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Development of Optimal Pump Schedules For Improved Energy Efficiency in Water Supply Systems

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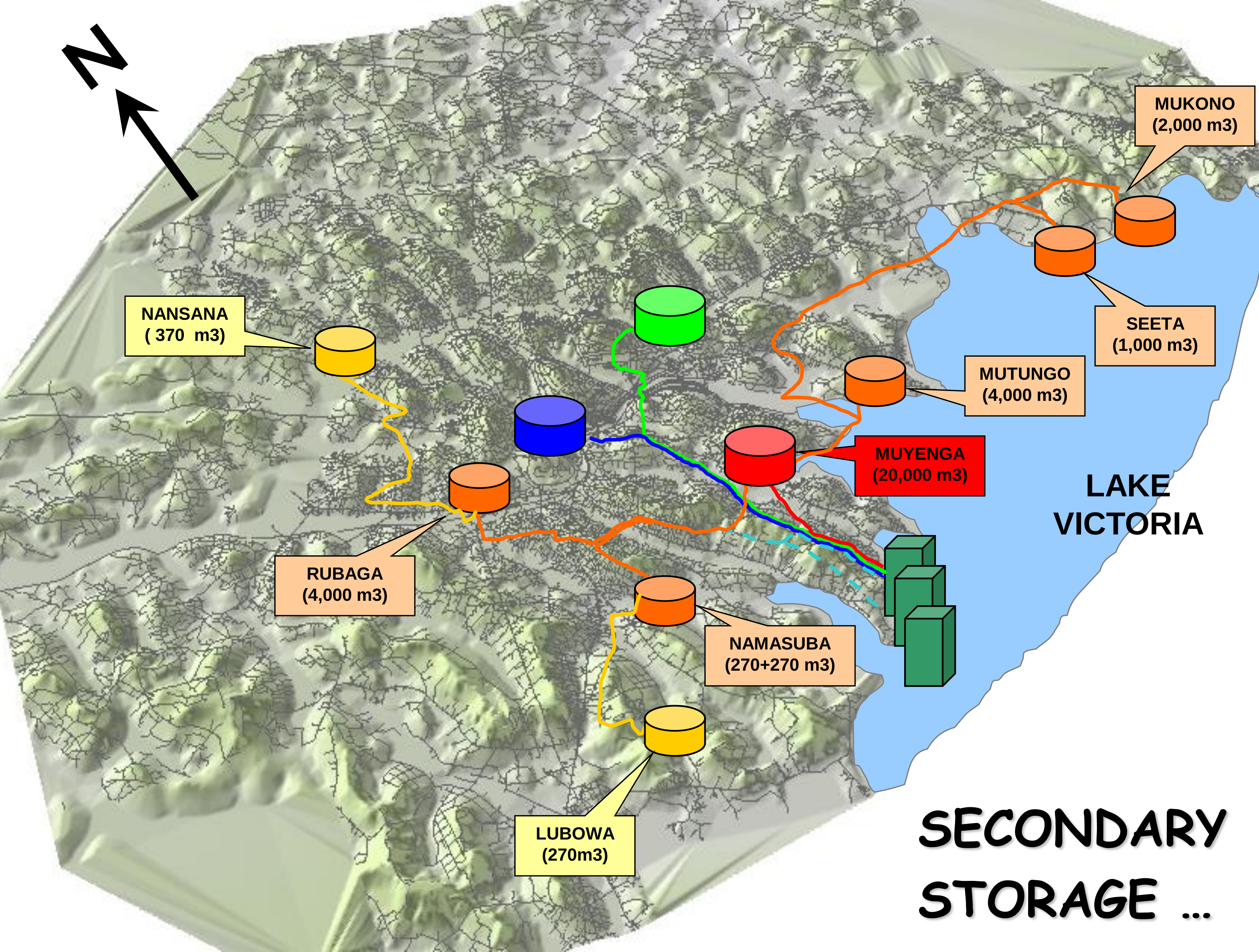
Introduction

- Water utilities are under pressure from regulators and environmentalists to reduce energy costs.

- This study therefore explored how pump optimization can enable deal with challenges of high energy costs and improve water utility performance.

- This was based on the case of the Gabba Muyenga sub-system of National Water and Sewerage Company (Uganda)


N
MUKONO
(2,000 m3)
NANSANA
(370 m3)
SEETA
(1,000 m3)
MUTUNGO
(4,000 m3)
MUYENGA
(20,000 m3)
LAKE
VICTORIA
RUBAGA
(4,000 m3)
NAMASUBA
(270+270 m3)
LUBOWA
(270m3)
SECONDARY
STORAGE ...

Objective

The Government of Uganda is promoting energy efficiency in recognition of the benefits among which are energy savings associated with the reduction of electricity consumption for the existing consumers and availing this to meet the incremental demand which would otherwise have to be met by investment.

