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STATISTICAL MODEL DEVELOPMENT TO ANTICIPATE FILTER BREAKTHROUGH AND OPTIMISE CHEMICALS DURING HIGH COLOUR RAW WATER EVENTS

A MODEL DEVELOPED AND APPLIED IN SYDNEY WATER'S WATER TREATMENT PLANTS

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ABSTRACT

Sydney Water operates the Nepean Water Filtration Plant (WFP) which has been receiving raw water with higher true colour from the Nepean dam in recent years. It was evident from higher true colour raw water that lower floc strength is the key issue, which causes filter breakthrough, resulting in significant decrease in filters run time, hence reduction of a plant's production rate. Therefore, a statistical process model was developed to anticipate filter breakthrough during higher colour of raw water and to optimise chemicals to prevent filter breakthrough. The process model analysed the previous four years' performance data of all dual media gravity filters, and developed correlation of filter breakthrough / performance with raw water qualities, chemicals dose rates, filter design and filter performance indicators. As an output, the process model can predict any filter turbidity breakthrough and plant performance deterioration, can provide instantaneous optimised chemical dose rates to stop filter breakthrough, and can save chemical usage and operator response time, providing a continuous optimisation guide to plant operators. The developed process model was applied at Nepean WFP during October to December 2016 in high colour event for raw water true colour at 25 HU @400 nm. This successfully eliminated the filters' turbidity breakthrough, increased plant production rate by 31%, increased all the filters run time by 60-300% and achieved significant chemical savings in the range of 20-51%. The developed process model can be applied to any water filtration plant for process optimisation.

INTRODUCTION

Sydney Water operates the Nepean WFP, which treats raw water from the Nepean Dam, south-west of Sydney. The process train at Nepean WFP consists of raw water pre-treatment by chlorine, lime, potassium permanganate ($KMnO_4$) and carbon dioxide (CO_2) dosing followed by coagulation-flocculation using ferric chloride, cationic polymer (poly-DADMAC) and non-ionic polymer (Polyacrylamides) dosing; then first stage clarification by roughing filters (micro-floc adsorption clarifier); and final stage filtration by dual media gravity filters. Historically, this plant has been operating at 230-240 L/s, running one of the three fixed-speed raw water pumps under normal raw water turbidity 1-5 NTU and true colour 10-18 HU (@400 nm). In 2012, following a wet weather event, raw water true colour increased, quickly reached to 40-45 HU, then gradually decreased over the next 12 months. Since then, every year raw water true colour reaches to a peak of above 30 HU and then gradually decreases over a period but never reverts to the historical average true colour (Figure 1). Colour reflects various compounds in the raw water, mainly the organic fractions, and hence is used as a surrogate parameter to exhibit presence of organic matter in water. The higher true colour in the raw water over the past number of years has also been complicated by historically lower turbidity over the same period. This higher colour and lower turbidity source water has presented considerable challenges to Sydney Water in maintaining filter performance (Mohiuddin et al. 2014). It was evident from higher colour raw water that lower floc strength is the key issue, which causes turbidity breakthrough in dual media gravity filters (Figure 2). Consequently, the plant's production rate was reduced to 150-160 L/s (34% reduction) (Figure 3) and the dual media filters' run time was significantly reduced to 10-15 hours (69% reduction). Chemical optimisation at the plant, carried out in the last few years, improved filter performance and the plant's production rate. However, because of the unpredictability of filter breakthrough and longer time required in optimisation to improve floc strength, the plant's production rate and the filters' performance were immediately reduced at the start of each raw water high colour event. Therefore, a statistical process model was developed by the authors to anticipate filter breakthrough during higher true colour of raw water and to instantly optimise chemicals to prevent filter breakthrough, maintain the filters' performance and plant production rate.

DEVELOPMENT OF THE PROCESS MODEL

The statistical process model used the previous four years' performance data of the dual media gravity filters, and analysed the parameters during each filter turbidity breakthrough. The analysis included filter performance statistics, filter backwash triggers, coagulation conditions, every chemical dose in treatment, filter design parameters, filter media specifications and raw water qualities.

