WANAKA DRINKING WATER ACTIFLO® TRIAL – ALGAE REMOVAL IN OLIGOTROPHIC LAKE WATER

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ABSTRACT

In late 2015 Queenstown Lakes District Council (QLDC) commissioned Veolia to trial the ACTIFLO® process at Beacon Point Intake, which is one of two intakes on Lake Wanaka for the Wanaka drinking water supply. Since 2008 the supply has been experiencing increasing amounts of algae being drawn from the intake into the water supply.

Actiflo is a compact high rate clarification system developed and patented by Veolia that utilises micro-sand enhanced flocculation (MEF) in conjunction with lamella settlers. The micro-sand particles provide a large surface area and act as a seed for floc formation, whilst also providing ballast which increases the settling velocity of these particles. Whilst this treatment system has been employed at a wide variety of reference sites worldwide, most of these sites experience a turbidity of > 500 NTU. This paper specifically highlights the success of the technology in removing algae in Lake Wanaka's low turbidity water.

A completely self-contained Veolia pilot system was used for simulating the operating conditions of a full scale Actiflo installation. The primary purpose of the trial exercise for QLDC was to determine the suitability of the Actiflo treatment process for full scale reduction in the amount of algae drawn into the drinking water supply.

A successful demonstration of Actiflo feasibility was proven during the trial.

KEYWORDS

Algae removal, oligotrophic, cyclotella, drinking water, micro-sand enhanced flocculation, ACTIFLO®.

1 INTRODUCTION

This paper describes the operation and results from the Actiflo pilot plant trial undertaken at QLDC's Beacon Point Intake water pump station located in Wanaka in the Otago region of the South Island of New Zealand (Photograph 1).

Photograph 1: Actiflo Plant Location for Trial

Beacon Point is one of two intakes on Lake Wanaka that supply drinking water to the Wanaka water supply scheme. The supply scheme has been experiencing an increased amount of algae being drawn from the lake intakes into the drinking water supply. This has resulted in an ever increasing number of customer complaints (usually logged as pressure loss), primarily because of the clogging of households water filters, strainers and fittings on household appliances. The problem is particularly exacerbated during summer months due to the increased water demand from consumers and (potentially) the more favourable growing conditions for algae. During summer the Beacon Point Intake abstracts up to 17MLD via a 0.9mm intake screen situated 11m below the lake surface. Water is pumped into a wet well and chlorinated before being stored in a reservoir and pumped into the reticulation network. Other than coarse filtration at the intake and chlorine disinfection prior to the reservoir, no other clarification or filtration treatment processes are used on the Wanaka potable water supply.

1.1 BACKGROUND

Previous investigations by QLDC had identified the presence of a microscopic centric diatom (10-20µm in diameter) called cyclotella as the most likely cause of the clogging issues (MWH, 2011). Cyclotella is associated with lake snow, which is an extracellular polysaccharide excreted by the algae that can lead to formation of a visible mucilage. This mucilage was observed on intake screens, treatment plant instruments, water pipes, water meters and household fittings.

Lake Wanaka water is classified as being oligotrophic, or of good quality. However, treated water does not meet the Drinking Water Standards for New Zealand (DWSNZ), as it has no protozoal removal process. Its normally low turbidity (approximately 1 NTU) and low suspended solids content present some challenges to conventional water treatment when it comes to the clarification process.

The Actiflo trial was part of a wider investigation by QLDC into a solution for the drinking water supply in Wanaka, and in particular, the removal of algae to reduce the risk of the algae nuisance and meeting the DWSNZ requirement of 3- log protozoal treatment. The purpose of this trial was to demonstrate that the Actiflo process was a suitable clarification step, and capable of providing achievable water quality standards using a small footprint clarifier.

Actiflo was identified as a suitable clarification technology for trial at Wanaka after a review of overseas experience. Removal rates of 99% algae were shown to be obtainable in Florida in the United States (Robinson and Fowler, 2006), with settled water turbidities of less than 1 NTU. A conventional clarifier, producing settled water with a turbidity of less than 2 NTU, is considered to be a well performing clarifier (Ministry of Health, 2016).

1.2 ACTIFLO PROCESS DESCRIPTION

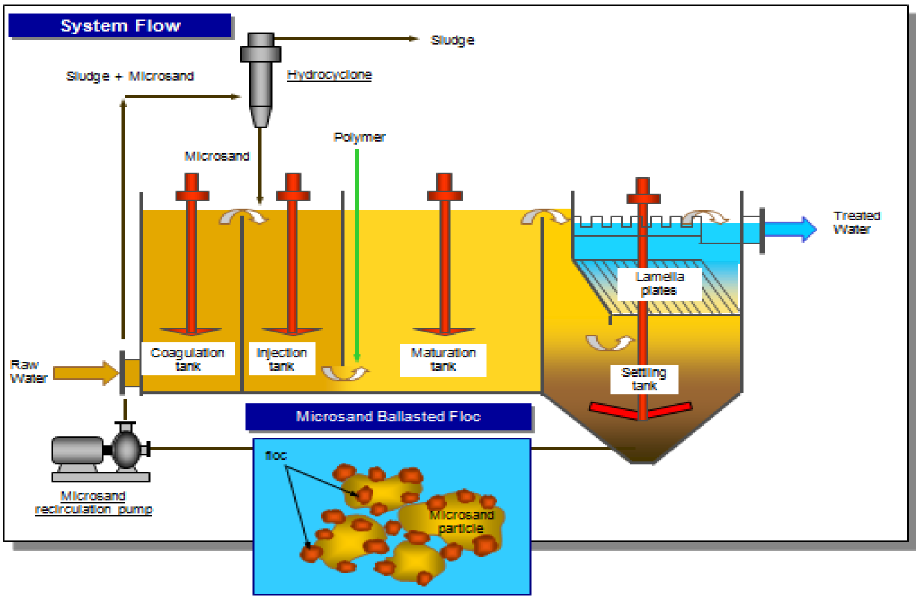
The Actiflo process is a compact high rate clarification system that utilises micro-sand enhanced flocculation (MEF) combined with lamella settling. The traditional processes of coagulation, flocculation and settling are employed, however Actiflo also uses two further processes to improve rapid floc settling:

- Micro-sand particles, which provide a large surface area and act as a seed for floc formation whilst also providing weight, which increases the settling velocity of the floc;

- Lamella settling, which increases the clarifier area within a small settling tank by using sloping tubes that also aid rapid floc settlement.

