The Impact of Real World Variation on the Commercial Optimisation Application, Pump Scheduling

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Abstract

For a water utility the use of a pump scheduling application can lead to cost savings in the millions of dollars per year. However, optimising energy costs without considering real world variation can lead to unsatisfactory schedules that conflict with required operation.

This paper discusses the impact of real world variation in the form of required variation, variable network conditions, and operational interventions. The following examples are used:

- water quality concerns caused by poor turnover of water in storage tanks
- tank levels outside preferred operating levels due to discrepancies between observed and predicted water demand
- tank levels and pipe pressures outside preferred operating levels/pressures that occur when part of the network is manually operated and in mismatch to the optimal schedule.

Where required variation, variable network conditions and operational interventions are accounted for in the optimisation application, the risk of unsatisfactory schedules can be mitigated and a near optimal schedule can be achieved.

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1 Pump Scheduling

For a water utility the use of a pump scheduling application can lead to significant cost savings; an example United States water utility saved US$1.1M in 2007, and for a European water utility 2016 savings were estimated to exceed €750k. However, optimising energy costs without considering variable behaviour requirements and variable network/operational conditions can lead to unsatisfactory schedules that conflict with operational requirements.

1.1 Water Utility Networks

Water utility networks treat water from sources such as rivers, lakes and wells. The potable water is then pumped or delivered via gravity flow to pressure zones and storage tanks. These pressure zones represent land regions of different elevations that are hydraulically disconnected through a series of controlled pumps and valves. Storage tanks and the network of connected pipes supply water demand such as the use of household taps. Figure 1 illustrates the movement of water from water source to demand.

The optimiser minimises energy costs by producing pump/valve schedules that take into consideration energy tariffs and pumping efficiencies. The schedule adheres to a number of operational constraints and is adapted in real time to account for changing water demand, operational conditions, and limitations on data accuracy and communications connectivity.

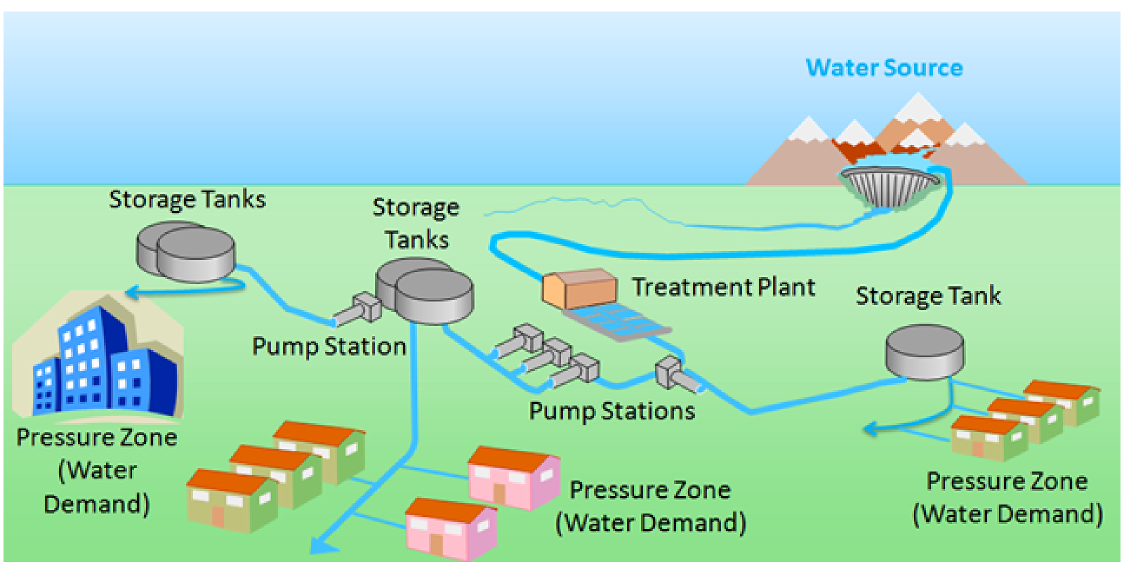

Figure 1: Water utility network

2 Real world variation

There are several sources of real world variation in a pump scheduling optimisation application. In this paper we'll look at required variation, variable network conditions, and operational interventions. The following examples will be used to convey issues that arise when real world variation is not accounted for:

- water quality concerns caused by poor turnover of water in storage tanks
- tank levels outside preferred operating levels due to discrepancies between observed and predicted water demand
- tank levels and pipe pressures outside preferred operating levels/pressures that occur when part of the network is manually operated and in mismatch to the optimal schedule

Where required variation, variable network conditions and operational interventions are accounted for in the pump scheduling optimisation application, the risk of unsatisfactory schedules can be mitigated and a near optimal schedule can be achieved.

