BLENDING AND SLOW SAND FILTRATION AT LITTLE RIVER WTP

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ABSTRACT

Christchurch City Council (CCC), with assistance from CH2M Beca, has carried out an upgrade to the Little River Water Treatment Plant (WTP) to meet the Drinking Water Standards for New Zealand (DWSNZ). The original plant treatment process consisted of slow sand filtration and chlorination for a single surface water source. Turbidity spikes during periods of wet weather caused non-compliance with the DWSNZ.

To provide a balance between increasing the security of supply, reliability of treatment, and cost, it was decided to upgrade the plant with the addition of a new groundwater source (which required softening), refurbishment of the slow sand filters including new media and underdrains, and UV disinfection.

Having both a groundwater and surface water source provided greater security of supply and also allowed the sources to be blended to assist with hardness in the groundwater source. Taste testing was used to develop the process philosophy for blending that best suited the local community.

The slow sand filter process was retained as they provide cost effective treatment. They also produce no residual waste stream, and only require periodic scraping of the sand. Although there are no other known slow sand filters in New Zealand, there are numerous slow sand filter installations operating successfully overseas. Therefore the design was carried out in consultation with slow sand filter experts from CH2M in the US.

This paper outlines the drivers behind key decisions and covers key design, commissioning and operational requirements, as well as a summary of the lessons learned. The performance of the upgraded filters is also reviewed. The applicability and cost-effectiveness of slow sand filtration technology to other small communities is discussed.

KEYWORDS

Water Treatment, Slow Sand Filtration, Blending, Softening, Small Communities

1 INTRODUCTION

The Little River Water Treatment Plant supplies the township of Little River on Bank Peninsula with drinking water. Little River is classed as small community supply under the Drinking-water Standards for New Zealand 2008 (DWSNZ).

Prior to the upgrade in 2015, the plant was supplied by a surface water source which was treated by slow sand filtration and chlorination. The catchment is partially protected, thus requiring bacterial and 3-log credit protozoal treatment to meet DWSNZ.

This process regularly had turbidity spikes exceeding 1NTU, associated with rainfall events, which did not comply with the slow sand filtration requirements in DWSNZ. Even if the slow sand filtration operation complied with DWSNZ it would only achieve 2.5 log credits which would be insufficient for protozoal compliance. In addition, there were periods where there was insufficient flow from the surface water source to meet demand.

Therefore the sources needed to be augmented and the WTP needed to be upgraded to meet DWSNZ.

2 DISCUSSION

2.1 UPGRADE OPTIONS

To provide a more reliable source, a bore was drilled near the WTP. Water quality analysis showed the bore had elevated hardness and salinity (up to 320 mg/L hardness which exceeded the DWSNZ guideline value of 200 mg/L) and bromide (up to 0.6 mg/L which would likely cause issues with the production of disinfection by-products if chlorinated).

As the bore did not have secure status, it required treatment for bacterial and 3-log credit protozoal. Softening was also required to reduce the high hardness.

The consented surface water maximum daily flow is 216 m^3/d (average 2.5 L/s). The consented maximum daily bore flow is 260 m^3/d (3 L/s) at a maximum instantaneous flow of 6 L/s and these are also the maximum daily flows for the two sources combined.

UV was selected to achieve protozoal compliance as it is a relatively reliable and low cost option for good quality water.

Due to the presence of bromide in the bore water, chlorination was not considered to be a suitable disinfection method due to the risks of brominated disinfection by-products. Thus UV disinfection was selected as the primary method of achieving both DWSNZ protozoal and bacterial compliance.

Although softening followed by UV disinfection of the bore water alone would have been the lowest cost option, the addition of the surface water source with upgraded slow sand filters was considered to significantly increase the security of supply without significantly increasing the cost. The UV disinfection could also be used to achieve protozoal and bacterial compliance for both sources.

Blending of both sources was selected as the normal operating mode for the plant to minimise cost (the surface water source does not need to be pumped or softened) and to maintain the quality of the bore supply (avoids high turbidity associated with starting the bores after a long period of dormancy and keeps softeners turning over).

2.2 SELECTED TREATMENT OPTION

An overview of the upgraded treatment process is shown in *Figure 1* below. If the bore were to gain secure status in the future, once softened the flow could bypass the UV treatment.