Problem Statement

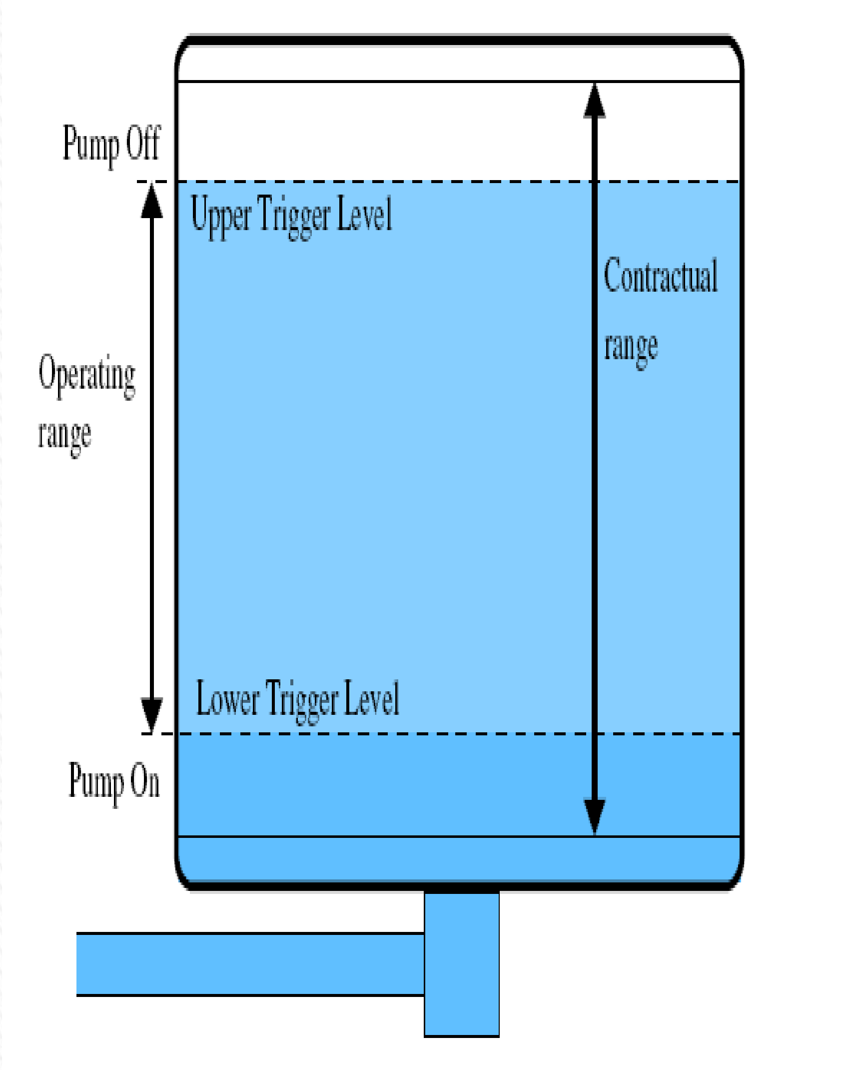
Globally, the increasing costs of water supply coupled with the recently policy on sustainability compel water utilities to improve efficiency of their water distribution systems by reducing energy costs. The irony however, is that many water utilities particularly in the developing countries continue to operate based on trial and error methods, resulting into system failures

Likely consequences of trial and error operations

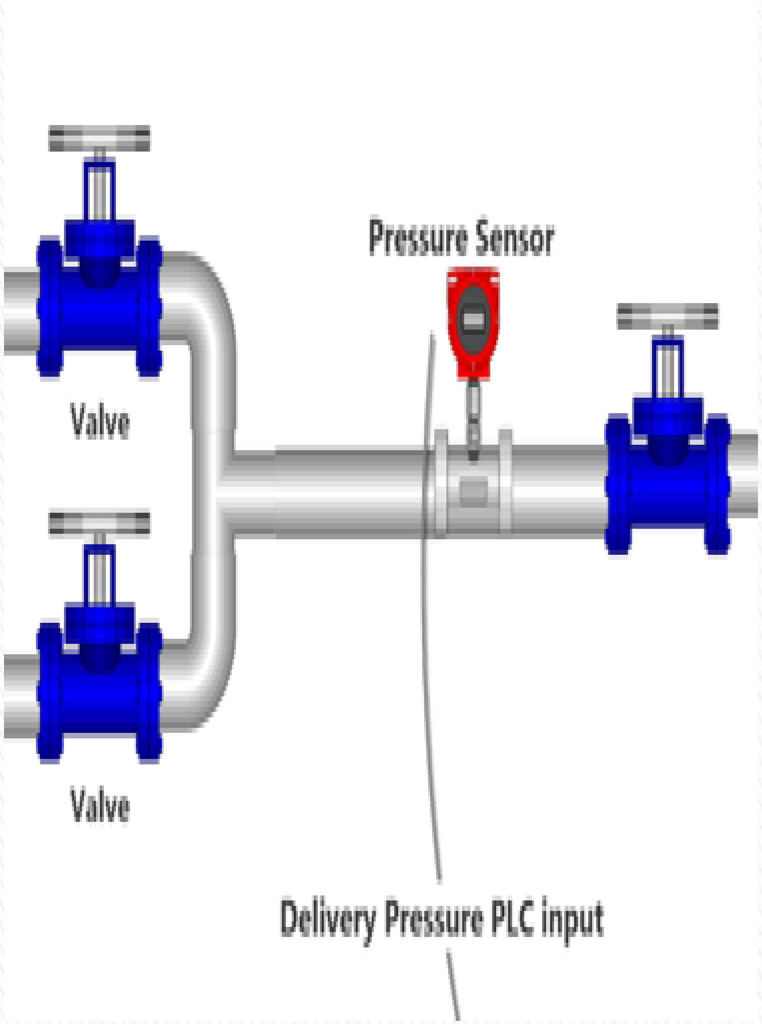
Procedure for formulation of optimal pump schedules