2.1 Required variation

2.1.1 Storage tank level variation

Sometimes variation is a requirement. Most water utilities require turnover (circulation) of water in storage tanks in order to deliver quality water. When water in tanks is not circulated, chlorine levels can become depleted. Maintaining satisfactory residual chlorine is essential to combat potentially harmful bacteria in the pipe network. Issues can occur even when water is passed through the tank. See Figure 2 where freshly added water doesn't mix adequately in the tank, instead the same water is drawn out of the tank. This leads to the top layer subsisting of aged water with low chlorine residual.

One way of ensuring water turnover is to repeatedly vary tank level from low to high to low again.

Water utilities often have a preference for full tanks at the start of the day, but there are generally no operational constraints that require specific tank levels at other times. To optimise energy costs, the optimiser requires some flexibility of tank level during the day. However, the optimal pump schedule may not vary the tank level enough to achieve required water turnover.

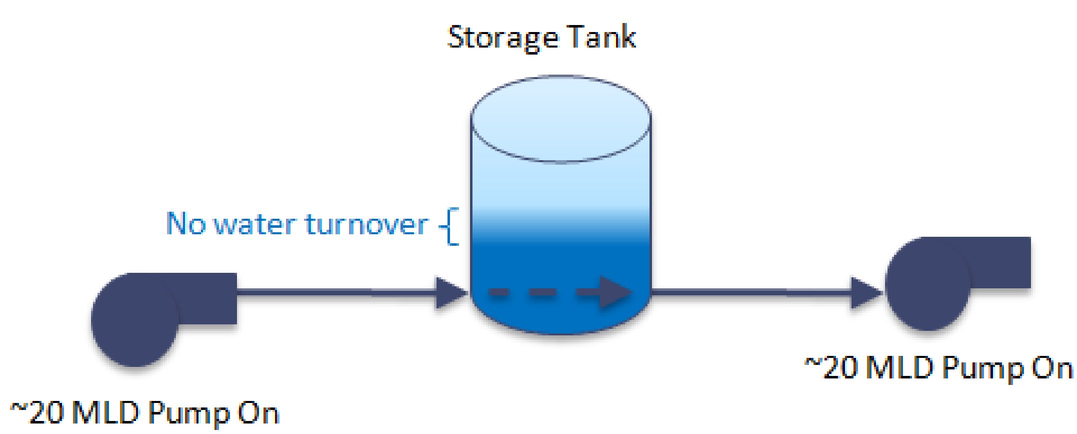

Figure 2: Stale water level example, no water turnover

2.1.2 Cycling storage tank targets

One way to achieve tank level variation is to periodically change the end of day target level. The target levels for the end of the day constrain the optimiser; only pump schedules that result in tank levels that are at or above target level at the end of the day will be produced. Typically, it's cheaper to supply water demand using existing storage in the pressure zone rather than pumping in additional water. For tanks with levels that tend not to vary, lowering the target level typically results in a lower end of day tank level as more of the existing storage can supply demand over the day. Repeatedly changing the target level to be lower over a series of days, then higher over a series of days, allows for greater tank level variation and an acceptable turnover to be achieved.

2.1.3 Minimum supply volume

In some cases, storage tanks are used as below grade storage instead of as a tank that supplies the water demand directly. This storage is typically emergency supply. The water is drained off from a main storage tank and pumped back when required.

It's optimal to avoid the additional pumping where another water path exits. Hence, where possible, the pump scheduler doesn't use below grade storage tanks. However, after a few days this would result in poor quality water that when pumped back to the network would not meet water quality requirements.

Incorporating a minimum volume that the below grade storage tanks must supply each day ensures water turnover in these tanks, meeting water quality requirements.

2.2 Variable network conditions

2.2.1 Variable water demand and tank level discrepancies

Sometimes large discrepancies can occur between observed and predicted water demand. Some causes include significant weather events such as extreme temperatures and storms, large atypical water use by industrial clients, and bank holidays. These changes usually last a few hours, or in the case of a drought, a few weeks. A demand prediction algorithm can adjust accordingly to recent historical water demand to predict accurate water demand throughout the event.

However, there are typically some water demand zones in a network where it's difficult to accurately predict water demand. Causes for this can include pipe leaks, valve changes in the field directing unmetered water between demand zones, unexpected supply such as a customer substantially refilling an on-site storage tank, and unexpected water demand such as several households refilling swimming pools. Inaccurate flow/level metering can also cause errors in historical water demand calculations used in predicting water demand.