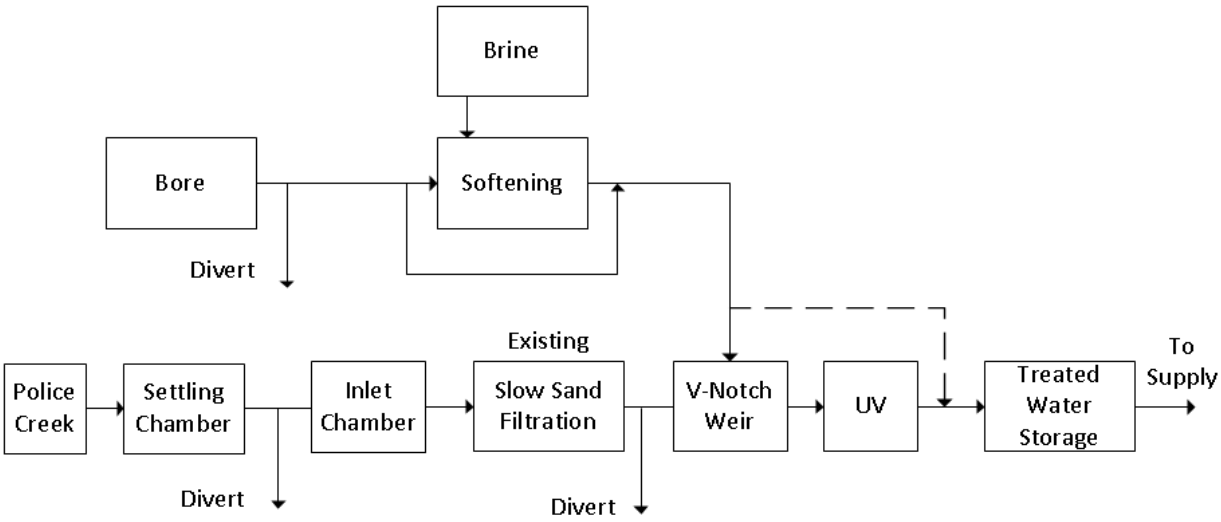

Figure 1 – Little River Process Schematic

The first diversion before the slow sand filters prevents very high turbidity water from overloading the filters which would increase the risk of high turbidity breaking through and also shorten the lifespan of the media. The diversions after the filters and on the bore line prevent high turbidity water (i.e. greater than 1 NTU) going to the UV which would result in the treated water not complying with DWSNZ

In the event of a lack of surface water, the plant operating mode switches to bore water only. This could cause an undesirable taste from the sodium that is added during the softening process and/or scaling of household appliances if bore only source is a frequent occurrence. The consideration of these issues is covered in Section 4.

2.3 WATER SOURCE BLENDING

Ion exchange was the selected softening treatment for the bore water as it is lower cost to install and operate compared to other methods of removing hardness. Softening is required because hardness can cause scaling within the UV disinfection equipment as well as on plumbing and reticulation. In ion exchange, the 'hard' minerals (magnesium and calcium) are removed from the water by replacement with sodium, as shown in *Figure 2*. A brine solution is used to replenish the sodium in the column once it is exhausted. A high sodium content can cause objectionable taste.

