

DETERMINATION OF BEST PRACTICE MONITORING AND OPERATION OF PUMPING STATIONS

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ABSTRACT

Measures for improving pumping efficiency can be realised in many ways, from field testing and proper maintenance to the use of optimal computer control.

Halcrow has undertaken an investigation in order to identify tools and products to measure and reduce energy consumption to maximise efficiency of Melbourne Water's pumping stations. Suitable products were assessed using a matrix approach, followed by presentations from the top five ranked products.

Halcrow's ENCOMS software was selected by Melbourne Water to complete a desktop study of pumping efficiency at Brooklyn Sewage Pumping Station in order to estimate potential savings.

INTRODUCTION

Melbourne Water is among the top 15 energy users in Victoria, and among the top 120 energy users in Australia. The energy consumed by Melbourne Water pumping stations is in the order of 95 GWh/yr, with over 47% of Melbourne Water's energy consumption used in pumping water and sewage.

Melbourne Water has established targets for Greenhouse Gas Emission Reduction and Renewable Energy Use, these are:

- Zero net greenhouse gas emissions by 2018; and
- 100% renewable energy use or export by 2018.

These targets have directed Melbourne Water's focus, among other initiatives, on the efficiency of its operations.

STAGE 1 ASSESSMENT OF OPTIONS.

In 2008, Melbourne Water engaged Halcrow to identify software tools, monitoring procedures and methodologies or other methods that could be used either on a one-off basis or as a continuous process, such that Melbourne Water could be sure

it was operating its water and wastewater pumping stations at best possible efficiency.

The investigation aimed to determine world's best practice for:

- Monitoring of pumpset efficiency;
- Monitoring of pumping station efficiency; and
- Monitoring and operation of pump system efficiency.

Products were identified initially through general product awareness within the project team, through discussion with other colleagues, contact with academics and via a comprehensive search of the internet. A total of twenty one (21) products were identified as having the potential to satisfy Melbourne Water's objective for a product which helps to measure and/or reduce energy consumption in order to maximise the efficiency of its pumping stations.

Information on each of the products considered suitable for the intended application was collected in order to undertake an evaluation, firstly to decide if the product was suitable for continued appraisal and secondly to provide evidence for a comparative assessment using a detailed set of weighted assessment criteria defined by Melbourne Water and Halcrow. The focus for the criteria was on achieving desired outcomes through using a tool or product and minimising risk to Melbourne Water's system operations.

Specific information collected/requested included:

- Product type and capabilities;
- Track record;
- Scope of use (eg. industrial sectors);
- Geographic locations serviced (eg. location of supplier and support available);
- Pump and valve control capability;
- Type of operation (eg. real time, batch type);
- Product compatibility with existing pump control/communications systems (eg. PLC, SCADA); and
- Cost.

The comparative assessment was undertaken to identify the top products for the proposed three levels of application, ie. pumpset efficiency, pumping station efficiency and pumping system efficiency. The results found that the comparative assessment for the optimisation products (ie. those suitable for management of 'pumping system efficiency') was less conclusive than for products suitable for 'pumpset monitoring, and 'pump station monitoring'. Consequently, a second phase assessment was undertaken on a short-list of optimisation tools/products. Additional assessment included the following factors:

- User feedback on actual efficiency gains achieved; and
- Comparative Cost versus Score assessment.

From this additional assessment, the top five optimisation products were identified to be considered for implementation by Melbourne Water. Each of the five product suppliers were invited to present their product, and propose a methodology for implementation.

Subsequently, Halcrow's ENCOMS software was selected to complete a desktop analysis to determine the expected benefits of implementation on the operation of the Brooklyn Sewage Pumping Station.

STAGE 2 DESKTOP ANALYSIS OF POTENTIAL EFFICIENCY GAINS.

The overall objective of the Stage 2 study was to develop an optimal pumping scheduling program, demonstrate its functionality, and to assess the potential energy savings and likely benefits based on simulations using historical data from Melbourne Water's Brooklyn Sewage Pumping Station.

Brooklyn Pumping Station (BPS) is one of two major sewage pumping stations located in Melbourne's Western Transfer System. It pumps on average 360ML/d (45% of Melbourne's sewage) to the Western Treatment Plant (WTP) via the Western Trunk Sewer and Hoppers Crossing Pumping Station.

