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# An Optimised Energy Saving Model for Pump Scheduling in Wastewater Networks

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**Abstract** The cost of electricity used for pumping in water and wastewater networks typically represents the largest part of the total operational costs. Hence, energy management is becoming increasingly more critical in water and wastewater sectors. Most sewer networks and pump stations operate based on the common high/low sewage levels and not taking into account energy costs associated with pumping. Scheduling the pumps in these systems is a smart choice for saving more electricity cost. The intelligent and smart control of the utility's assets could present operational cost saving opportunities by considering the price of purchased electricity from the spot market; however, this must be balanced with the environmental constraints to manage system odours, spills and overflow. The purpose of this study is to improve and optimise the pump control switching with the aim of reducing electricity consumption costs. To this end, the hydraulic modelling approach using Infoworks ICM has been used to simulate the performance of the pump controller. This model considers the both electricity spot price and sump elevation as inputs into smart control logic programming to operate pumps

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more efficiently. Results show this smart controller improves conventional pump switching models in terms of energy optimising and cost savings.

# 1 Introduction

Energy is one of key businesses and Australia is the world's ninth largest energy producer, accounting for about 2.4 % of world energy production (Liu, et al., 2016). Energy costs comprise part of the largest expenditure for nearly all water and wastewater utilities worldwide (Ostojin, et al., 2011). Literature shows that utilities use approximately 3% of total electricity production in developed countries such as United Kingdom, United States and Australia (Walski & Andrews, 2015). A large amount of electricity is consumed by wastewater operations due to increase rate of sewage every year. This is largely due to the spreading of cities and their resulting population growth. For this reason there is a pressure to reduce the energy consumption in public and private sewage operations (Hass & Dancey, 2015). One of the greatest potential areas for energy cost savings is the scheduling of daily sewage pump operations (Ostojin, et al., 2011).

Between 90% and 95% of the electricity purchased is used for sewage pumping in utilities (Bunn & Reynolds, 2009). The cost of energy is often related to the time of day at which the energy is used. In order to promote the use of off-peak energy and hence provide smoother loading of energy production facilities, different energy rates have been introduced by many energy providers. Therefore, avoiding peak hour pumping and having effective and optimised pump scheduling is one of the ways to reduce energy costs and thus decrease operating and maintenance costs for wastewater network operators (Zhang & Kusiak, 2011).

Generally, sewer networks are divided into two types, gravity and forced by pumps networks (Ermolin, 1999). Ideally, efficient sewer systems are designed to drain sewage by gravity of the topology where the sewer flows from the high point to the low point (Fiter, et al., 2005). However, pump stations are often required subject to topology, ground conditions, location of wastewater treatment plants and other factors. (Hao, et al., 2013) Pump stations are typically controlled by conventional on/off switching based on sewage elevation in the inlet wet well without considering energy costs. This type of control would lead to poor performance across a variety of performance indicators, including energy costs, hydraulic performance and efficiency. It is a major challenge to improve the conventional switching for energy optimisation and cost savings. In this case study, the smart controller intakes two main inputs including electricity spot price and sump elevation in both dry and wet weather conditions. This smart controller has a list of logic and rules in the form of an IF-THEN statement that combine these inputs to generate pump control commands (Konetschka, et al., 2017).

The remainder of this paper is organised as follows. Section 2 illustrates the conventional on/off pump switching in wastewater networks. Section 3 describes the proposed smart controller model. Then, a case study is conducted to simulate and validate the proposed model. Section 5 shows the case study results. Section 6 presents the conclusions.

# 2 Conventional Pump Switching

A sewage pump station consists of a wet well that holds wastewater and a number of pumps in order to empty the wet well in accordance with the control programme executed by a Programmable Logic Controller (PLC). In general, there are two pumps (i.e. 'duty' and 'standby' pumps) which are utilised in alternation under the normal operating condition. When the duty pump requires maintenance, the standby pump will be turned on. However, under a wet weather event it was expected that both pumps would operate. Figure 1 is an example of a sewer pumping station operation envelop.