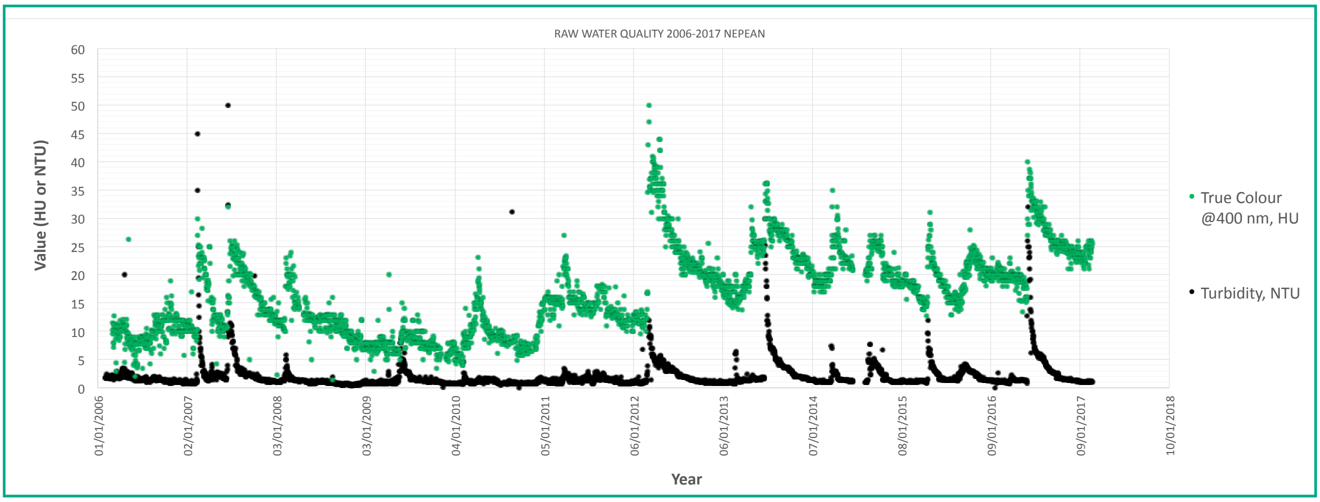

Figure 1. Nepean raw water quality: Historically 2006-11, 81%ile true colour is <15 HU, Recent 2012- 17, 90%ile true colour is 20-30 HU

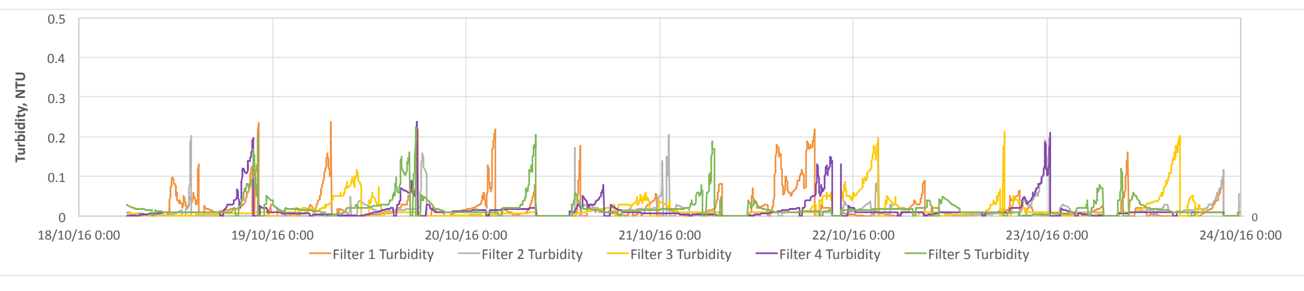

Figure 2. Sudden rise of filter turbidity during high true colour raw water leading to the filter breakthrough

The process model then correlated all these parameters and differentiated between the optimum and suboptimal condition of the plant under a range of model input scenarios. Figure 4 shows the inputs to the model covering:

- raw water qualities
- filters' performance data
- chemical dosing – including pre-treatment, coagulation and post-treatment
- other parameters of the plant (roughing filter performance, hydraulic loading, filter design, filter media specification, etc.)

From these inputs, the model developed the following equation to anticipate filter breakthrough:

Filter breakthrough = f (raw water quality, chemical dose rates, filter design, filter performance indicators)

