FILTER OPTIMISATION AT VICTORIA'S LARGEST WATER TREATMENT PLANT

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ABSTRACT

The Winneke Water Treatment Plant was subjected to an extensive filter optimisation programme. Pragmatic applications were used that can be readily applied to any conventional filtration plant. This paper disseminates robust and practical solutions assisting other engineers and operators better utilise their filtration plant.

KEYWORDS

Conventional rapid sand filter, optimise, backwash sequence, control.

1.0 INTRODUCTION

Melbourne Water's Winneke Water Treatment Plant has a capacity of 450 ML/d and supplies up to 30% of Melbourne's drinking water.

It was commissioned in 1980 and is located north east of Melbourne, adjacent to Sugarloaf Reservoir. The reservoir is an off line storage where water is pumped from the Yarra River and Maroondah Aqueduct.

Sugarloaf Reservoir water is pumped to Winneke's inlet structure, where it is dosed with lime and alum. A flocculant is used to aid clarification in 4 upflow solids contact chambers. Clarifier supernatant is filtered through 12 conventional rapid sand filters. Filtrate is chlorinated and pH corrected with lime prior to entering the clear water storage. Treated water is distributed to the water supply system on a demand basis.

2.0 WHY WAS FILTER OPTIMISATION REQUIRED?

In recent times the Winneke Water Treatment Plant has regularly operated at flows greater than original intended capacity. Efficient filtration and backwashing became essential, however filters were operating significantly below optimal performance.

A further driver for efficient filter operation was the current project of increasing Winneke's capacity to 620 ML/d. New filter design and operation is based on existing filters. Successful commissioning relies on established filters having an effective backwash sequence.

A consultant also carried out an audit identifying a number of possible process improvements.

The Winneke filters required a multi-pronged strategy of reform. One prong incorporated improvements to an inefficient backwash sequence. The second addressed media height differences on either side of the filter gullet. The third was to reduce media losses. The fourth was flow hunting. The final prong identified and rectified a number of other process improvements. As filtration involves a myriad of operating variables, optimisation was a compromise between conflicting target parameters.

3.0 STEP BACK TO THE ORIGINAL DESIGN

Treatment plant operating parameters regularly change to accommodate for current climate, raw water quality and plant upgrades. As time marches on, these parameters can deviate significantly from the original design. Current operating parameters should be periodically scrutinised against the plants' original design.

3.1 Backwash Sequence

The Winneke filter backwash sequence had strayed significantly from the original design. The sequence that was used is outlined in Table 1.

Table 1: ***Previous Backwash Sequence***

Step	Blower	Pump	Duration
1	Blower (27.4m/hr)	1 Pump (5.7 m/hr)	5 Minutes
2	Blower (27.4m/hr)	OFF	2 Minutes
3	Blower (27.4m/hr)	1 Pump (5.7 m/hr)	1 Minute
4	OFF	2 Pumps (17.5m/hr)	3 Minutes
5	OFF	1 Pump (12.4m/hr)	5 Minutes

Note: The sequence detailed above is similar to most of the 12 Winneke filters.

This backwash sequence included a number of steps that provided minimal additional value. Backwash water flowrates were not sufficient for adequate media expansion. Air scour rates were below limits recommended for adequate flocculant break up. Each filter backwash sequence was different, resulting in unequal performance. This inefficient backwash sequence began during a 1997 PLC upgrade.

Following any control upgrade, the original design should be reviewed ensuring a reliable transition between systems. In an attempt to increase backwash efficiency, in February 2005 the sequence was changed to closely follow the original design manual:

Table 2: ***Original Design Manual Backwash Sequence***

Step	Blower	Pump	Duration
1	Blower (37.4 m/hr)	OFF	2 Minutes
2	Blower (37.4 m/hr)	1 Pump (5.7m/hr)	3 Minutes
3	OFF	2 Pumps (21 m/hr)	5 Minutes

Note: These air and water flowrates are at near maximum available capacity.