- Pump trial tests were performed on the selected sample pumps by applying one or a combination of tank level control and pressure control strategies.

- Scheduling period was divided into peak, shoulder and off-peak regimes, Secondly, a solution was to be hydraulically feasible that is to say that there are no nodes in the network experiencing negative and excessive pressures



Trigger levels on a tank



Applied dynamic pressure control strategy

Application of the formulated schedules on a real case network

- The formulated optimal pump schedules were applied to the case study as a proof of concept through installation of tank level probes/sensors at Muyenga reservoirs and pressures control triggers installed at the inlet point of the DMA under investigation to trigger pumps on/off based on the applied schedule protocols and set constraints

Level-controlled triggers at Muyenga

Pressure-controlled triggers at Mbuya Booster

Impact of pump operations on energy cost

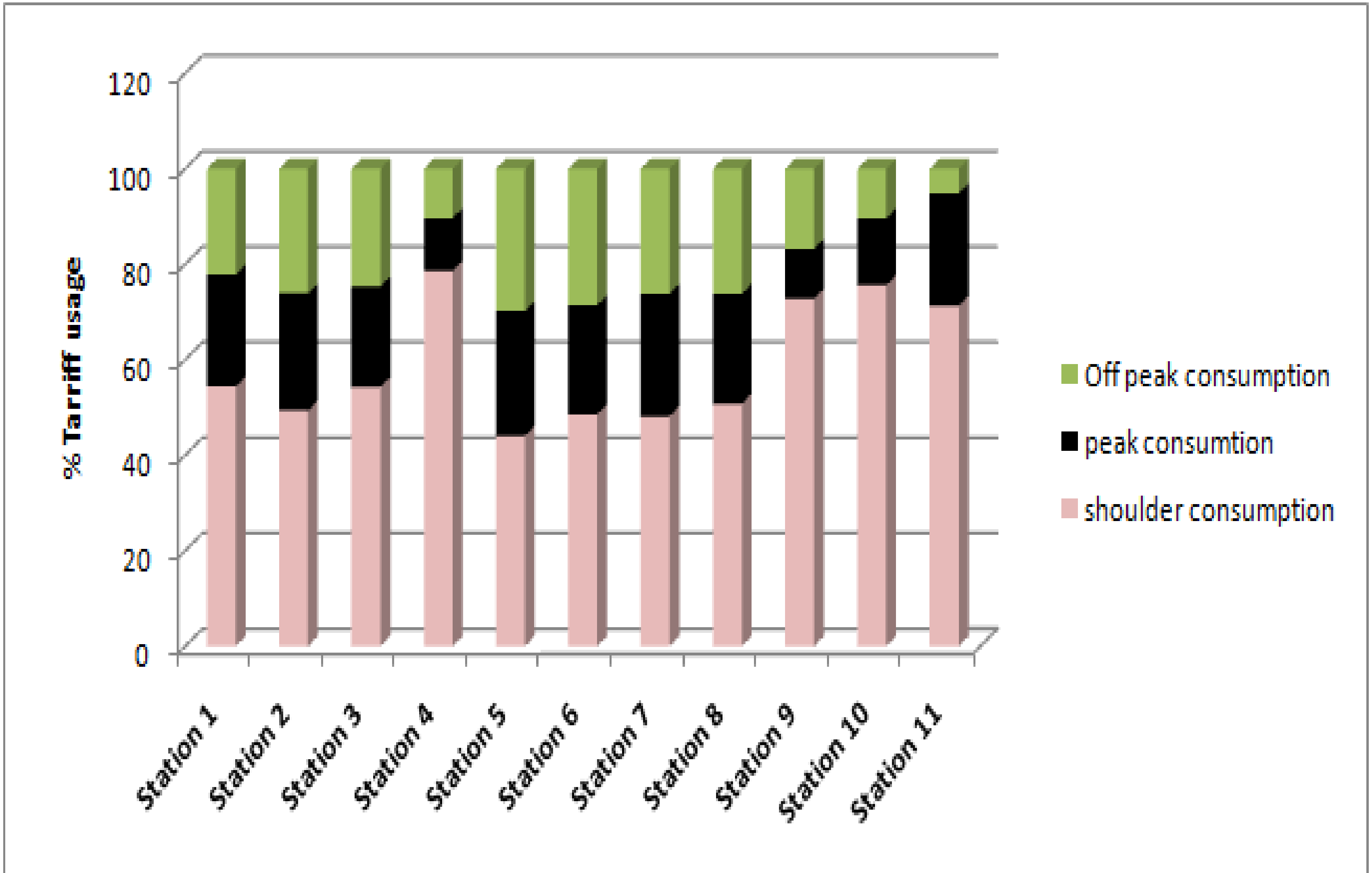
Model 1 Energy Consumption based on time of the day tariff