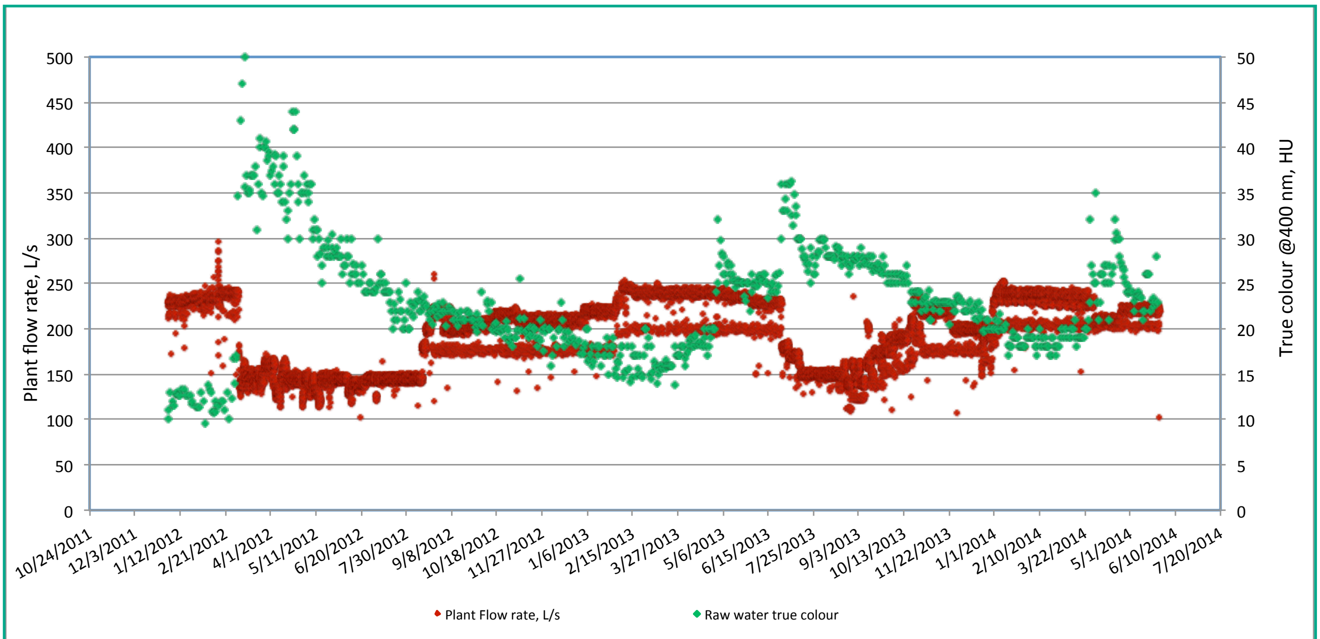

Figure 3. As the raw water true colour increased above 25 HU@400 nm, plant production rate had to drop from 240 L/s to 160 L/s in 2012 and 2013

OUTPUT AND RESULTS OF THE STATISTICAL PROCESS MODEL

As an output:

- The statistical process model can predict filter turbidity breakthrough and plant performance deterioration during any sudden rise of raw water true colour (model calculated plant's performance at current raw water quality and chemical dose rates).
- The statistical process model can provide instantaneous optimum chemical dosages to eliminate the filter breakthrough due to changes in raw water quality and anticipate the plant's performance at model optimum chemical doses (optimisation using the model and forecast of plant performance improvement).
- For process data analysis, the model user can select a wide range of data sets from data selection criteria to see all the correlations among the parameters.

The model user can easily compare model- calculated filter performance at the current plant parameters and model-predicted performance with model-suggested optimised parameters. Plant operators can then choose to optimise chemicals, based on the model-calculated optimised parameters. Outcomes of the model focus on improved water quality, reduced filter breakthrough, increased plant production and filters' run time, chemical savings, and savings in operator response time to optimise chemicals during raw water quality changes.

APPLICATION OF THE DEVELOPED PROCESS MODEL

The developed process model was applied at Nepean WFP during October to December 2016. In October 2016, raw water turbidity and true colour was 1-2 NTU and 25-26 HU respectively. All the dual media gravidity filters were experiencing severe turbidity breakthrough (Figure 5 and 6) and as a consequence filters' run time was decreased to the range of 10-25 hours (Table 1). The plant production rate was reduced to 180 L/s (Figure 6, Table 1) which limited the plant net production capacity to around 14 ML/d excluding the filter backwash water.