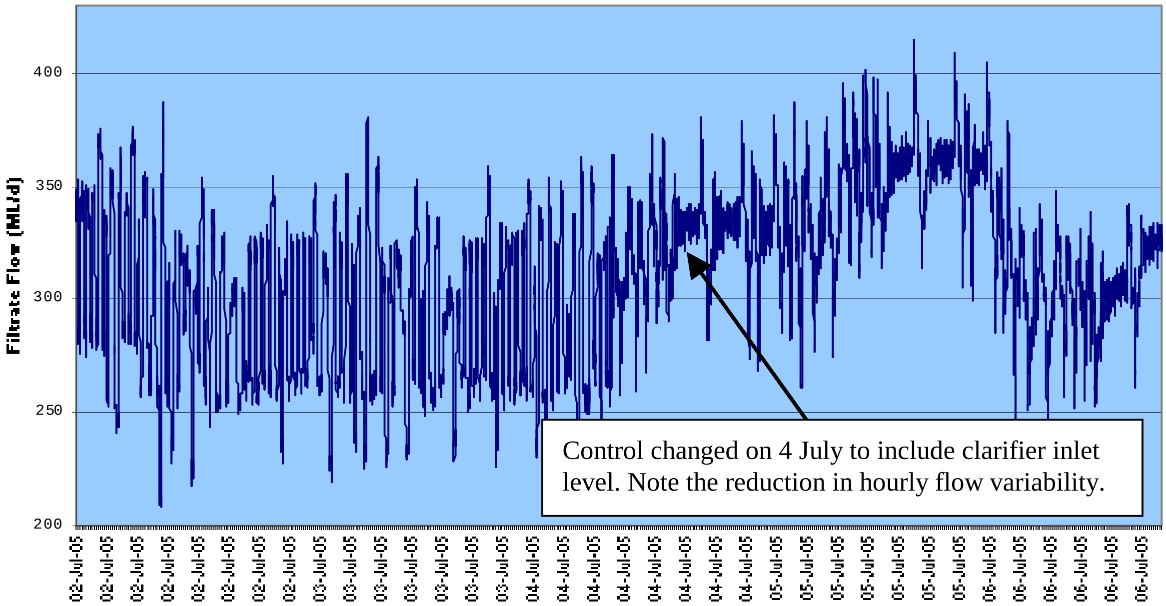
Reverting back to the original design resulted in significant reductions in backwashing time, backwashing volumes, energy consumption, operating costs and headloss.

3.2 Filtered Water Flow Control

Original plant design intended filtered water flow to be controlled from the level in *both* the clarifier inlet and clarifier outlet. However, for many years only the clarifier outlet level was programmed to control. This resulted in a rapid control loop causing filtrate flow hunting of 80 - 100 ML/d every hour. This caused a number of process difficulties, most notably chemical dosing control.

A trial began on July 4th 2005 with filtrate flow controlling according to original design. As shown in Figure 1, flow variability reduced.

Figure 1: ***Filtrate Flow Before and After Control Change***



Further reductions in flow variability were subsequently achieved through control tuning. Reduced backwash water volumes also facilitated reduced flow variation.

Flow spikes in Figure 1 indicate backwashing. As backwash water is supplied from the filtered water channel, flow variation during backwashing is unavoidable without significant capital upgrade.

Using all available July 2005 data, flow and pH variability prior to and following the control change is outline in Table 3.

Table 3: ***Flow & pH Variability Prior to and Following Control Change***

	Flow Variance	**Flow Std Dev**	**pH Variance**	**pH Std Dev**
Prior to Control Change	1222	35	0.28	0.53
Following Control Change	999	32	0.14	0.38
Percentage Reduction	18	10	49	29

Reverting to the original plant design reduced flow variance by 18%, and more importantly reduced pH variance by 49%.

4.0 BEYOND ORIGINAL DESIGN

Operating a plant based on the original design is not likely to achieve optimisation. The plant engineer or operator must also consider other steps to attain this.

In the years following design, the goal posts of what is perceived as best practice will shift. Operating parameters must be periodically reviewed to ensure contemporary treatment practice is adopted. Optimisation is a perpetually moving target.