Year	**Electricity Consumed (million kWh)**				**Amount (UGX,Million)**	**Cost of Energy per unit (UGX/kWh)**
	Shoulder (R_1)	Peak (R_2)	Off-peak (R_3)	Total		
07/11/2013 to 08/10/ 2014	5.5 (29%)	4.81(26%)	8.49 (45%)	18.796	4144.11	220.48
06/11/2012 to 07/10/ 2013	8.24(48%)	4.63(27%)	4.14(24%)	17.006	3949.67	232.25

Model 2 Energy Consumption based on time of the day tariff

Year	**Electricity Consumed (million kWh)**				**Amount (UGX, Million)**	**Cost of Energy per unit (UGX/kWh)**
	Shoulder (R_1)	Peak (R_2)	Off-peak (R_3)	Total		
07/11/2013 to 08/10/ 2014	3.09 (25%)	3.17(25%)	6.18 (50%)	12.433	2728.10	219.41
06/11/2012 to 07/10/ 2013	2.17(27%)	2.01(25%)	3.81(48%)	7.99	1731.32	216.69

Bar Chart showing time of day (TOD) energy consumption break-up for model 3 pumps



Modeling for pump efficiency determination

A regression analysis with a linear relationship to predict energy use efficiency

- The resultant model took the form

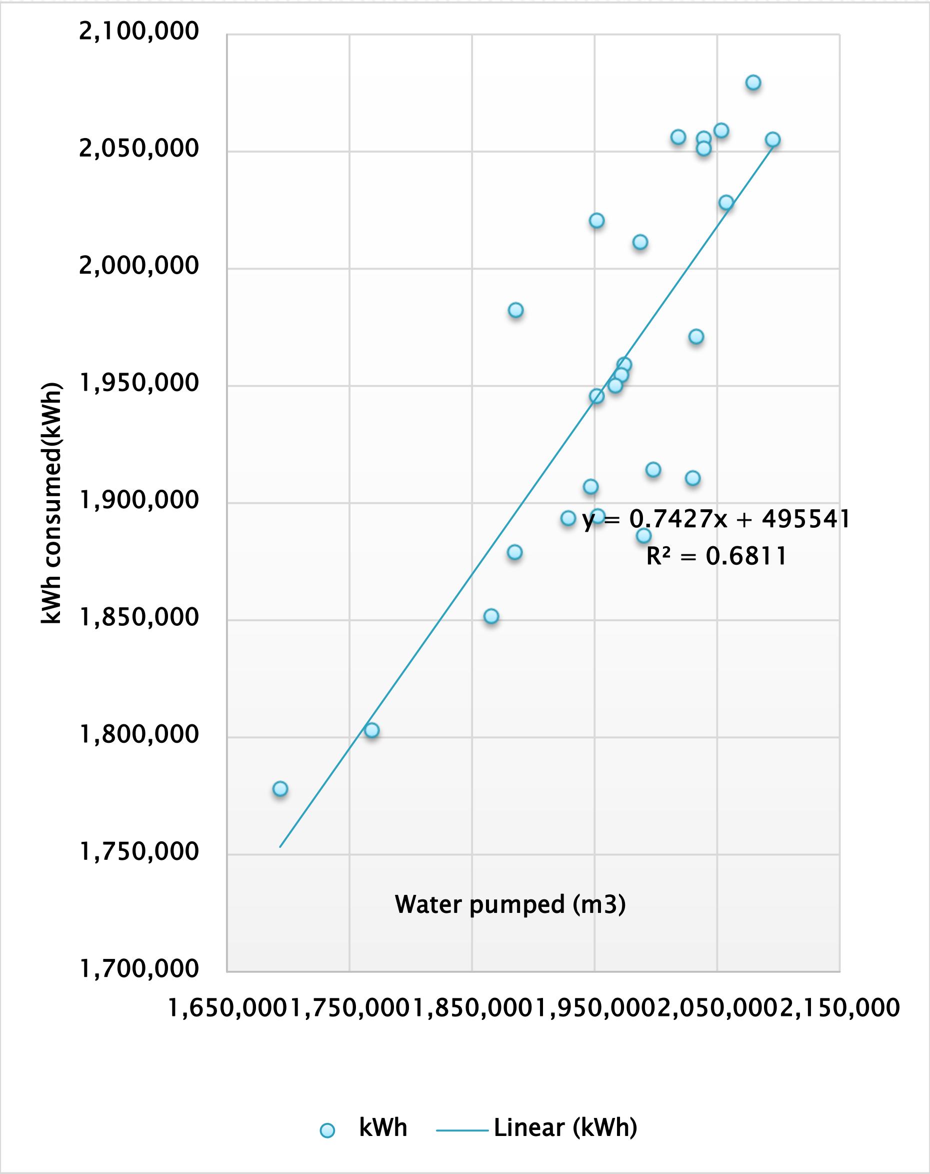
$$Y = \beta_0 + \beta_1 x$$

- Where Y was the totalized power consumed, X was the totalized water pumped, and the regression coefficients.