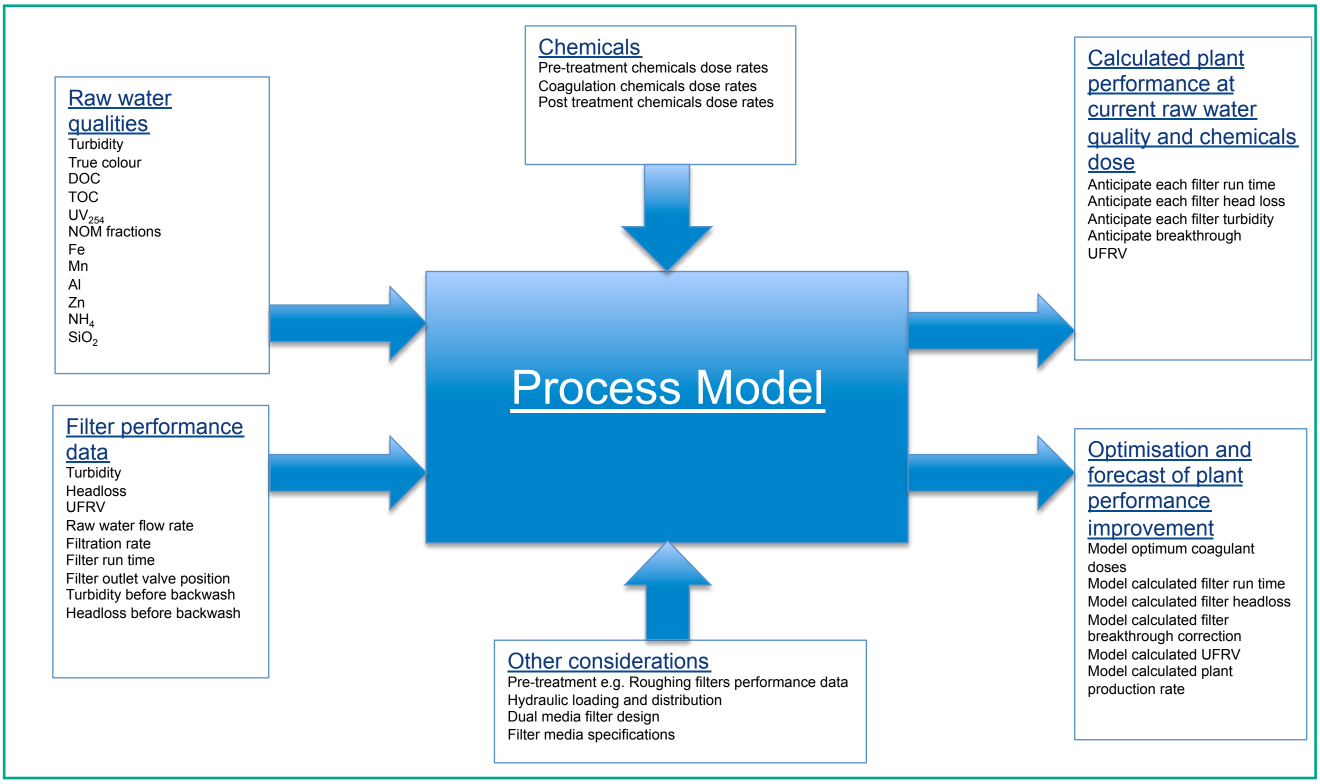

Figure 4. Process Model to anticipate filter breakthrough and optimise chemicals

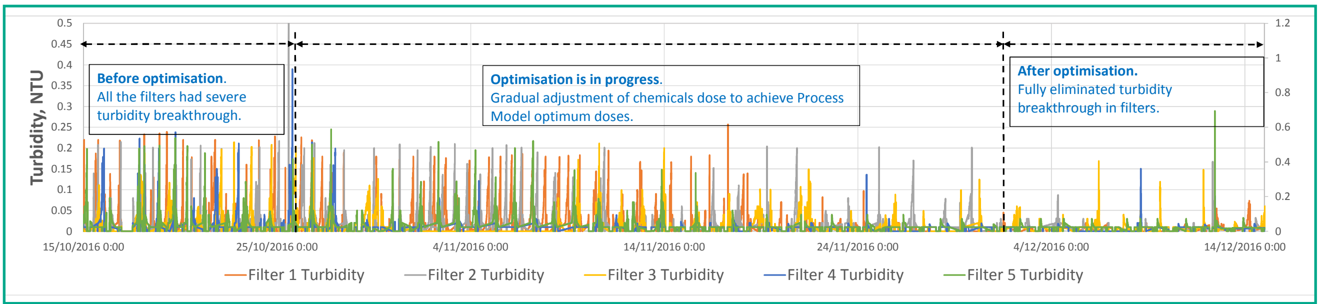

Figure 5. Severe turbidity breakthrough in all filters before optimisation (Oct 2016), and fully eliminated turbidity breakthrough after optimisation (Dec 2016)