Invaluable insight can be gained through communication with a plants' original design engineer. Auditing consultants can identify possible process improvements. Detailed searches on recent literature such as AWWA's '*Water Quality and Treatment, 1999*' and Kawamura's '*Integrated Design of Water Treatment Facilities, 2000*' will also assist optimisation.

4.1 Communicate with Original Design Engineer

Discussions with an original Winneke design engineer concluded '*filter under-drains and launders were not originally designed to operate with a combined air and low flow water step*'.

The Winneke WTP was commissioned at a time when current industry thinking adopted the combined air and water step, even though the plant was not designed for this. Winneke WTP has always operated with this combined air and water backwash step, as specified in the original design manual.

Further trials were undertaken with the combined air and low flow water step removed. This two-step process of air only, followed by high rate water yielded reduced backwash time, backwash water volumes and operating costs without compromising backwash effectiveness.

The original design engineer can provide insight of the intended functionality and process design philosophy of the plant.

4.2 External Process Audit

A water treatment consultant, City Water Technology carried out a preliminary process audit at Winneke in November 2004. This identified a number of possible process improvements. Many of these recommendations facilitated improved filter operation.

4.3 Backwash Water Optimisation

After reverting the backwash sequence back to the original design and removing the combined air and water step, the backwash sequence included air scouring followed by high rate water washing.

Backwash water turbidity at termination of backwashing should be 10 – 15 NTU (AWWA, 1999). This provides optimal filter media cleaning and minimised wash water volumes. Grab samples were taken during backwashing to determine when this occurred. Depending on process conditions, this was typically after 5 minutes 20 seconds.

The final optimised backwash sequence is detailed in Table 4. This sequence varies greatly from the previous sequence (Table 1) and the original design (Table 2). This technique is an extremely powerful filter optimisation tool. It should be repeated regularly to maintain optimisation.

Table 4: ***Optimised Backwash Sequence***

Step	Blower	Pump	Duration
1	Blower (37.4 m/hr)	Nil	4minutes
2	Nil	2 Pumps (21 m/hr)	5 minutes 20 secs

The new backwash sequence does more with less. It resulted in:

- 38% reduction in backwash water volumes, or over 700 ML per annum.
- Operating cost reduction of ~$30,000 pa due to reduced water treatment and energy costs.
- Backwash pump and blower extended life due to reduced operation time.
- Increased filtration capacity of 3.5 ML/d due to:
- Backwash water volume savings (2 ML/d)
- Backwash time savings provided increased production time (1.5 ML/d).

Optimising backwash water flows and times by measuring backwash water turbidity can provide significant operational savings.

4.4 Backwash Draw Down Level

Current industry thinking deviates from Winneke's original design. Prior to commencement of backwashing, filters have always drained to significantly *below* the top of the media, as specified in the original design. Current industry practice suggests levels should be 25 - 50 mm *above* the media surface to improve flocculant break up. Level probes were subsequently elevated to achieve this.

4.5 Reject To Waste

A filter ripening trial occurred where reject to waste (RTW) times were adjusted to determine the effect on filtrate water quality. During each filter ripening period, turbidity typically increased from 0.05 NTU to 0.07 NTU for approximately 10 minutes. Particle counts typically increase by approximately 600% above normal filtrate levels for approximately 5 minutes.

It was found there is no correlation between the RTW time and filter ripening data for RTW times up to 20 minutes. RTW times over 20 minutes are not operationally feasible. A filter with no RTW can have superior water quality than a filter with a long RTW.

Although inclusion of the RTW is generally recommended to control protozoan organisms, it did not improve filtrate water quality. Its removal increased filtration capacity by 220 ML pa, reduced operating costs by $3,000 pa and improved plant reliability.

The original design RTW time was 3 minutes and the old backwash sequence RTW was 1 minute. However, optimisation was achieved with *no* RTW. Once again, contemporary treatment practice deviates from the original design.