The pumping station comprises two (2) dry pump wells, each accommodating two (2) fixed speed pumpsets and two (2) variable speed pumpsets. All pumps have a nominal capacity of 2.2kL/sec at 21.7m head and have a peak absorbed power rating of 545kW at 422rpm.

Flows are drawn from the incoming Brooklyn Trunk Sewer and discharge to the upstream end of the Western Trunk Sewer. Flows from the North Western Sewer enter the Western Trunk Sewer just downstream of the pumping station discharge

chamber, and consequently impact on the discharge conditions.

A schematic of Brooklyn Pumping Station is shown in Figure 1.

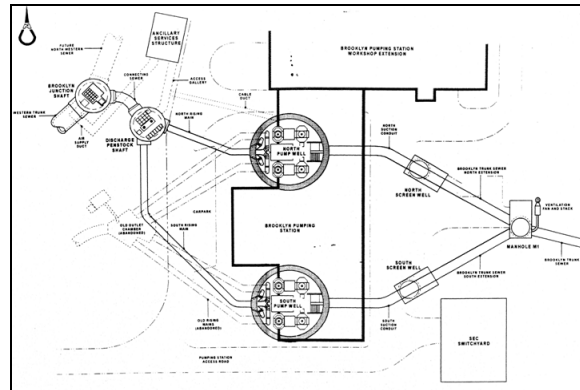


Figure 1 Schematic of Brooklyn Sewage Pumping Station

Principles of Operation

"Follow-the-Flow" is the normal operating mode for Brooklyn Pumping Station. It was developed to ensure that normal depth of flow was maintained in the incoming sewer in order to minimise hydrogen sulphide attack and siltation and to eliminate the costs and operating problems associated with wet wells for large pumping stations.

The objective of the "Follow-the-Flow" operating mode is to adjust the speed of the variable speed pumps such that the output of the station is matched to the inflow for all flows. With this approach, the level of wastewater in the incoming sewer is maintained at a normal depth without either backing up or drawing down.

Such operation is achieved through the use of programmable logic controllers (PLCs) to control the pumping process using a mix of variable and fixed speed pumps which pump directly from the incoming sewer.

Review of Historical Operational Records

Historical operational records from Melbourne Water have been reviewed, covering the following periods:

- 01 January 2005 – 27 February 2005;
- 31 January 2008 – 01 April 2009; and
- 21 December 2007 – 23 December 2007.

These data sets include the water depths at manhole M1 (baseline/invert level - 23.08m) on the Brooklyn Trunk Sewer (BTS) and at the discharge chamber (baseline/invert level - 6.75m), discharge flow rate, power consumed and operating speed (RPM) for each of the eight (8) individual pumps. In addition, total station flow and total power consumed, together with the North Western Sewer (NWS) flows for most of the above periods were

provided. All data is recorded in one minute time intervals.

A review has been completed, of selected drawings relating to the operation of the Brooklyn Pumping Station. Drawings reviewed include pump characteristic curves and efficiency curves for all eight (8) pumps as recorded during the initial commissioning, plan and section drawings showing the layout of Brooklyn Pumping Station, the Brooklyn trunk sewer section and discharge chamber section.

Extensive screening of the operational records has been carried out in order to achieve the best level of calibration possible for the hydraulic model.

During the model calibration stage, analysis was carried out on the historical operational records and the following observations were made:

- The “Follow the Flow” policy was not always achieved. For example, the plot based on the operational record on 22 December 2007 indicates that most of the operating points are actually not on the “Control line” as shown in Figure 2. This is mainly due to the energy saving procedure of delaying the introduction of a second pump on a rising hydrograph, not using a third pump and early stopping the second pump on a falling hydrograph.

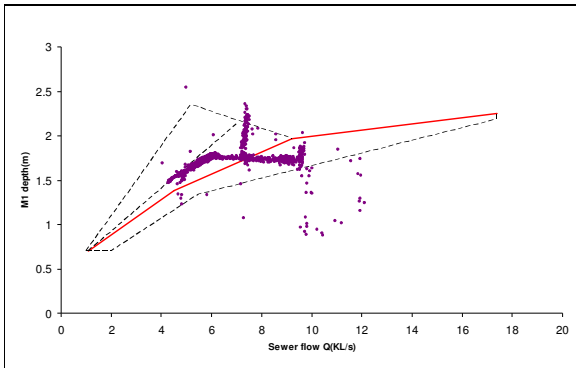


Figure 2 Operating points on the Control Diagram (22 December 2007)

- It appears that Pump No. 5 consumes more energy than Pump No. 6, when they both operate at the same fixed speed setting of 420 RPM. As shown in Figure 3 and Figure 4, Pump No. 5 uses on average about 10.3% more power than Pump No. 6, to deliver the same amount of sewage.