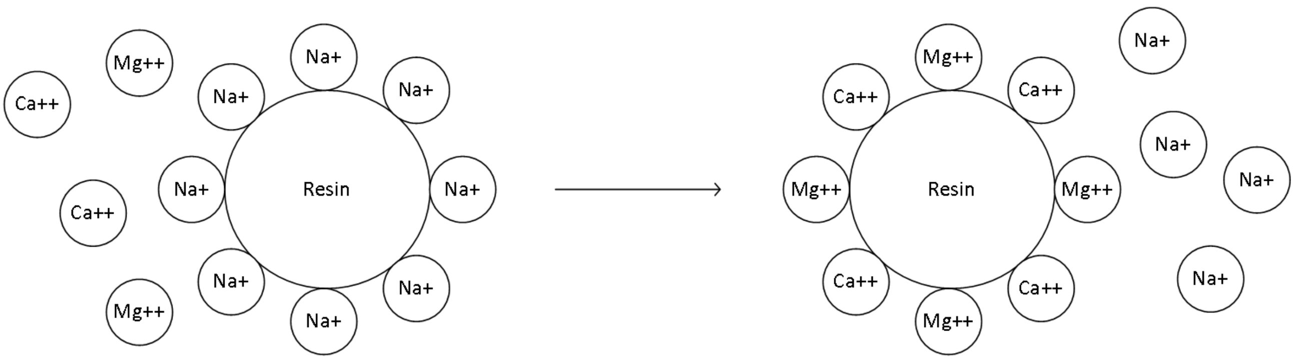

Figure 2 – Ion exchange resin before and after softening treatment

As the softening process removes all hardness in the water, which is not necessary, a proportion of the flow bypasses the softening units to achieve a low hardness and acceptable taste. To assess the impact of softening on taste, a taste test was carried out, comparing several softened and un-softened blends with Christchurch City tap water. The ratios and findings are shown in *Table 1* below. The DWSNZ guideline aesthetic value for hardness is 200 mg/L and guideline value for sodium is 200 mg/L.

Table 1 – Softened Water Blending Ratios and Taste

	Raw Bore Water	70/30 Blend	40/60 Blend	Tap Water[1]
Raw Water Content	100%	70%	40%	Christchurch tap water
Softened Water Content	0%	30%	60%	
Hardness (mg/L)	310	220	130	45
Sodium Content (mg/L)	90	130	180	6
Comments on Taste	Fresh, less taste than the 70/30 blend.	Slightly salty, 'earthy' taste, more agreeable than the 40/60 blend.	Recognisable as the water with the highest proportion of softening, with a strong taste and a metallic after taste.	Recognisable as tap water.
Overall Impression	Acceptable	Acceptable	Unacceptable	

[1] Typical average chemical analyses of hardness and sodium content from Water Supply section of CCC website.

To achieve a low hardness and acceptable taste, it was concluded that under normal operation 30% of the bore water will be softened. Taking into account blending with the surface water source (at a ratio of 1:1, surface water to bore water), this results in a hardness of around 140 mg/L and a sodium content of around 130 mg/L. Softening a proportion of the bore water also reduces operating costs including brine use.

In the event of high turbidity in the surface water, or a lack of surface water, the operating mode will switch to bore water only. In this situation 40% of the bore water will be softened to achieve a low hardness which may cause an unacceptable taste from the sodium added during the softening process. If taste is a problem, the amount of softening could be reduced, as the resulting increased hardness is unlikely to cause significant scaling for short term events.

2.4 SLOW SAND FILTRATION

Although there are no other known slow sand filters for a small community water supply in New Zealand, there are numerous slow sand filter installations operating successfully overseas, especially in North America. Therefore the design was carried out in consultation with slow sand filter experts from CH2M in the US. It has the benefits of low operating costs, minimal treatment residuals and is a 'passive' process meaning operator intervention is minimal.

Slow sand filtration has been available as a technology since 1829, when the first filter was installed in London for the Chelsea Water Company. The same basic design is still standard practice. *Figure 3* below shows a schematic cross section of a typical slow sand filter.