5.0 FILTER MEDIA BED HEIGHTS

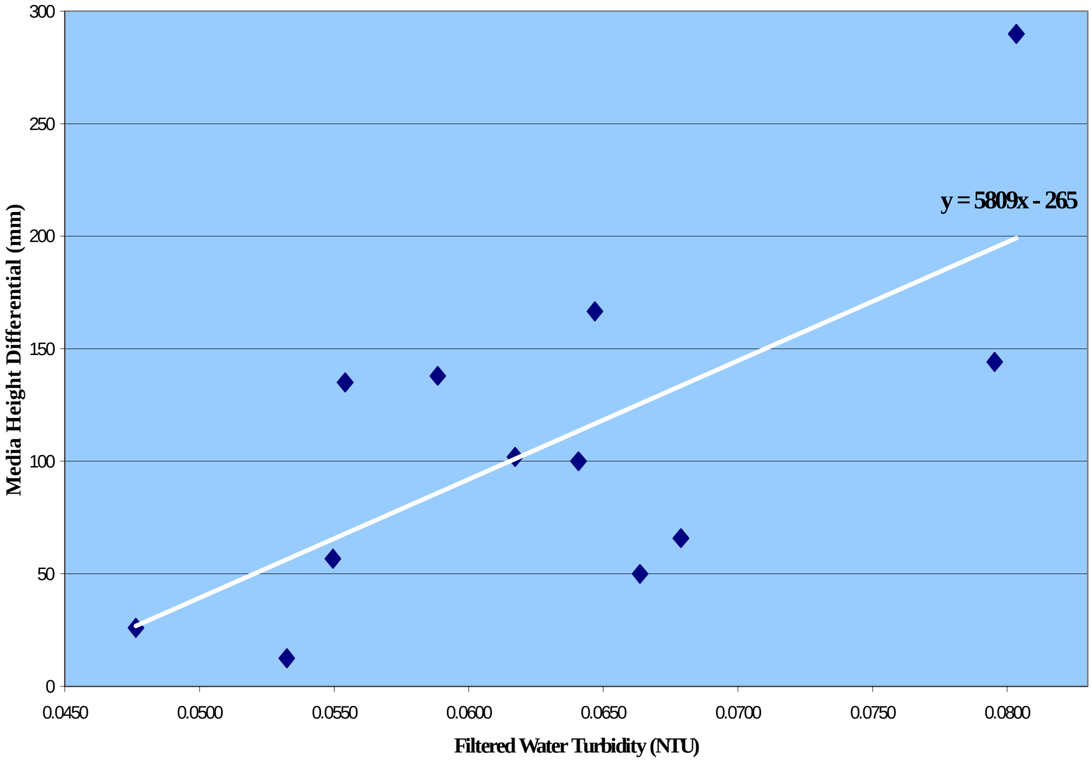
Media heights were not the same on each side of a filter gullet. This is predominantly due to low gullet launders, a history of inappropriate backwashing and air entrapment. Height differences ranged from zero to 300mm. Height differential resulted in different hydraulic capacity on each side of the gullet. This caused poorer filtration on the low media side. Filter media levels on each side of the gullet must be equal to achieve optimisation. A differential height impacts filtrate turbidity, media sludge concentration and sand carryover.

5.1 Equalising Media Heights

Media heights were equalised using a crane and excavator to transfer a calculated volume of sand.

5.2 Effect on Turbidity

Filters with greater media height differential on each side of the gullet had increased filtered water turbidity. This relationship is shown in Figure 3.



Notes: This correlation is an original finding; all datasets yield similar results to above; each data point represents one filter.

Figure 3: ***Filter Outlet Turbidity vs Media Height Differential on Each Side of Filter Gullet***

Following levelling media heights, equal filtration occurred throughout the bed. This facilitated reduced average filtrate turbidity from 0.060 NTU to 0.052 NTU (13%). This mitigates public health impacts by facilitating reduced protozoan risk.

5.3 Effect on Media Sludge Concentration

Media grab samples were taken and sludge volumetric percentage measured. Media sludge concentration was found to be a function of media height. The greater the media height, the greater the media sludge concentration. Following media height equalisation, sludge concentrations became similar on each side of the gullet.