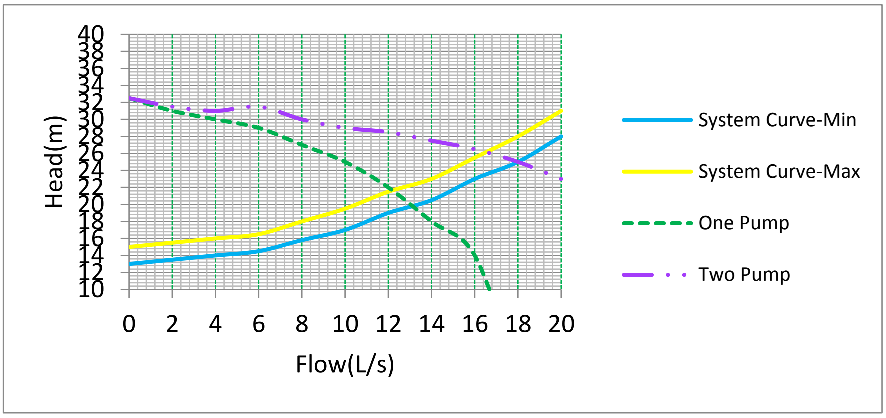


*Figure 1 Example of a Sewer Pumping Station Operation Envelop (Hayde, 2012)*

As it can be seen in Figure 2, sewage pumping control is a simple on/off control system based on the fluid level in the wet well.

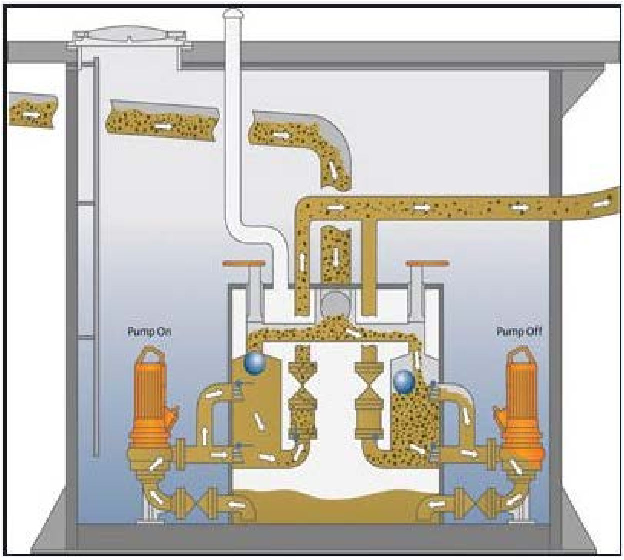


*Figure 2 A typical conventional sewer wet well*

Local PLCs start and/or stop the pumps based on sensors or float switches detecting the level within the wet well using predetermined set points. The PLC generally uses the control logic algorithm. This algorithm includes accumulating wastewater in the wet well until the liquid reaches the duty pump switch on level and then this pump will be started. It runs until the switch off level in the wet well is reached. The pump duty assignment is cycled between the pumps ensuring both pumps are operated approximately equally in order to retain equipment reliability, availability and maintainability.

# 3 Smart Controller Modelling

The smart controller uses two key inputs including of the sewage elevation and electricity price in order to generate pump status (on/off) as an output. The starting point to model the smart controller is to create logic control programming. To this end, a series of logic ranges would be allocated to inputs. As it can be seen in Figure 3, four ranges consider for electricity price from one to four (i.e. Low Tariff, Low-Medium Tariff, High Medium Tariff and High Tariff). In addition, three ranges from Low to High assign to the sump elevation. The smart controller has a list of logic rules in format of 'IF-THEN' statement that can calculate the pump status as an outcome. Infoworks ICM and its built-in-type Real Time Control (RTC) editor are applied to assess and simulate 'IF-THEN' logic rules.