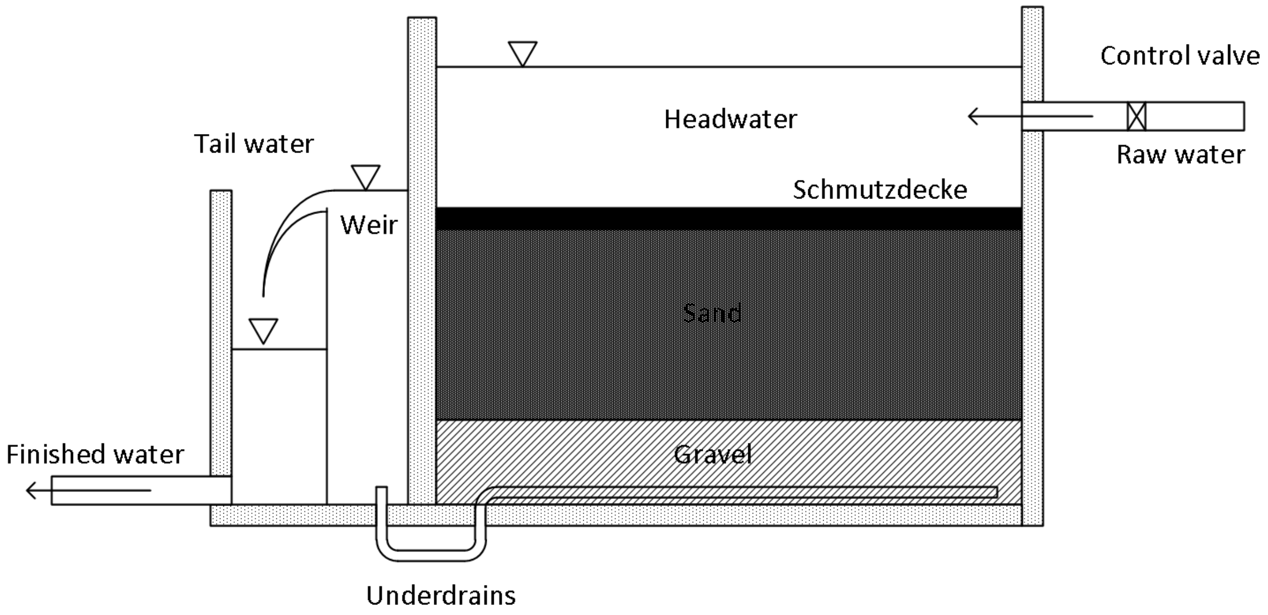

Figure 3 – Sand Filter Schematic (Manual of Design for Slow Sand Filtration, AWWA 1991)

Slow sand filtration differs from rapid filtration in that the raw water is physically filtered and biologically treated, removing both sediments and pathogens. The top layers of the sand become biologically active by the establishment of a microbiological community on the top layer of the sand referred to as the 'schmutzdecke'. These microbes come from the source water and establish a community after a period of time. Sand filters are highly effective for removing bacteria, protozoa, viruses, turbidity and heavy metals. However, excessive turbidity can cause the filter to clog more rapidly and low temperatures can decrease the performance of the process.

Depending on the sand media quality and the turbidity of the raw water, it can often take from 4 weeks to 16 weeks for the filtered water to have a lower turbidity than the raw water. Some filters may still produce water with higher filtered turbidities than raw turbidities after 6 months.

To allow for maintenance, the filter should have two or more equally sized cells, independently operated. Maintenance is carried out when the headloss across the filter has increased and thus restricted the flow to a minimum amount. The headwater is drained so the top layer of sand can be scraped off. Water is then circulated through the filter until the schmutzdecke is established. When the level of the sand reaches a minimum level after successive scrapings, the media must then be replenished.

2.4.1 SAND GRADING

The sand grading is important to achieve a properly function filter. The key criteria are the sieve size that 10% passes (d_{10}), and the uniformity coefficient (C_u;d_{60}/d_{10}).

The media guidance provided by Huisman and Wood (1974), in their book Slow Sand Filtration, published by the World Health Organization) has been widely followed and generally supported by subsequent research. They recommended a d_{10}=0.15-0.35 mm and a C_u from 1.5 to 2.0 (and always <3.0). Bellamy's work in the 1980s demonstrated effective removal rates for coliform bacteria and Giardia cysts using sands with d_{10} as high as 0.62 mm. The removal rates did decrease as the media size was increased but the decrease was relatively small.

Based on the work by these authors and others, the American Water Works Association Research Foundation Manual of Design for Slow Sand Filtration (1991) recommends d_{10}=0.2-0.3 mm and C_u<2 (although it provides a comment that C_u<3 may be acceptable if local sands do not fall within the recommended value). In the experience of Paul Berg, a slow sand filter expect with CH2M, sands with d_{10} values as low as about 0.18 mm and as high as 0.32 mm have been used with no apparent detrimental effects.

It is also important to limit the amount of fine sand as this can be washed through and lead to elevated turbidities. The sand placed in the filter must be washed sand to reduce turbidity due to fines during start up.

What is asked for in the specification needs to be balanced with what can be obtained locally at a reasonable price. Also, the transport and placement of filter media can produce more fines, therefore this must be carried out with care.