5.4 Effect on Sand Carry Over

Filters with a greater media height differential between each side of the gullet were found to have greater overall media loss. The filter with the greatest media height difference (300mm) lost the greatest volume of sand (over 30%).

This is due to a lower pressure differential across the low bed, causing greater backwash flows. This creates additional turbulence in the low bed, which promotes sand carryover. Media height difference and media loss is a snowballing problem.

6.0 AIR ENTRAPMENT, SAND CARRYOVER AND SAND LOSSES

Sand has carried over into the Winneke filter gullets since commissioning. From 1980 to 2005, each filter lost an average 0.28m of the original 1.00m of sand. An investigation into the cause of this sand carry over was undertaken.

During backwashing, a very significant amount of air rose through the media bed for up to 8 minutes *after* the air blower turned off. This gave the appearance of air scouring in a section each filter. The rogue air rose whilst high rate water flowed over the launders and into the gullet. This contributed significantly to sand carry over.

Further investigation found the backwash water system normally contains approximately 40 m^3 of air. This was the source of the rogue air.

Backwash water pump non-return valve sealing tests found profuse leaking. This allowed water to pass from the backwash water duct into the backwash water tank. Large volumes of air then entered the backwash water duct through an air valve. After replacing all backwash water pump non-return valves, the majority of air escaping through the bed ceased. Leaking valves were a major cause of trapped air and sand carry over.

Sand carry over was also attributed to a history of inadequate backwashing and low filter gullet launders.

Excessive backwash water system air ingress must be absolutely avoided to minimise sand carry over and sand losses.

7.0 PEA GRAVEL LAYER

Winneke WTP originally had a 150mm pea gravel layer below 1000mm of sand. Pea gravel is now scattered throughout the sand. In some sections the layer no longer exists whilst in some sections the gravel layer is over 500mm. This significant pea gravel disruption is due to the backwash water control valve operation speed, a history of inappropriate backwashing and air entrapment.

7.1 Backwash Water Control Valve Operating Speed

'*Opening the backwash valve slowly is essential…(to prevent) gross disturbance of the gravel'* (AWWA, 1999). To reduce disturbance of what is remaining of the pea gravel layer, the backwash water control valve opening time was increased from 9 seconds to over 60 seconds. Similarly, the backwash water control valve closing time was increased from 9 seconds to 30 seconds to help reconstruct the pea gravel layer.

7.2 Backwash Sequence

'*Movement of the gravel can also occur when air scour and water backwash are used simultaneously*' (AWWA, 1999). This occurred for extensive periods during the old backwash sequence. The optimised backwash sequence has no combined step. It also has a long high rate wash step to aid bed reconstruction.

7.3 Air Entrapment

Trapped air released through the bed during the high rate water wash contributed to pea gravel disruption. Backwash pump non-return valve replacement has reduced trapped air. This will reduce pea gravel disruption.

8.0 HEADLOSS

Optimised filtration provided the following headloss reductions:

Table 5: ***Average Headloss Prior to and Following Optimisation***

	Clean Bed Headloss (m)	Terminal Headloss (m)
Non-Trialled Filters	0.64	1.51
Optimised Filters	0.50	1.29
Improvement	0.14 (22% reduction)	0.22 (15% reduction)

Note: May 2005 data was used.

Optimised filters have reduced headloss, which facilitates filter run times of over one hour longer.

9.0 CONCLUSIONS

Significant operational gains can be made from vigorous water treatment plant optimisation. This process should occur periodically and involve trialling original design specification operating conditions, reviewing and adopting current industry literature, engaging a water treatment process auditor and if possible communicating with the original design engineer.

Winneke Water Treatment Plant filter optimisation reduced annual operating costs by $30,000, reduced filtrate turbidity by 13%, increased filtration capacity of over 4 ML/d, reduced media losses, reduced headloss by 15%, reduced flow variance by 18%, reduced pH variance by 49% and reduced annual backwash water requirements by over 700 ML.

10.0 ACKNOWLDEGEMENTS

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