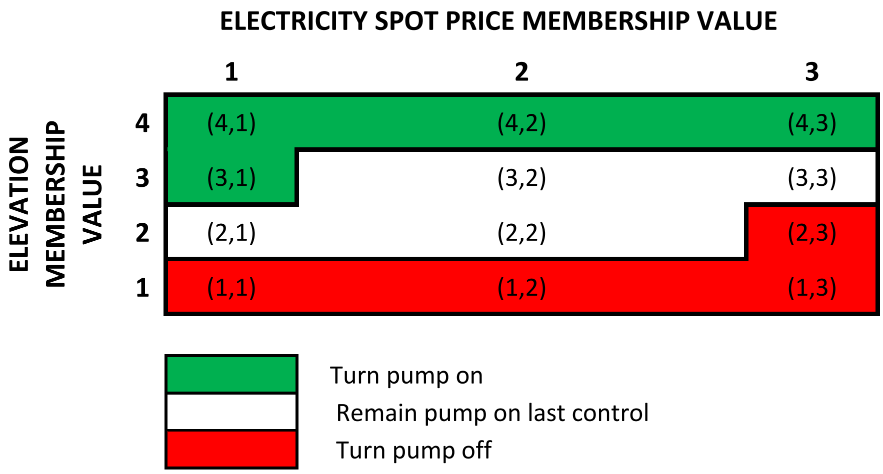


*Figure 3 Smart controller rules (Konetschka, et al., 2017)*

Modelling the smart controller within Infoworks ICM requires extensive use of RTC function. The RTC function contains six commands that can be used to control flows via pumps. The Six commands are describes as follows.

Range – A range can be set for a variable, either created or from within the simulation.

Table – This allows for data to be entered that can be used in a number of ways, in this simulation it has been used to input data in order to create a variable.

Variable–This enables the user to create a new variable that is not currently within the simulation. The new variable may be entirely from inputted table data or related to current variables within the simulation.

Logic – This command/function essentially sets up the IF side of the control. It is required to select different ranges and an operator (e.g. AND, OR) that will be used in the IF statement.

Rule – This command/function acts as the THEN side of the control. Rule allows the pump to be set at either a status (on/off) or flow rate (i.e. 10L/s) if a 'logic' or 'range' is satisfied.

The output of these functions is dependent on the order in which they are listed in the RTC editor. Therefore if any command/function is referencing another then it should be listed below. Within the RTC editor the commands/functions can be entered either under a global sections or an individual structures (pump) control. Any commands/functions entered under global will affect all structures within the network and be available to use for any range, variable, logic or rule command/functions in structure controls.

# 4 Case Study

The Murray Bridge wastewater network was selected for this case study. The Murray Bridge wastewater network locates on the bank of the Murray River in the South-East of Adelaide. The wastewater network contains 31 pump stations in total which is covering both residential and industrial users (refer to Figure 4). Out of 31 pump stations, 26 of them have been modelled using the smart controller. Infoworks ICM simulation has been applied in this case study for the energy optimisation and cost savings. Infoworks ICM is hydraulic extended period of wastewater networks.

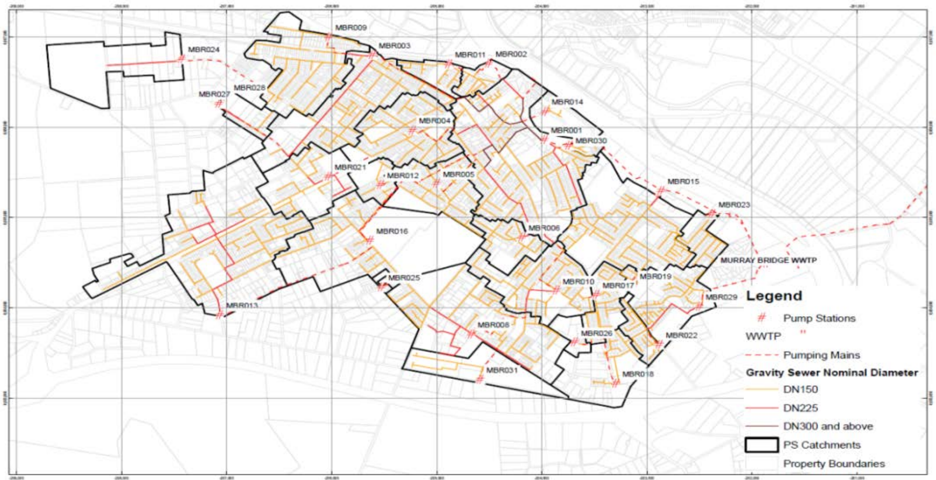


*Figure 4 Murray Bridge wastewater network (GHD, 2015)*

Pump station 1 has variable speed control pumps; therefore, it would be more complicated to apply the smart controller modelling. Additionally this pump station operates within a small wet well elevation with pumps in operation close to all the time; hence no optimisation in the order of pumping would be possible for this pump station. The other four pump stations were not modelled as they either were not included within the hydraulic model created nor have all required data was not readily available for the control system to be implemented.