2.5 LITTLE RIVER WTP SLOW SAND FILTERS

The two slow sand filters at Little River WTP operate in parallel. Some bulging of the timber structure was noted following the 2011/12 Canterbury earthquake sequence. At the maximum consented surface water flow to the plant their combined surface area results is a loading rate of 0.18 m/h. The maximum flow allowed under DWSNZ is 0.35 m/h, however typically filters are limited to less than 0.2 m/h. Thus the existing design of the slow sand filters was maintained for treating the surface water source. As part of the WTP upgrade they were dismantled and rebuilt with a new timber structure, liner, underdrains and sand.

The existing sand was found to not meet the requirements outlined above for slow sand filtration media. Therefore a number of sources were investigated to find suitable media, with the only material that complied with the specification available from Australia. New Zealand suppliers of filter media generally had a uniformity coefficient that was too high or the d_{10} was too fine. The New Zealand sand that best met the requirements was a turf sand, but this had a C_u slightly greater than 2. However, this was ultimately selected to reduce costs.

2.5.1 COMMISSIONING

After the sand was placed in the filters, the following steps were taken during the commissioning/ripening process:

- Slow initial bottom filling (rate of filling 0.1-0.2 m/hour)
- Filters were run to waste.
- Initially, a maximum of feed water with a maximum of 5 NTU was specified. However, as the filters were commissioned in winter, the surface water regularly exceeded this. Therefore this was relaxed to allow more continuous filter operation and to allow more organic matter to build up the schmutzdecke.
- Due to the higher turbidity feed water, the headloss increased to the point where the top layer needed to be scraped to reduce the headloss. This was carried out in accordance with the AWWARF Manual (Hendricks, 1991), and also included leaving an undisturbed perimeter ring to prevent short circuiting down the side of the filter.