$$D = (\beta_1 * 100)$$

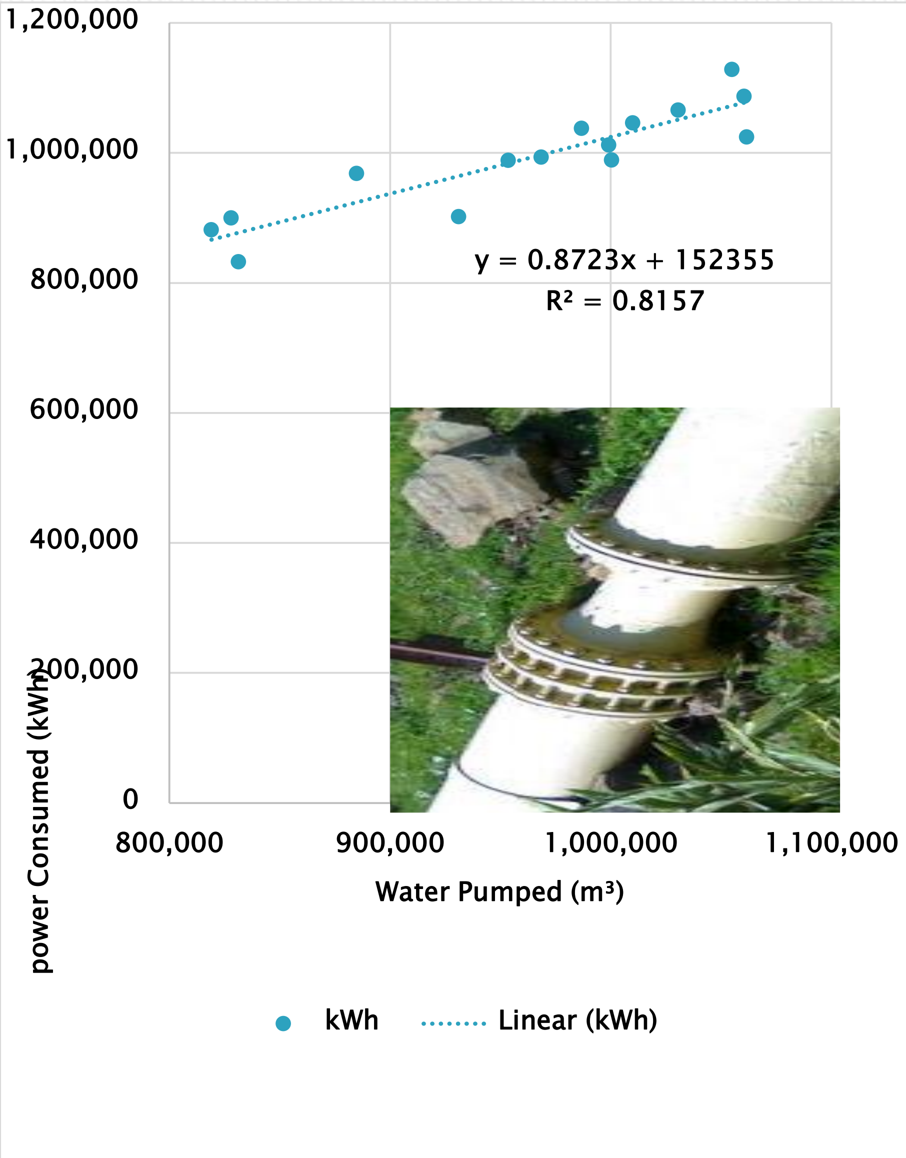
- The value D was the percentage of energy efficiency.