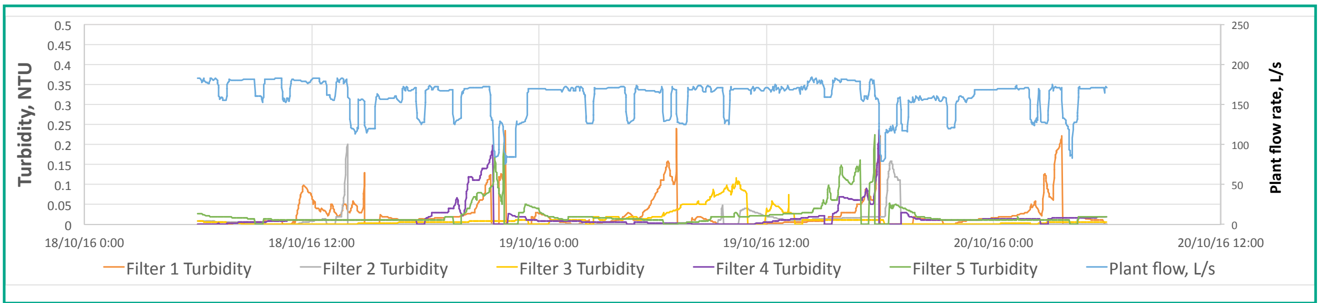

Figure 6. Before optimisation, 2-day trend indicating severe filter breakthrough and reduced production rate to 180 L/s

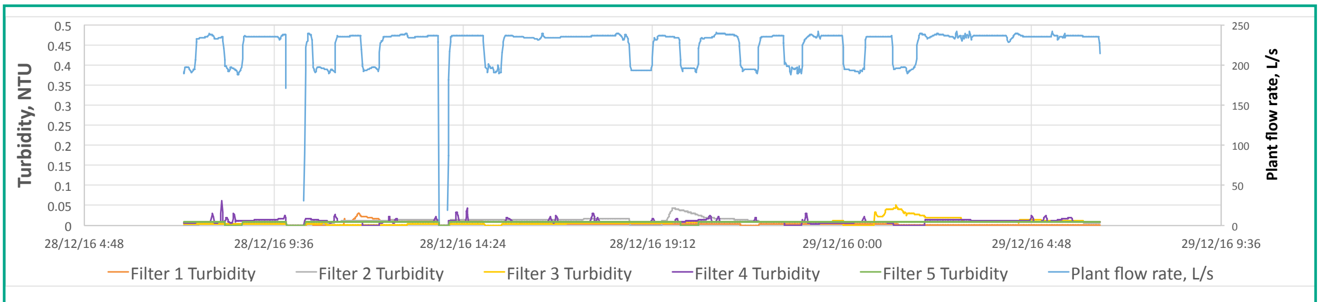

Figure 7. After optimisation, 2-day trend indicating fully eliminated turbidity breakthrough and increased production rate to 235 L/s.

Due to lower production from the plant and higher water demand in the network, the main reservoir (13.5 ML capacity) level was occasionally dropping to critical level. This indicated severe depletion of network water storage and sometimes it took a few days to catch up the depletion when water demand became lower than the plant's production.

The developed process model was applied at that time in October 2016. The process model indicated severe breakthrough in all dual media gravity filters and demonstrated that the filters' breakthrough could be corrected by optimising the chemicals.

The model predicted optimum chemical dosages at that condition showed far different dose rates than the existing dose rates at the plant (Table 1). By implementing the process model, the chemical dose rates were gradually adjusted over the period of November to December 2016. This has fully eliminated the filters' turbidity breakthroughs at that condition (Figure 7), increased the plant production rate by 31% (235 L/s) (Figure 7, Table 1), increased all the filters' run times by 60-300% (40-48 hours) and achieved significant chemical savings in the range of 20-51% (Table 1).

Table 1. Chemicals doses and plant performance before and after optimisation using the process model

	Before optimisation 16/10/2016	Process Model predicted optimum chemical doses	After optimisation using the Process Model 30/12/2016	% Variation between before and after optimisation
Raw water turbidity, NTU	1.7	1.7	1.2	
Raw water true colour @400 nm, HU	25	25	24	
Pre-dose chlorine, mg/L	3.5	1.3	1.7	-51%
Ferric chloride, mg/L	13	8	7	-46%
Cationic polymer, mg/L	2.8	1.6	2	-29%
Non-ionic polymer, mg/L	0.25	0.25	0.2	-20%
Plant flow rate, L/s	180		235	31%
Plant daily production capacity, ML/d	14.552		19.304	33%
Filter 1 run hours	10		40	300%
Filter 2 run hours	12		48	300%
Filter 3 run hours	24		48	100%
Filter 4 run hours	25		40	60%
Filter 5 run hours	21		48	129%

CONCLUSION

The statistical process model is a very quick guide for the plant operators to anticipate potential plant performance issues relating to raw water quality change. The process model correlates parameters and can use the live data from SCADA and provides instantaneously calculated information of filter breakthrough and suggested optimum chemical dosages. The model can continuously suggest to the plant operators the optimum chemical dosages for any raw water condition, saving operators' response times during a plant emergency, preventing plant performance deterioration and saving costs from un-optimised chemical dosages. The developed process model is fully transferrable and can be applied to any water filtration plant for process optimisation.

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