Scenarios run on both dry and wet weather conditions. Inputs have been provided from different sources. Electricity spot price and sump elevation are considered as inputs in the smart controller and ‘IF-THEN’ statements determine the pump status including on, off or remaining on the last control which shown in Figure 3. Electricity spot prices have been collected from Australian Energy Market Operator (AEMO) at five minute increments at July 2016. Initial sump elevation and initial pump status collected from the hydraulic model using Infoworks ICM.

Modelling the smart controller using Infoworks ICM needs to use the RTC editor which developed as a version of the smart controller. The RTC commands and functions are; Range, Table, Variable, Logic, Controller and Rule. Figure 5 is an example of how the RTC editor has been used to model a smart controller via Infoworks ICM. Below the figure is a detailed version of the concept used in each step of the real time control.

During creating the RTC controls all global commands and functions are completed first. The first step is to create a range for time set as that time span of the electricity data used. A table is then formed to enter electricity pricing data that is a function of the time range set above. A variable is then created from the table of electricity data such to allow ranges to be created from different times in which electricity prices are classed as high, medium and low. Ranges of electricity prices can then be entered through using the range command. In the example three ranges used with range 1 signifying low prices and range 3 signifying extreme prices.

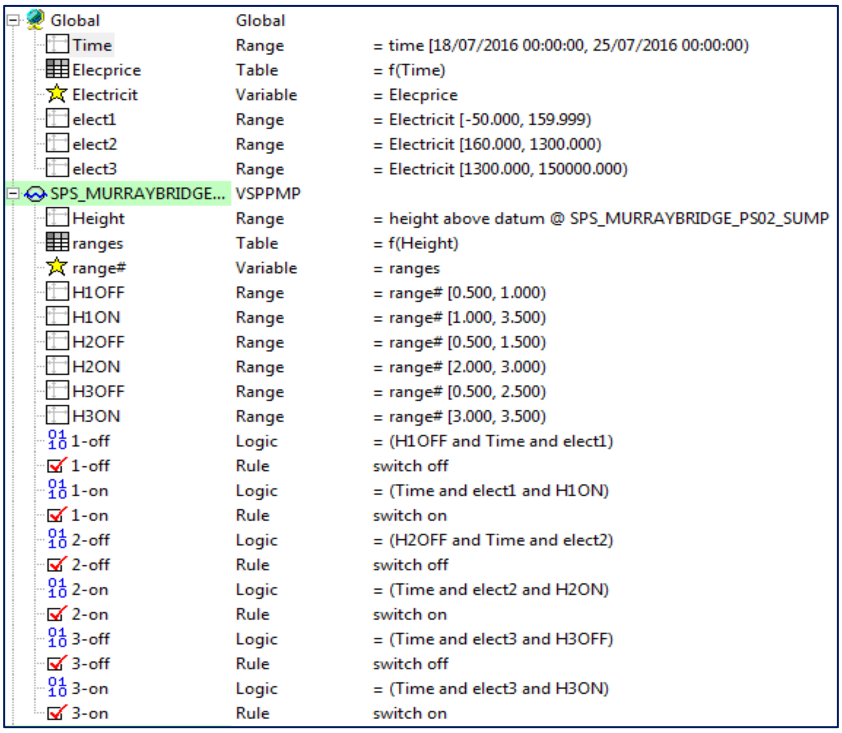


*Figure 5 RTC editor controls for pump stations (extracted from Innovyze Infoworks ICM application)*

In addition, a table is then created as a function of the sumps elevation and pump specific elevation ranges are entered with their associated membership values. Membership value boundaries for elevation can be adjusted by the user, for example all pumping stations may have the same boundaries at 25%, 50% and 90% or the other option is for boundaries to be individually customised. A variable is then created from the table for additional ranges based on these membership values. Ranges are used to control the heights at which pumps will be turned on or off for each electricity range. Ranges are set up based on the variable created with membership values ranging from 1 to 3. Within each OFF range the minimum has to be less than 1 and each ON range has a maximum greater than 3. It should be noted that there is a gap between the maximum of the OFF range and the minimum of the ON range. The gap left therefore acts as a last control function. The logic function is used to combine each electricity range with the associated ON and OFF elevation ranges. Through combining these three ranges an IF style statement: IF (Time is within suitable range AND Electricity Price is Low AND Elevation is Low).