For these water demand zones, when the observed water demand varies significantly from the predicted demand and the tank levels are close to the preferred operational levels, then tank levels can end up outside preferred operating levels. See Figure 3 below for an example of variable water demand at 9:30am.

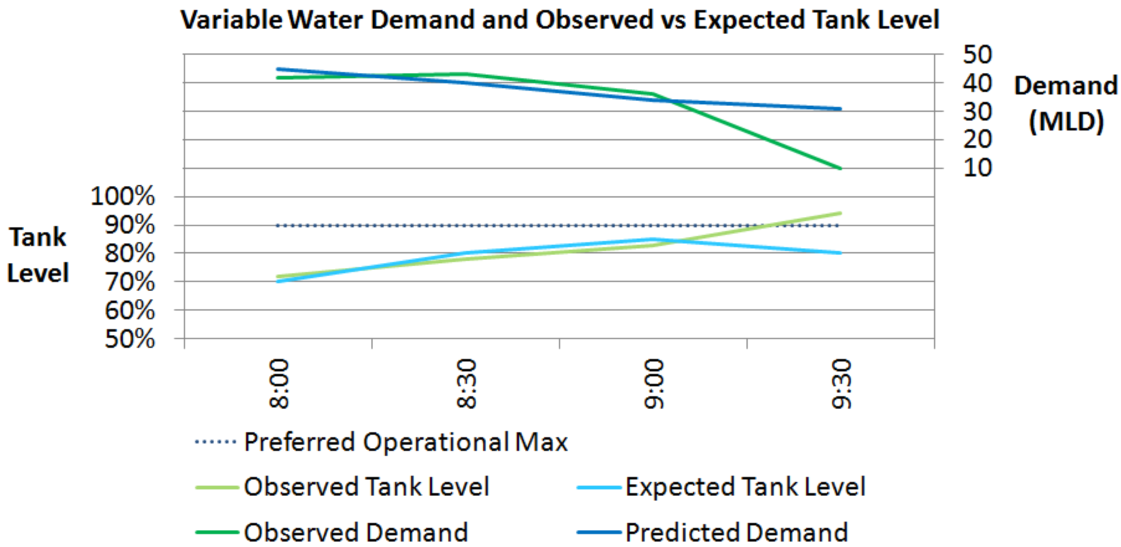

Figure 3: Variable water demand and discrepancy between observed and expected tank level

2.2.2 Preferred operating level buffers for storage tanks

To mitigate the occurrences of pump schedules that result in storage tank levels outside preferred operational limits, buffers (offsets) can be added to the tank limits, i.e. the optimiser tries to keep the tank above the preferred operational minimum by the buffer amount and below the preferred operational maximum by the buffer amount. Thus when the optimiser schedules estimate the tank level to drain to the buffered minimum/maximum and water demand is much larger/smaller than expected, the tank level may go outside the buffered minimum/maximum but will stay within or close to the original preferred minimum/maximum tank level. A near optimal schedule that satisfies operational requirements can be achieved.

2.2.3 Water demand adjustment when tank levels are near preferred operational levels

In some cases successive schedules will be produced that estimate tank levels to remain steady or increase/decrease outside the preferred operational levels. Yet, due to variable network conditions, observed tank levels may gradually increase/decrease outside the preferred operational levels.

For these problematic water demand zones, additional adjustments can be made to account for variable network conditions. When current tank levels are close to the preferred operational levels, the water demand prediction for the next two hours can be increased/decreased (shifted to/from the rest of the day) to encourage pump schedules that will keep the tank within preferred operational levels. For example, a tank level that is close the preferred minimum level will have predicted demand increased for the next two hours and the pump schedule will reflect this by increasing the filling of the tank and/or decreasing controlled draining of the tank. Thus a near optimal schedule can be achieved that is more likely to keep tanks within preferred operational levels when observed water demand varies from expected.

2.3 Operational interventions (variable operation)

2.3.1 Planned maintenance and unplanned operation versus optimal schedules

During planned maintenance pumps are manually operated to accommodate with pump/meter testing and tank/pipe cleaning. This operation is frequently different to optimal pump schedules which are produced with the assumption that all pumps and tanks are available within typical operational constraints. Similarly, unplanned operation is often in mismatch to optimal schedules. Unplanned operation can include pumps tripping out of service and becoming unavailable for several hours, running part of the system in manual to accommodate maintenance activities, or any other unexpected operational intervention.

