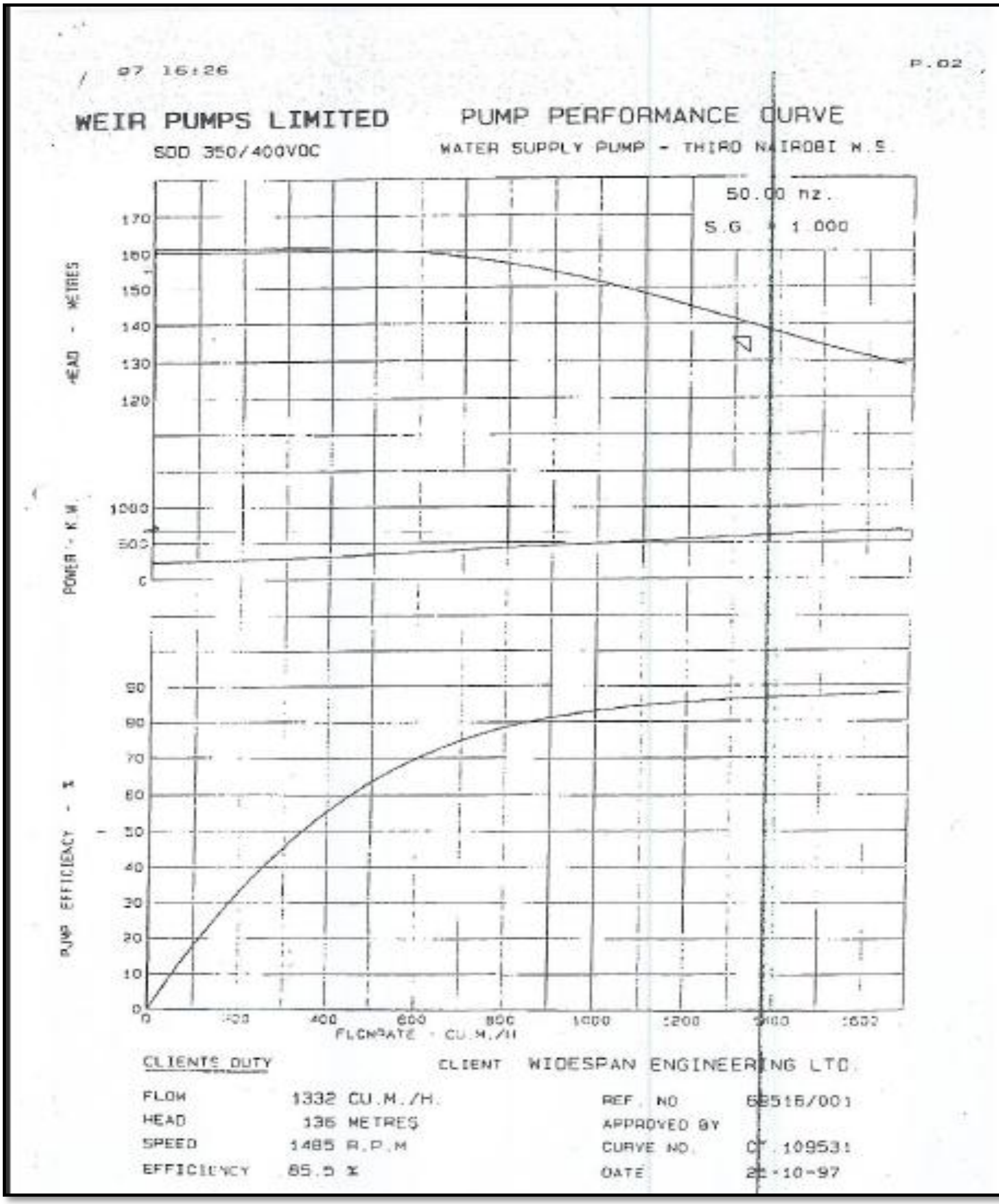
The net balance for the supply as at 28/02/2012 is KShs. 11,557,593.40. Please pay this amount

2120

APPENDIX - 2



APPENDIX - 3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P.02
WEIR PUMPS LIMITED
PUMP PERFORMANCE CURVE
SDD 350/400VDC
WATER SUPPLY PUMP - THIRD NAIROBI W.S.
S.G.
1.000
HEAD - METRES
POWER - K.W.
PUMP EFFICIENCY - %
FLOWRATE - CU.M./H
CLIENTS DUTY
FLOW 1332 CU.M./H.
HEAD 136 METRES
SPEED 1485 R.P.M
85.5 %
CLIENT WIDESPAN ENGINEERING LTD.
REF. NO
APPROVED BY
CURVE NO.
DATE

APPENDIX - 4

The technical data of the TECO Electric motor are listed below:

Type: AEVE TK 001

Manufacturer: TECO Electrical & Mechanical Co. Ltd

Serial/ Work No: D78292-1 & 2.

Rated Output: 709 kW

Supply Voltage: 3,300 V

Frequency: 50 Hz

Speed: 1,488 rpm

Winding RTD: 2 X 3 Winding

Insulation Class: F

Winding Cooling: Air

Protection: 1P44

Connection: Y

Lubricant: ESSO Unirex Lithium N3

The technical data of the uniglide vertical centrifugal pumps are listed below:

Frame size: SDD 350/400

Drilling Standard: BS4504 NP 16

Manufacturer: Weir Pumps Ltd.

Serial/Work No: 69516/001 & 69516/002

Rated speed: 1,485 rpm

Impeller diameter: 646 mm

Impeller material: Bronze LG4

Pump Shaft: Stainless Steel 431S29

APPENDIX - 5

ULTRASONIC FLOW EQUIPMENT SPECIFICATIONS

Maddalena™ Ultrasonic Flow Meter and Signal Converter

Model: A 3000

Rating: UP 67/ NEMAS 6

Code: 085F5002

Serial number: U2219/03

Power supply: 230 VAC, 50-60 Hz

Micronics™ Ultrasonic Flow Meter

Model: PF 330

Transducers: B Type – Diameter 50 mm – 2,000 mm.

Transducer Operating Temperature - -20 degrees C to + 80 degrees C.

Outputs: Opto Isolated 0/4 – 20mA, RS 232/USB.