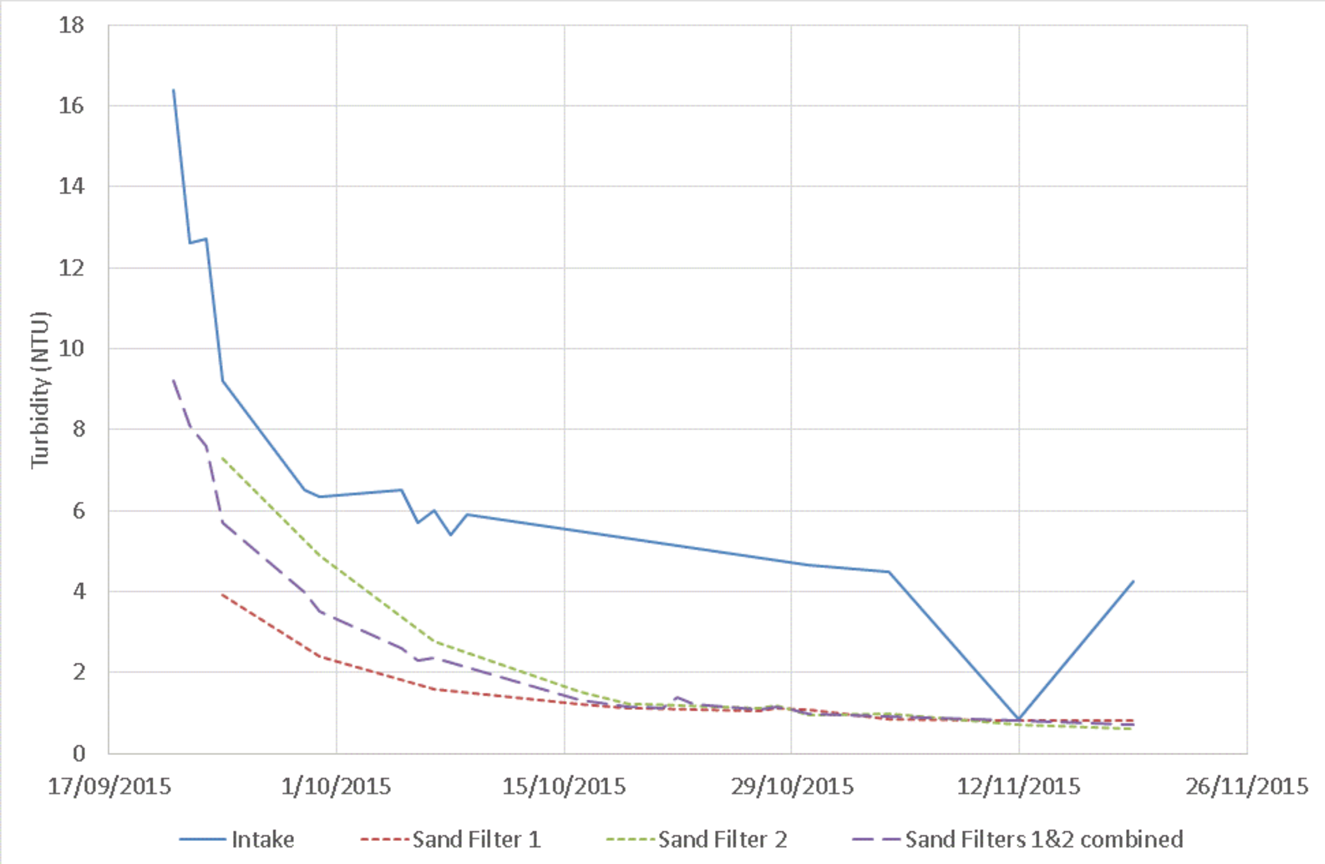

Figure 4 – Slow Sand Filter Performance During Commissioning

Commissioning of the sand filters coincided with cold winter weather in Little River which slowed development of the schmutzdecke for Sand Filter 1. When Sand Filter 2 was commissioned it was slightly warmer and to help speed up the ripening of the filter it was seeded with 50 litres of water from Sand Filter 1.

It wasn't until closer to the summer that the performance of the filters reached the expected level.

2.5.2 PERFORMANCE

Figure 5 and *Figure 6* show the performance of the sand filters over the six months since the plant was fully commissioned. Despite some high turbidity in the raw water (up to 150 NTU), the filtered water turbidity generally remained less than or equal to 2 NTU 99.7% of the time. There were some turbidities up to 10 NTU recorded, but all the turbidity above 2 NTU only occurred as a single data point.

Note that the raw water should normally be diverted to waste if the turbidity was greater than 5 NTU, however there was a problem with entrained air affecting the raw water turbidity readings. Also while the filters were being commissioned the very fine material in the sand produced higher filtered turbidity.

These results have enabled the UV disinfection to comply with the turbidity requirements of DWSNZ (not exceeding 1.0 NTU for more than 5% of the compliance monitoring period, and 2.0 NTU for any 3 minute period).