# 5 Results

The smart controller for optimising energy usage and cost savings in the sewer networks has been modelled within 24 hour electricity spot prices in both dry and wet weather conditions using Infoworks ICM. According to the evaluation performance of the smart controller, in terms of reducing energy costs, results for the base pump switching control (control base on sewerage elevation) has been compared with the using smart controller for pumping. Results in Table 1 show 79% energy savings during the dry weather condition across these pump stations. Table 2 shows energy saving results at the wet weather condition. These results demonstrate 84% energy cost savings across these pump stations under specific dry and wet weather patterns which tends to suggest using such as operating regime on the Murray Bridge sewerage networks could be advantages. Impact on sewage delivered into these conditions, sewage treatment plant and its optimal operation may become another constraint that needs future consideration as well.

*Table 1 One day results using Infoworks ICM – dry weather condition*

| **Pump Number** | 02 | 03 | 04 | 05 | 06 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Cost | $0.76 | $15.09 | $3.81 | $3.65 | $0.51 | $2.00 | $2.24 | $9.78 | $0.20 | $0.13 | $6.76 | $0.05 | $3.45 | $1.08 |
| **Smart controlled cost** | $0.35 | $2.50 | $0.88 | $0.72 | $0.16 | $0.56 | $1.06 | $1.20 | $0.10 | $0.02 | 1.5 | 0.013 | 1.3 | 0.24 |
| Saving ($) | $0.41 | $12.59 | $2.93 | $2.93 | $0.35 | $1.44 | $1.18 | $8.58 | $0.11 | $0.11 | $5.26 | $0.04 | $2.15 | $0.84 |
| **Saving (%)** | 54% | 83% | 77% | 80% | 69% | 72% | 53% | 88% | 52% | 85% | 78% | 74 | 62% | 78% |
| **Pump Number** | 17 | 18 | 19 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 29 | 30 | | **Total** |
| Base Cost | $0.63 | $0.73 | $0.08 | $0.42 | $0.40 | $2.85 | $0.93 | $0.00 | $0.02 | $0.84 | $1.44 | $0.04 | | **$57.89** |
| **Smart controlled cost** | $0.14 | $0.19 | $0.00 | $0.14 | $0.00 | $0.15 | $0.35 | $0.00 | $0.00 | $0.07 | $0.30 | $0.00 | | **$11.94** |
| Saving ($) | $0.49 | $0.54 | $0.08 | $0.28 | $0.40 | $2.70 | $0.58 | $0.00 | $0.02 | $0.77 | $1.14 | $0.04 | | **$45.95** |
| **Saving (%)** | 78% | 74% | 99% | 67% | 99% | 95% | 62% | 99% | 80% | 90% | 79.167 | 95% | | **79%** |

*Table 2 One day results using Infoworks ICM - wet weather condition*

| **Pump Number** | 02 | 03 | 04 | 05 | 06 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Base Cost** | $1.23 | $21.33 | $5.82 | $5.49 | $0.63 | $3.16 | $4.58 | $10.73 | $0.44 | $0.18 | $6.86 | $0.07 | $5.06 | $1.22 |
| **Smart controlled cost** | $0.45 | $2.50 | $1.05 | $0.91 | $0.18 | $0.66 | $1.30 | $0.01 | $0.12 | $0.03 | $0.66 | $0.01 | $1.60 | $0.30 |
| **Saving ($)** | $0.78 | $18.83 | $4.77 | $4.58 | $0.45 | $2.50 | $3.28 | $10.72 | $0.32 | $0.15 | $6.20 | $0.06 | $3.46 | $0.92 |
| **Saving (%)** | 63% | 88% | 82% | 83% | 71% | 79% | 72% | 100% | 73% | 83% | 90% | 86% | 68% | 75% |
| **Pump Number** | 17 | 18 | 19 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 29 | 30 | | **Total** |
| **Base Cost** | $0.81 | $1.14 | $0.13 | $0.65 | $0.50 | $0.69 | $2.05 | $0.00001 | $0.07 | $1.26 | $2.15 | $0.06 | | **$76.31** |
| **Smart controlled cost** | $0.22 | $0.22 | $0.00 | $0.17 | $0.05 | $0.22 | $0.73 | $0.0001 | $0.01 | $0.12 | $0.40 | $0.00 | | **$12.00** |
| **Saving ($)** | $0.59 | $0.92 | $0.13 | $0.48 | $0.45 | $0.47 | $1.32 | -$0.0001 | $0.07 | $1.14 | $1.75 | $0.06 | | **$64.31** |
| **Saving (%)** | 73% | 81% | 100% | 74% | 90% | 68% | 64% | -25% | 93% | 90% | 81% | 97% | | **84%** |