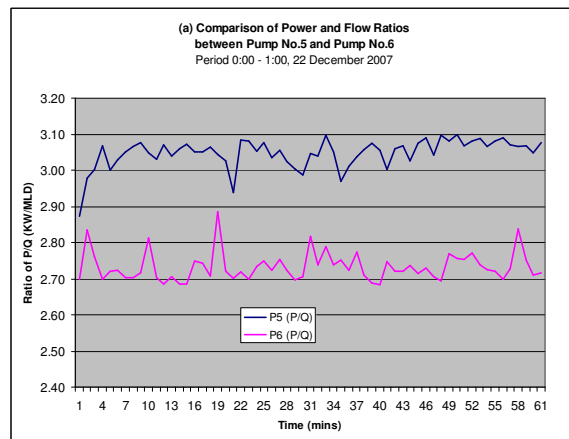


Figure 3 Comparison of Power/Flow Ratios for Pumps No. 5 and No. 6

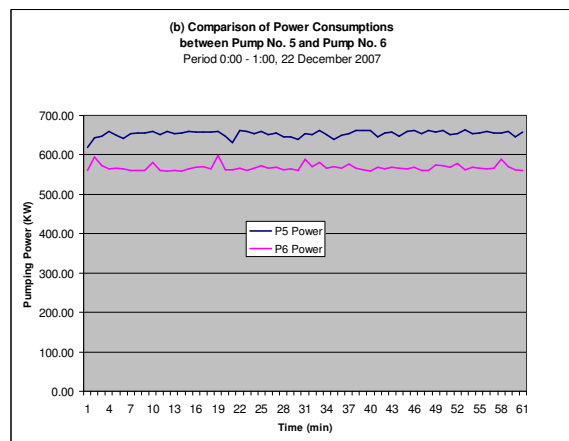


Figure 4 Comparison of energy consumption for Pumps No. 5 and No. 6

- It is evident that most of the pumps do not operate at the best efficiency points suggested by their characteristic curves.

Hydraulic Modelling

Based on site layout drawings, a simplified hydraulic model was constructed using Halcrow’s ENCOMS software. This software is compatible with United States Environmental Protection Agency EPANET 2.0 software for network hydraulic modelling.

The extent of the model covers the pumping station and extends from Brooklyn Trunk Sewer manhole M1 (BTS-M1) to the Discharge Chamber (DC). This is shown in Figure 5.

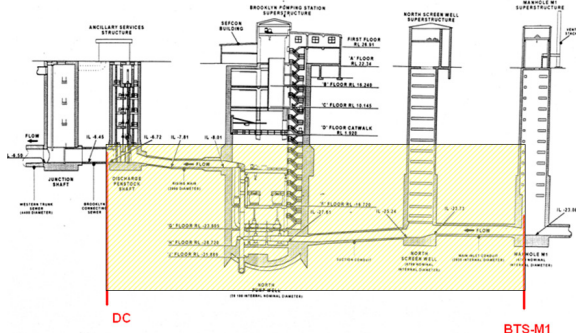


Figure 5 – Schematic of Brooklyn Pumping Station and scope of hydraulic model

Due to the complexity of the pumping system, a number of modelling options were tested. The model adopted for optimisation is shown in Figure 6.

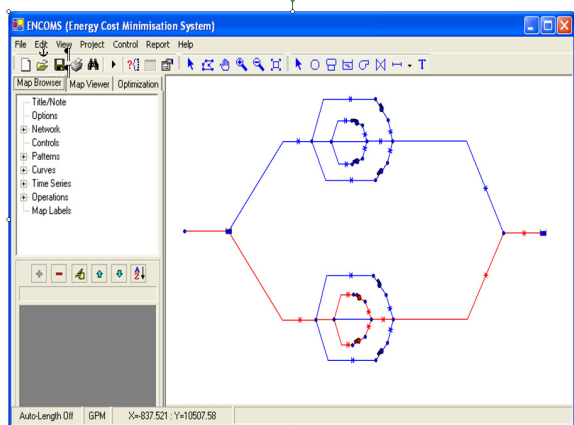


Figure 6 Model selected for Optimisation

Calibration exercises were carried out to determine the best combination of head-loss coefficients for pipes and minor loss coefficients for valves.