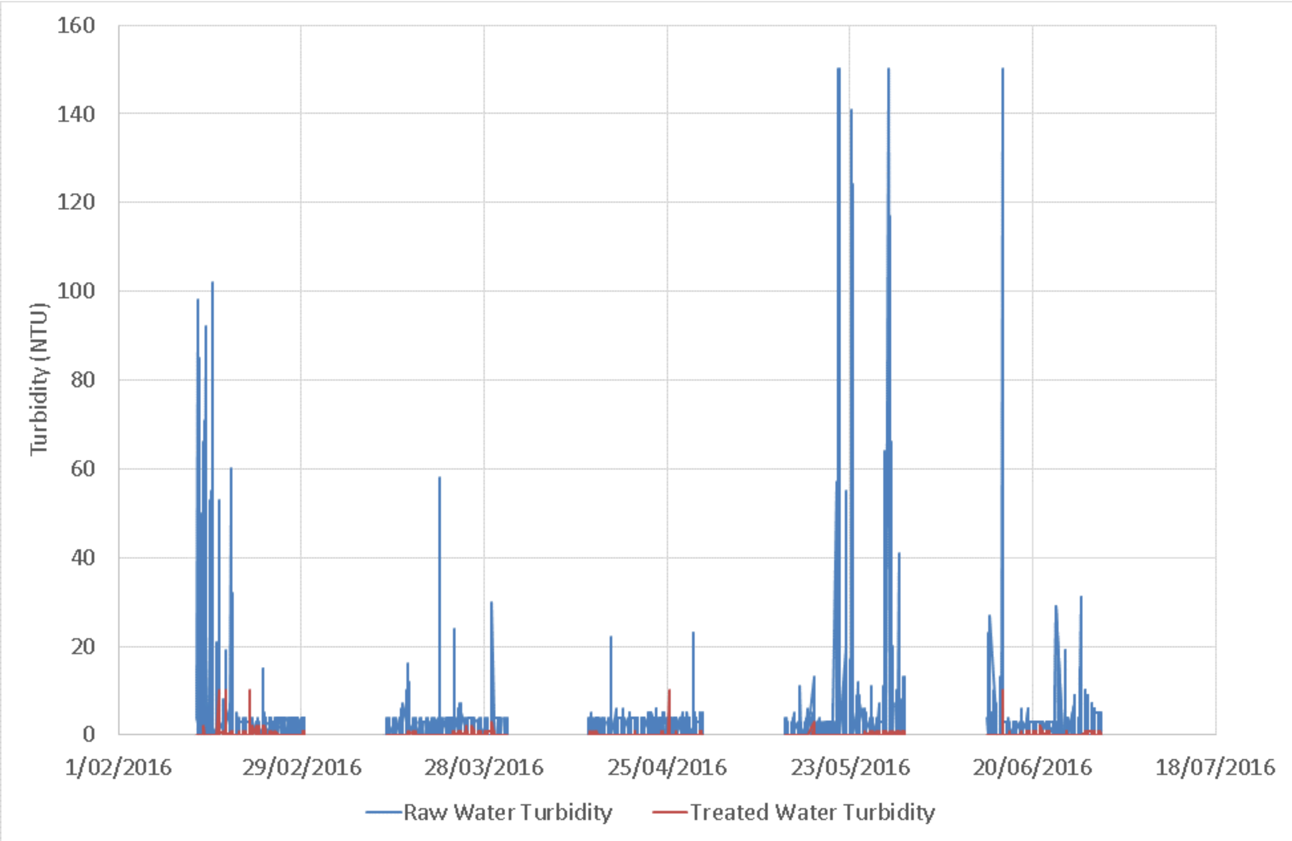

Figure 5 – Slow Sand Filter Performance – Raw Water and Treated Water Turbidity

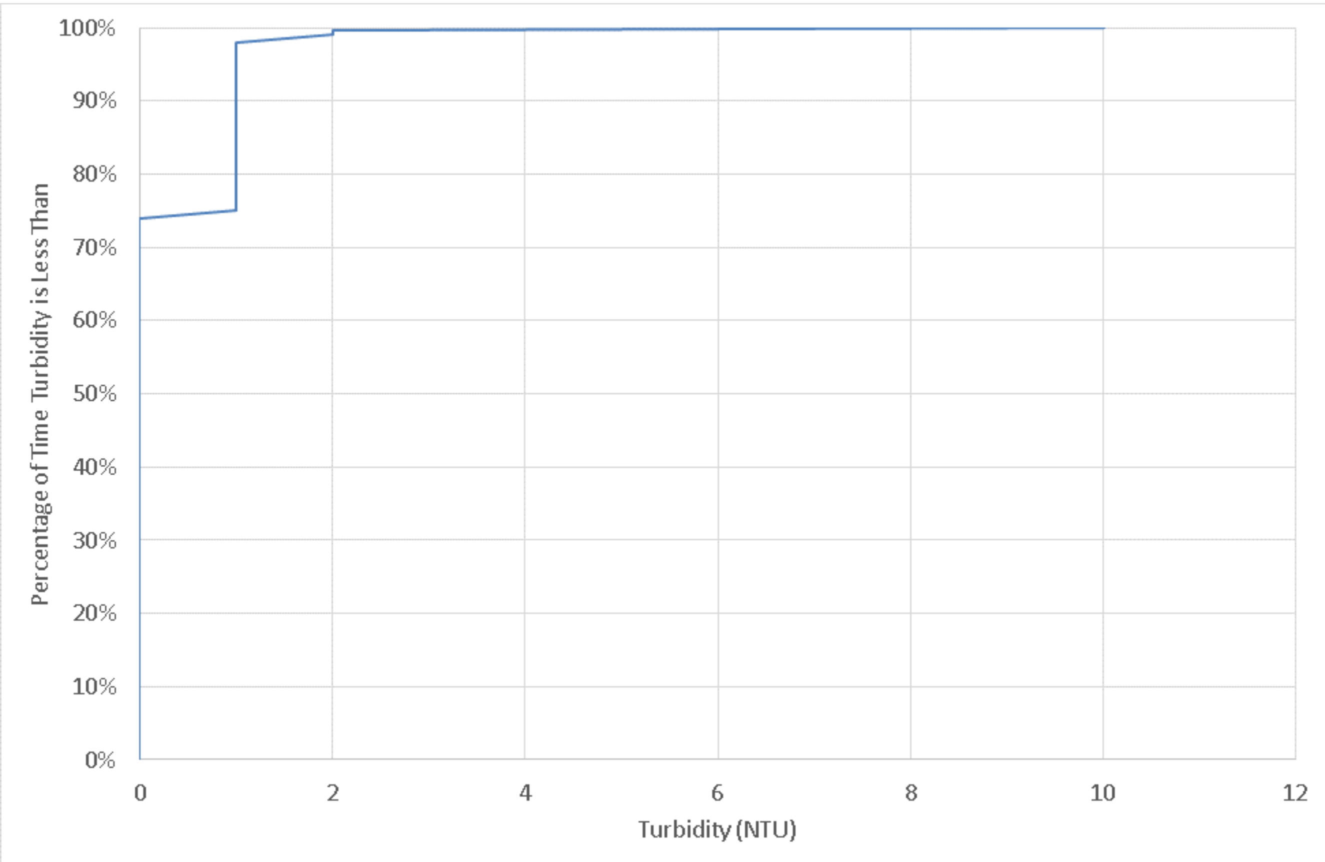

Figure 6 – Slow Sand Filter Performance – Cumulative Frequency Distribution for Treated Water Turbidity

2.5.3 KEY ASPECTS AND LESSONS LEARNED

From our experience with the design and commissioning of the slow sand filters at Little River, we have identified two key aspects:

SAND SELECTION

Sand selection is critical to the successful operation of the slow sand filters. The requirements for slow sand filters are different from other filtration. However, with enough investigation, a relatively local source should be able to be found. It is important to check that the amount of fines is less than recommended limits and that the sand is placed carefully.

TEMPERATURE

The commissioning was carried out in winter when the ambient temperature was low. As slow sand filtration is a biological process, this delayed the establishment of the filters. Where possible, slow sand filters should be commissioned in warmer weather.

3 COSTS

The total cost of the upgrade was approximately \$2 million. The biggest component of this cost was \$650,000 for a new concrete treated water reservoir. Other significant components included about \$170,000 for the demolition and construction of new timber tank slow sand filters and associated pipework and chambers, \$210,000 for the process building, softening and UV process equipment, and about \$470,000 for the electrical, instrumentation and controls for the site.

4 SUMMARY