linear regression analysis for model 1 energy efficiency analysis



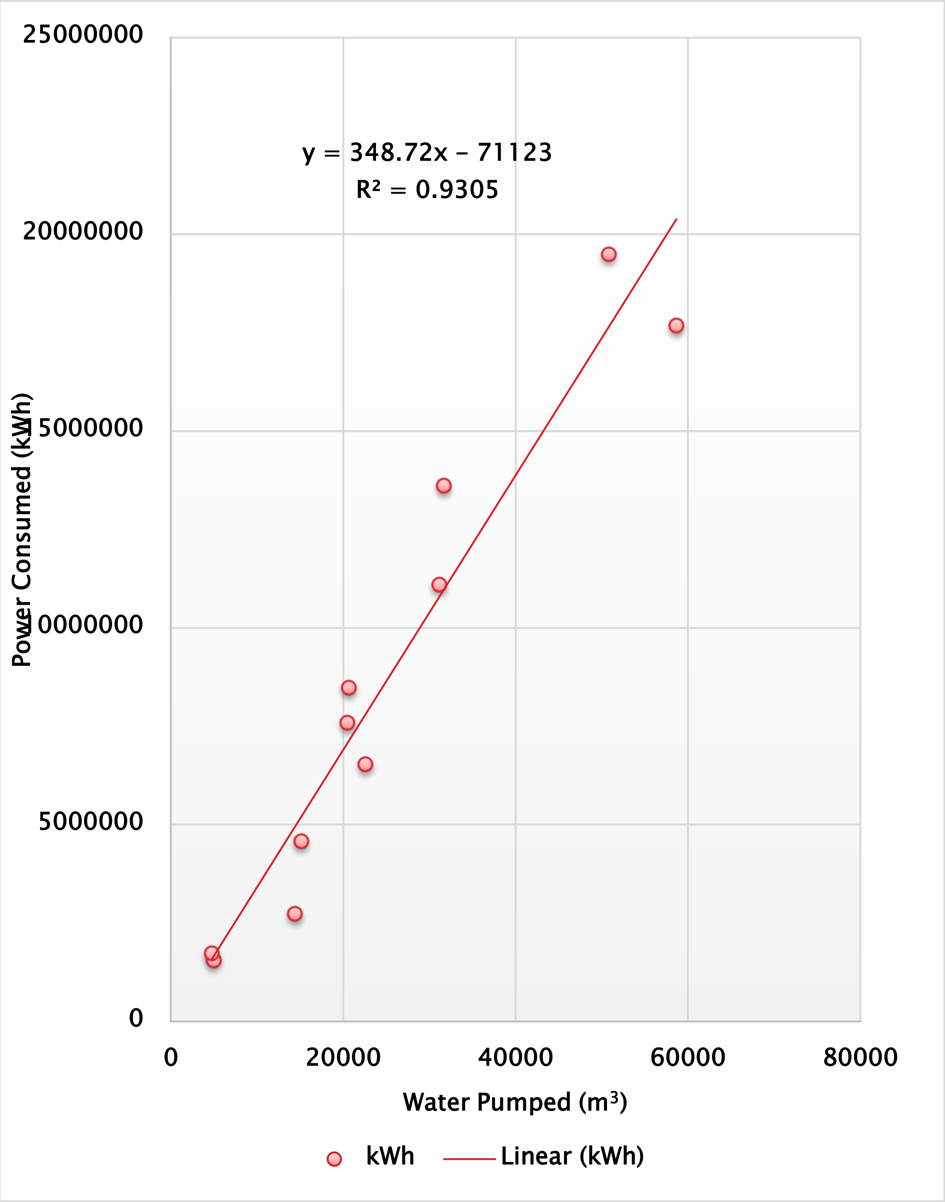
- specific energy consumption (kWh/m^3) of model 1 high lift pumps was satisfactory i.e. *Energy Efficiency rate of model 1=74.2 %* for a four combination; however the goodness of fit of the regression line which is measured using the coefficient of determination (R^2 = 68.1%) was rather low probably due to the marginal drop in efficiency as the number of pump combination increased which was due to low output and increased system resistance

linear regression analysis for model 2 energy efficiency analysis



The specific energy consumption (kWh/m^3) of model 2 high lift pumps was high in comparison to model 1 pumps This low efficiency rate for model 2 pumps was attributable to low output of the pumps which was a result of mismatch between the suction and delivery pipe sizes and also as a result of operating more pumps in parallel.

linear regression analysis for model 3 energy efficiency analysis



- **The results from linear regression relationship could not provide a single uniform efficiency rate for all sampled pumps, this implied that scheduling based on time of the day tariff and network re-modifications for improved (kWh/m^3) could only apply to individual stations , based on this background the possibility of allocating pressure controls in the network by considering the water demand required by users firstly as deterministic and subsequently as probabilistic was applied to trigger pumps on and off.**

Formulation of optimal pump schedules for energy efficiency

Formulation of optimal pump schedule for model 1 pumps

Operating cost of pumps based on tariff structure

Tariff	Operating Cost in 000'UGX/hr		
	Operation of 2 pumps in parallel	Operation of 3 pumps in parallel	Operation of 4 pumps in parallel
Shoulder	214.861	307.549	394.351
Peak	266.151	380.965	488.488
Off Peak	150.860	215.939	276.885

Details of Output and energy per day

Measured parameters	Operation of 2 pumps in parallel	Operation of 3 pumps in parallel	Operation of 4 pumps in parallel
Output of pumps,m^3/hr	1788	2454	2925
Power consumption ,kW	1115	1596	2046