Figure 7 compares the modelled flow (red) to recorded flow (green) for one of the selected calibration periods.

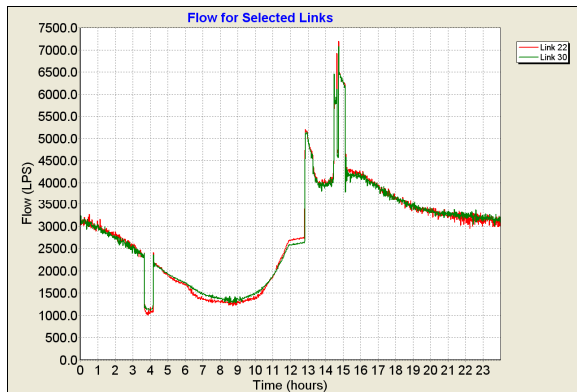


Figure 7 Comparison of Modelled and Measured Flows

The calibration results show that the root mean squared errors (RMSE) between modelled and

measured total flow is 2.5% for the operational data collected between 00:00 and 23:59 on 10 January 2009. Therefore, the performance of the model can be regarded as reasonably good for this operating condition.

ENergy COst Minimisation System (ENCOMS)

Halcrow's ENCOMS is an adaptive optimisation software package for optimal operational control of pumping systems [Rao, 2006; Rao et al 2007]. It represents the state of the art in pumping system optimisation empowered by genetic algorithms combined with network hydraulic modelling. It quickly identifies, in real-time, the optimal operational control settings and is updated continually at short intervals by SCADA data.

ENCOMS is designed to assist pumping system operators in selecting cost effective pump and valve settings to maximise pumping efficiency and to provide more reliable and safer operations.

The ENCOMS software is mainly applied to water distribution networks in which inline storage is normally available and the water demand (consumption) is also predictable.

Optimal Control Process

Halcrow has studied the existing "Follow the Flow" control philosophy and understands that it was developed to minimise hydrogen sulphide attack and siltation and to eliminate the costs and operating problems associated with wet wells. However, this strategy cannot guarantee that all duty pumps are operated at their best efficiency points.

In order to improve the pumping efficiency, Halcrow has modified the ENCOMS software and developed a new Optimal Pumping Scheduling (OPS) program. This new software focuses on selecting, in real-time, the speeds of the variable speed pumps, in combination with fixed speed pump operation, to ensure that best efficiency points are achieved as near as possible, having due regard to the principle of "Follow the Flow".

The optimal control process implemented in the Optimal Pumping Scheduling program is shown in Figure 8.

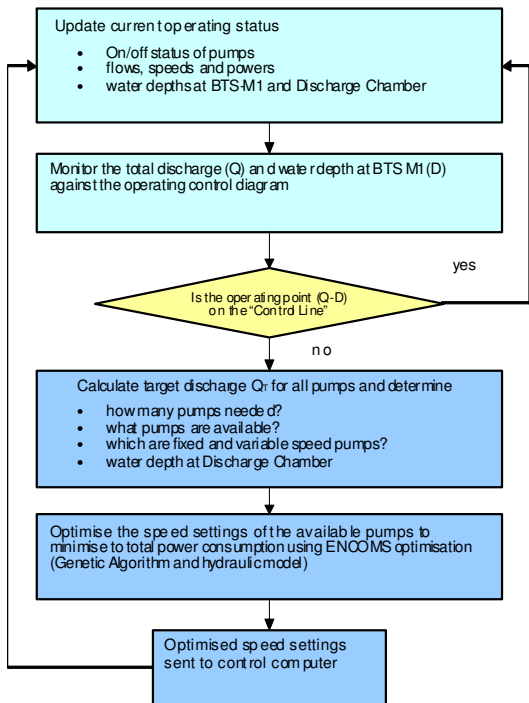


Figure 8 Flow chart of the optimal control process implemented in OPS

User Interface – OPS Control Panel

A new user interface has been developed to suit the application of the Brooklyn Pumping Station, and to demonstrate how the OPS functions. A screen shot of the OPS Control Panel is shown in Figure 9.