The Little River WTP was upgraded in 2015. The upgrade maintained the existing slow sand filtration of the surface water source, adding a diversion upstream and downstream of the filters to prevent turbidity spikes from rainfall events entering the treated water supply. A bore water source was added to increase security of supply, using ion exchange for softening to reduce the risk of scaling on household equipment. UV treatment was installed to achieve the required bacterial and protozoal treatment to meet the DWSNZ.

Under normal plant operation the surface and bore water sources are blended to minimise operating cost and maximise security of supply. As water softening replaces the minerals with sodium, which can cause unacceptable taste, taste testing of different blend ratios was carried out. This found softening 30% of the bore water to be the optimum balance between reducing hardness and acceptable taste (assuming a blend ratio of 1:1 surface to bore water). If availability of surface water is lacking, the plant will operate on bore water only and the amount of softening could be reduced for periods.

Slow sand filtration has been effective in providing pre-treatment of the surface water source prior to UV disinfection. It has a number of advantages over other forms of filtration, including minimal operator intervention and no residuals stream. This makes it particularly suited to smaller more remote water supplies but the raw water source must be of reasonably high quality (usually $\leq$5 NTU).

The sand selected and the ambient temperature when commissioning are critical factors in the treatment efficiency and the time taken for the filters to reach the required performance. Sufficient time needs to be provided to allow the filters to ripen. The ripening process cannot be sped up easily as the properly operating sand filter relies on a biological layer (schmutzdecke) forming on top of the sand.

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