Con't

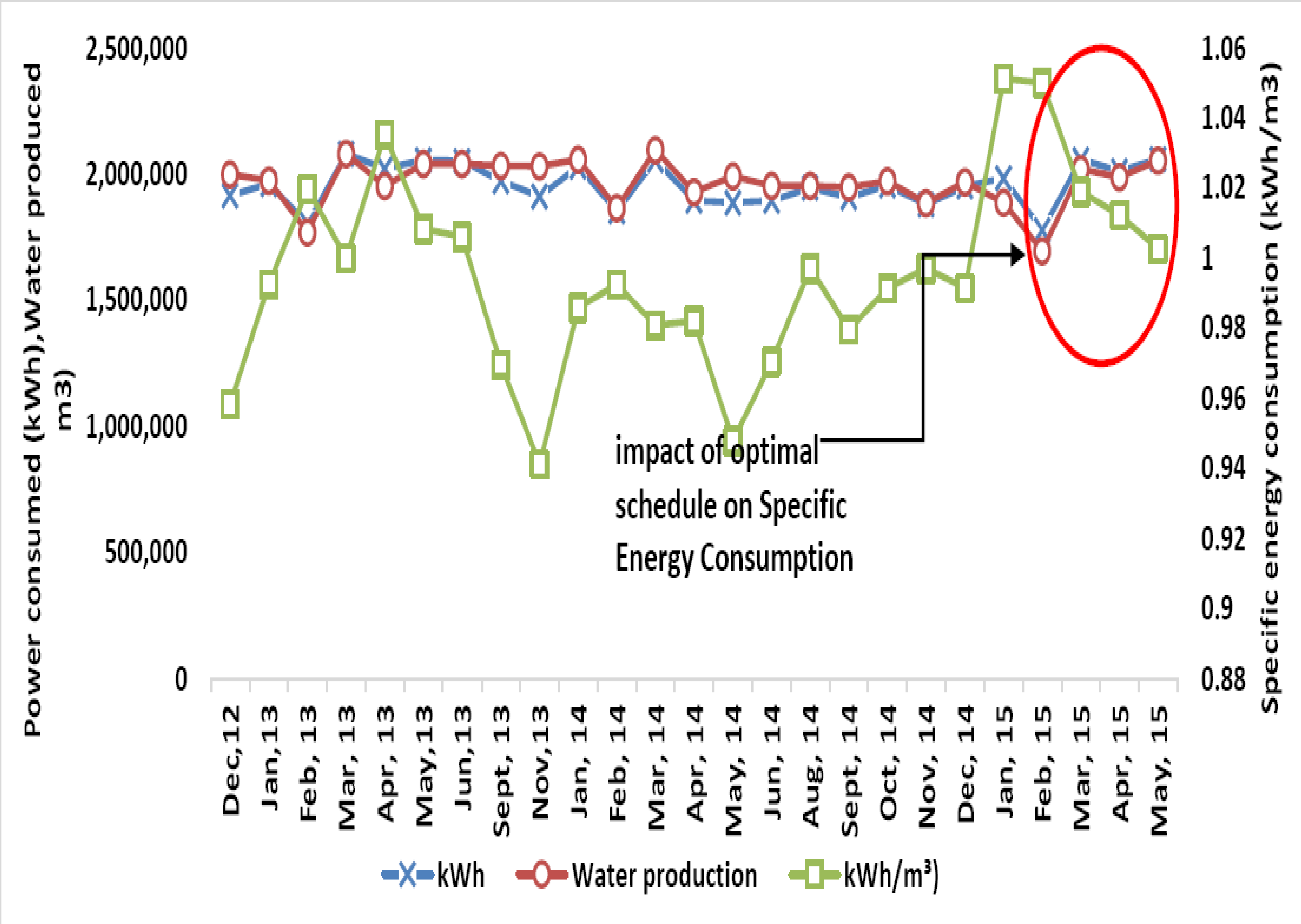
Based on the data generated, an energy decision support was developed And the impact of each schedule implemented is briefly shown below.

Cost and output per day based on number of operating hours (as at 28th January 2015)

Present Scenario				
Tariff	**Shoulder**	**Peak**	**Off peak**	**Total**
Operation of 2 pumps in parallel (hrs.)		6		6
Operation of 3 pumps in parallel (hrs.)	11		6	17
Operation of4 pumps in parallel (hrs.)	1			1
Output per day,m^3	29919	10726	14724	55369
Energy per day kWh	19602	6690	9576	35868
Total cost per day, UGX	**3777392**	**1596903**	**1295633**	**6669928**

Optimized schedule (cost and output per day based on number of operating hours)

Tariff	Shoulder	Peak	Off peak	Total
Operation of 2 pumps in parallel (hrs.)	2	6		8
Operation of 3 pumps in parallel (hrs.)	10			10
Operation of4 pumps in parallel (hrs.)			6	6
Output per day,m^3	25662	10726	19531	55918
Energy per day kWh	16594	6690	13424	36708
Total cost per day, UGX	3197664	1596903	1816301	6610868



2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Power consumed (kWh),Water produced m3)
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
Specific energy consumption (kWh/m3)
impact of optimal schedule on Specific Energy Consumption
Dec,12
Jan,13
Feb, 13
Mar, 13
Apr, 13
May,13
Jun,13
Sept, 13
Nov,13
Jan, 14
Feb, 14
Mar, 14
Apr, 14
May, 14
Jun, 14
Aug, 14
Sept, 14
Oct, 14
Nov, 14
Dec, 14
Jan, 15
Feb, 15
Mar, 15
Apr, 15
May, 15
kWh
Water production
kWh/m³)