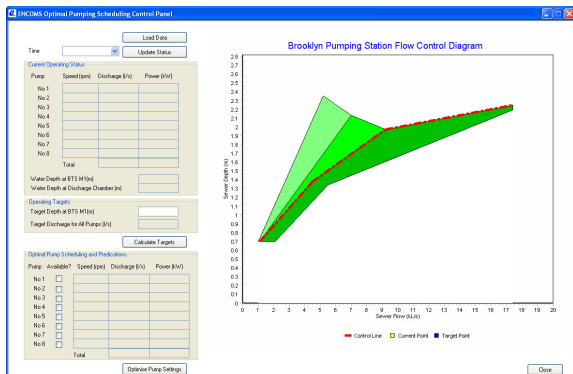


Figure 9 Screen shot of the OPS Control Panel

The OPS Control Panel loads all current operational data from the SCADA system required to perform the optimisation. The data is compared to the control chart, and the optimisation trials are completed. A set of new speeds for all operational variable speed pumps for the next minute of operation is generated.

Operational Simulations

As part of the desktop study, the OPS program was applied to simulate the operation of the Brooklyn

Pumping Station and assess the potential energy savings and likely benefits using historical data.

The historical operational records for one day (24 hours) on 14 January 2009 (a period where typical dry flows were recorded and two pumps were operational), were chosen for this simulation exercise.

For each simulation time step (one minute interval), the following assumptions were made:

- both the water depths at the BTS-M1 and Discharge Chamber are known as recorded; and
- the total discharge flow is known as recorded.

For each of the time steps, the OPS program is applied to optimise the speed setting of each active variable speed pump (for this example, Pumps No.3 and 4).

The 'Objective' function defined within the program is to minimise the total power consumption from all duty pumps, subject to the total discharge from all the duty pumps being equal to (or as close as possible to) the recorded value. The simulation runs continually for a 21 hour period.

Figure 10 shows the comparison of the optimal operations with modelled actual operation.

Adjustment has been made to account for differences between measured and modelled power consumption, i.e the calibration error.

The simulation results indicate that the total energy consumption from the optimal operation is 14,307kWh as compared with 15,502kWh modelled actual operation for the same period, indicating a potential saving of approximately 7.7%.

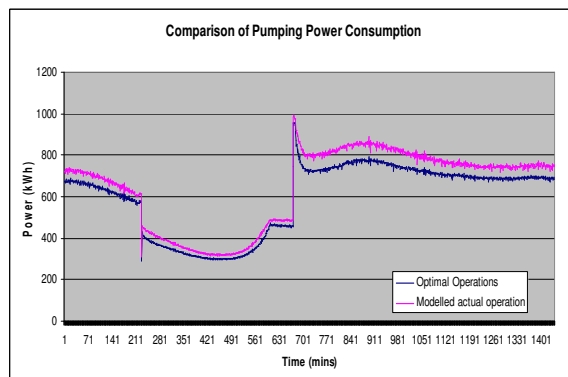


Figure 10 Comparison of pumping power consumptions

CONCLUSIONS

Stage 2 results indicate that, through use of the Optimal Pumping Scheduling program, there is a potential 7% reduction in power consumption on a typical dry day by operating a combination of fixed and variable speed duty pumps more efficiently. Improved pump efficiency will result in reduced operational costs as well as reducing greenhouse gas emissions.

These preliminary results are based on limited calibration and efficiency analysis, and there are still discrepancies in the model. Further work is required to re-confirm pump curves and increase calibration periods and durations.

Nonetheless, the results provide sufficient confidence to invest in model refinement and calibration over extended time periods before assessment of efficiency using consistent historical data covering an extensive range of operating conditions, including wet weather.

REFERENCES

Rao, Z. 2006. An overview of a generic, realtime near optimal control system for water distribution networks, Proceedings of IWA World Water Congress and Exhibition, 10-14 September, Beijing, China

Rao, Z. Wicks, J. West, S. 2007. Optimising water supply and distribution operations, Proceedings of the ICE - Water Management, Volume 160, Issue 2, pages 95 –101.