When part of the network is in manual operation and in mismatch to the optimal schedule, tank levels and pipe pressures can unexpectedly increase/decrease outside the preferred operational levels/pressures. The more connected tanks and pressure zones are, the more likely it is that issues from schedule mismatch will arise. See Figure 4 for example. It is optimal for water to fill a tank and to pump from this tank to a higher pressure zone at the same time. However, for maintenance requirements the pumps to the higher pressure zone are manually off. Water will continue to fill the tank according to the optimal pump schedule and the level may increase above the preferred operational maximum.

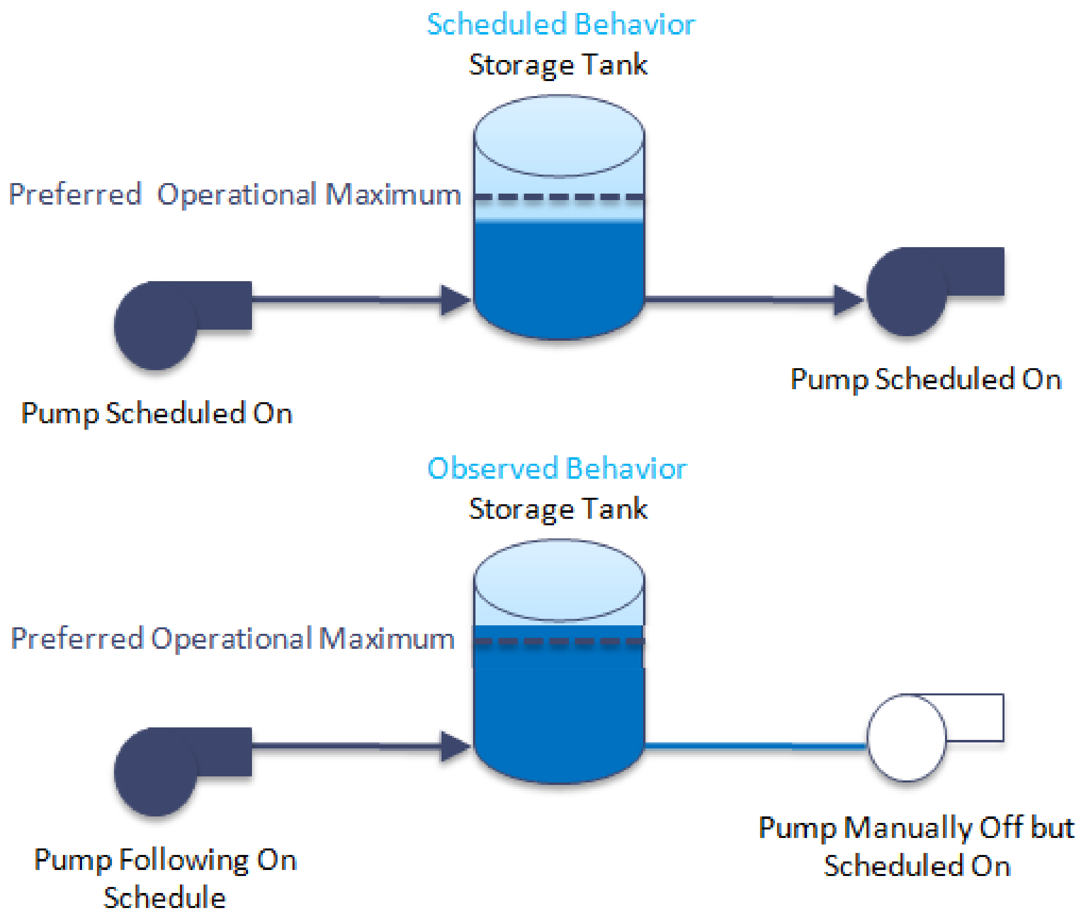

Figure 4: Pump status in mismatch to schedule

2.3.2 Using cost incentives to match manual pump status

So as not to over constrain the optimiser, cost incentives can be used in place of hard constraints to incentivise the optimal pump schedule to match manual operation. Essentially, objective costs are increased for manually operated pumps that are off and decreased for manually operated pumps that are on. As a result the optimiser is flexible enough to achieve near optimal schedules that take into account planned and unplanned operational intervention.

3 Summary

Variation in the form of required variation, variable network conditions, and operational interventions can have a significant impact on pump scheduling. If not accounted for, this variation can lead to unsatisfactory schedules with water quality concerns or tank levels and pipe pressures outside preferred operational levels and pressures. However, when accounted for, near optimal pump schedules can be achieved that meet the operational requirements of the water utility.