Impact of model 3 optimal scheduling operations on energy costs

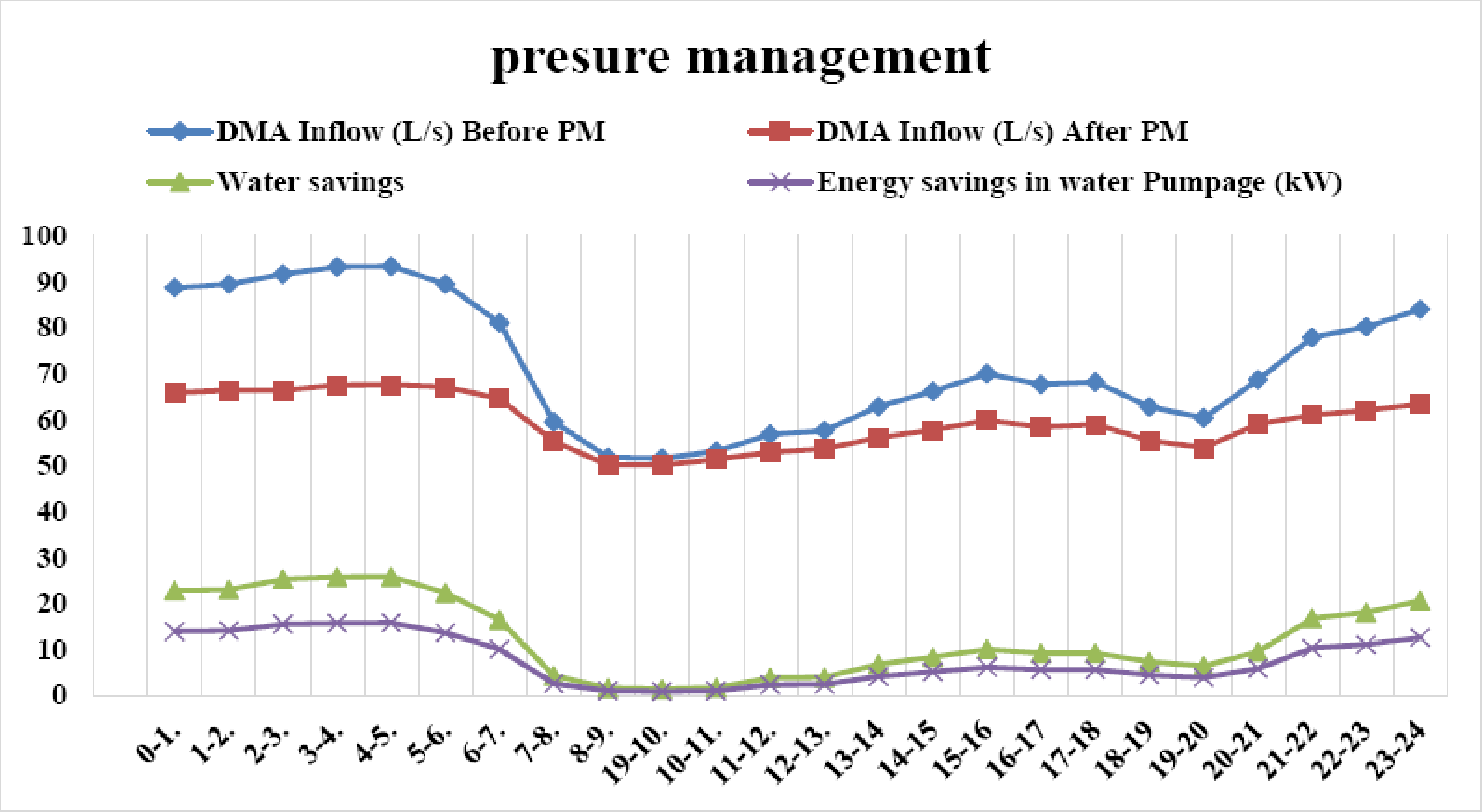


Figure 34: Impact of pressure modulation on water and energy savings

Energy saving

Energy savings in the DMA

- Energy cost savings per day: UGX950, 400
- Annual energy savings: 0.068 Million kWh
- Annual cost savings @ 80% realization factor: UGX15 million (@UGX 220.7 per kWh)
- Cost of implementation: UGX 6.5 million
- Simple payback period: 1.2 years

Conclusion

- Power savings are predominantly from shifting pumping from high day tariffs to lower night tariffs.
- Assessment and comparison of pumping cost per unit of water i.e. UGX/000'm^3 and kWh/000'm^3 indicates the level of efficiency of the sub system and system on a whole
- Suitable pump sizing results into significant energy savings
- Significant energy cost savings can be obtained by introducing pressure management
- Scheduling is more appropriate if supply exceeds demand

Recommendations

- It is recommended to optimize operation of pumps utilizing time of the day tariff so as to save the operating cost.
- It is recommended to install suitable sized pumps for operations
- It is recommended to implement intelligent pressure management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