Figure 6 and 7 present the sump level and pump switching pattern under conventional pump switching and using smart controller during a week. It is obvious that conventional pump switching works based on sump level without considering the tariff rate. However, by using the smart controller, low level of sump in the wet well is maintained during the low cost tariff and the high level of swamp is kept up through the high cost tariff. Thus, electricity cost has been saved.

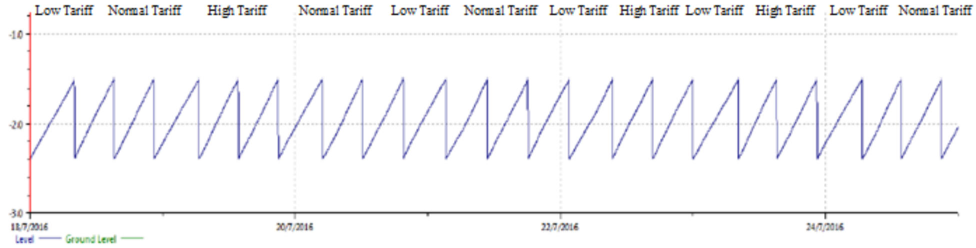


*Figure 6 Sump elevation pattern under conventional pump control during a week*

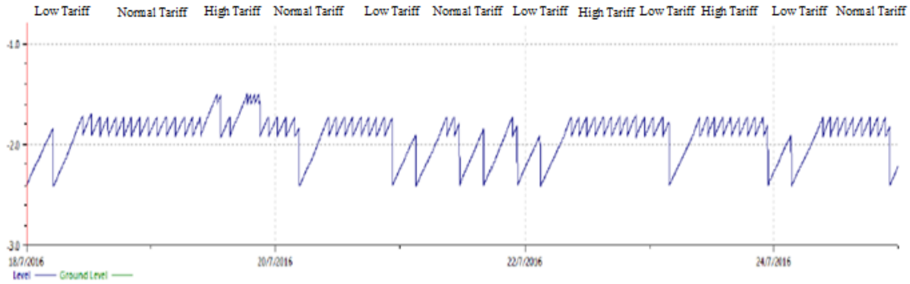


*Figure 7 Sump elevation pattern using smart controller for pump control during a week*

## 6 Conclusions

The large amounts of energy are consumed daily in modern wastewater networks to operate pumps. Consequently, energy optimisation in pump station consumption and electricity cost savings are critical to manage and operate these systems in cost-effective manner. The majority of pump stations in sewer networks utilise conventional control for pump switching based on only sewerage levels. In order to have optimised operating expenditure, it is essential to consider not only sump elevation but also the electricity spot price to generate an optimal smart controller model in sewer networks. This study presents a new intelligent and smart controller to optimise pump switching at the Murray Bridge wastewater pump station. To this end, two major inputs, electricity price and wet well level and a list of rules including IF-THEN statements were considered to produce pump switching commands by the smart controller. In addition, Infoworks ICM and its built-in-type RTC editor were used as an assessment and simulation method for modelling the smart controller. The potential energy consumption optimising and cost savings demonstrated within the case study. According to the results, the smart controller could help to reduce energy usage and then enhance electricity cost savings. Findings show 79% cost savings of electricity after using the smart controller compared to the conventional controller in a day with the dry weather simulated condition. Moreover, in a day with the wet weather condition, 84% electricity cost savings has been exposed by applying this smart controller. Further study could be carried out to assess and analyse influences of pump operations on pump maintenance in terms of number of pump switching and try to decrease this factor to improve asset reliability and maintainability. Moreover, environmental constraints such as sewage defect time and spill need to investigate more in future.

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