The Actiflo process for drinking water applications can be operated at a rise rate of 40-60 m/hr. The schematic diagram is shown below:

Figure 1: Actiflo Process Diagram



In this process:

1) Raw water is first dosed with a coagulant prior to entering the coagulation tank;
2) The coagulated water is mixed again in the injection tank where polymer is added;
3) The water then flows into a maturation tank, where micro-sand ballasted floc forms and matures. Within this tank the water receives further mixing, enhanced by the installation of a draft tube surrounding the maturation tank mixer (not shown in Figure 1);
4) Micro-sand ballasted floc then enter the settling tank. In the settling tank the floc settles rapidly to the bottom of the tank. Settled water flows up through the lamella tubes and passes over a weir before leaving the Actiflo unit;
5) The sludge/micro-sand mixture collected at the bottom of the settling tank is pumped to the hydrocyclone, which separates the micro-sand from the sludge by centrifugal force. The recovered clean micro-sand is then recycled into the maturation tank, whilst the separated sludge is continuously discharged.

1.3 CHEMICALS

Jar testing was undertaken prior to the start of the pilot plant commissioning in order to identify the optimum coagulant and polymer for use in the trial. Micro-sand and the chemicals listed in Table 1 were used in the preliminary jar testing.

Table 1: List of Chemicals used in Jar Testing

Chemical	**Type**	**Form**
Coagulant	Poly Aluminium Chloride (PACL) 34% w/w	Solution
	Aluminium sulphate 49% w/w	Solution
	Ferric Chloride	Solution
Polymer	Polymer A (Cationic)	Powder
	Polymer B (Anionic)	Powder

According to the preliminary jar testing and the relevant total algae count analysis, dosing PACL (coagulant) at 12 g/m^3, with polymer A at 0.1 g/m^3 and with a micro-sand concentration of 5 g/L, achieved an algae removal of 99.6%. Therefore PACL and polymer A were selected for conducting the pilot plant trial. In addition, the pH of the sample after dosing with PACL and without any pH adjustment was 7.2, which is acceptable in terms of both process and treated water pH. It was therefore decided that pH adjustment could be avoided in the pilot plant trial.

1.3.1 POLYMER BATCHING

Polymer was batched and dosed on site using chemical tanks and a dose pump installed inside the pilot unit (Photograph 2). The batching process consisted of adding a known quantity of solid polymer to make-up water to achieve the desired concentration of 0.05 %. Batches were prepared in the batching tank at the end of each day and left to mature overnight. The required agitation was provided by a mixer in the polymer batching tank (Photograph 3).

Photograph 2: Pilot Unit

Photograph 3: Polymer Batching Tank

1.3.2 MICRO-SAND

The micro-sand used during the trial was 0.10-0.25µm at a sand concentration of 5g/L.

This sand was recycled via the recirculation pump and hydrocyclone.

1.3.3 CHEMICAL DOSE CALCULATIONS

All chemical dosages were checked by performing draw-downs. A draw-down test measures the volumetric dose rate of the chemical being dosed into the system via the dose pump. Chemical is added to a measuring cylinder, and the time taken to drain a known volume is recorded. This value can then be converted to ml/min.

2 ACTIFLO PILOT TRIAL

The pilot trial was organized and delivered as a joint project between the local Veolia Queenstown Operation Team and the Veolia Project Technical Assets Group (PTAG). The Operation Team were responsible for initial site preparation, plant installation and ongoing operation for 3 months. PTAG provided the technical and training support, including commissioning of the pilot plant on site.

The trial objectives included testing of:

1) Settled water quality (the percentage of algae removal achievable) - pH and turbidity were also recorded;

2) Optimum coagulant dose rate of PACL;

3) Optimum dose rate of Polymer A;

4) Testing of alternative Polymer C (cationic), Polymer D (non-anionic) and Polymer E (anionic);

5) Maximum flow rate (a range of the pilot plant flow rates of between 5.0 m^3/hr and 7.5 m^3/hr were tested, equivalent to clarifier rise rates of between 40 m/hr and 60 m/hr).

3 TRIAL SYSTEM SETUP

The Veolia containerised pilot plant was installed adjacent to the Beacon Point Intake wet-well on the shore of Lake Wanaka. Raw water was fed to the plant from a submersible pump installed in the intake wet-well. The Actiflo settled water was returned to the intake wet-well, and waste sludge was fed by gravity to a temporary plastic storage tank beside the pilot plant (Photograph 4). Stored waste sludge was removed by tanker to the wastewater treatment plant.

Photograph 4: Trial Unit Laydown Area showing the Plastic Sludge Tank

After commissioning of coagulant and polymer dosing, the plant trial was started. Visual inspection of the floc formation was made through a window installed in the bottom of the settling tank. This enable the operator to visually assess the floc size being produced (Photograph 5).

Photograph 5: Inspection Window at bottom of Settling Tank
Showing Floc Formation and Sludge Scraper

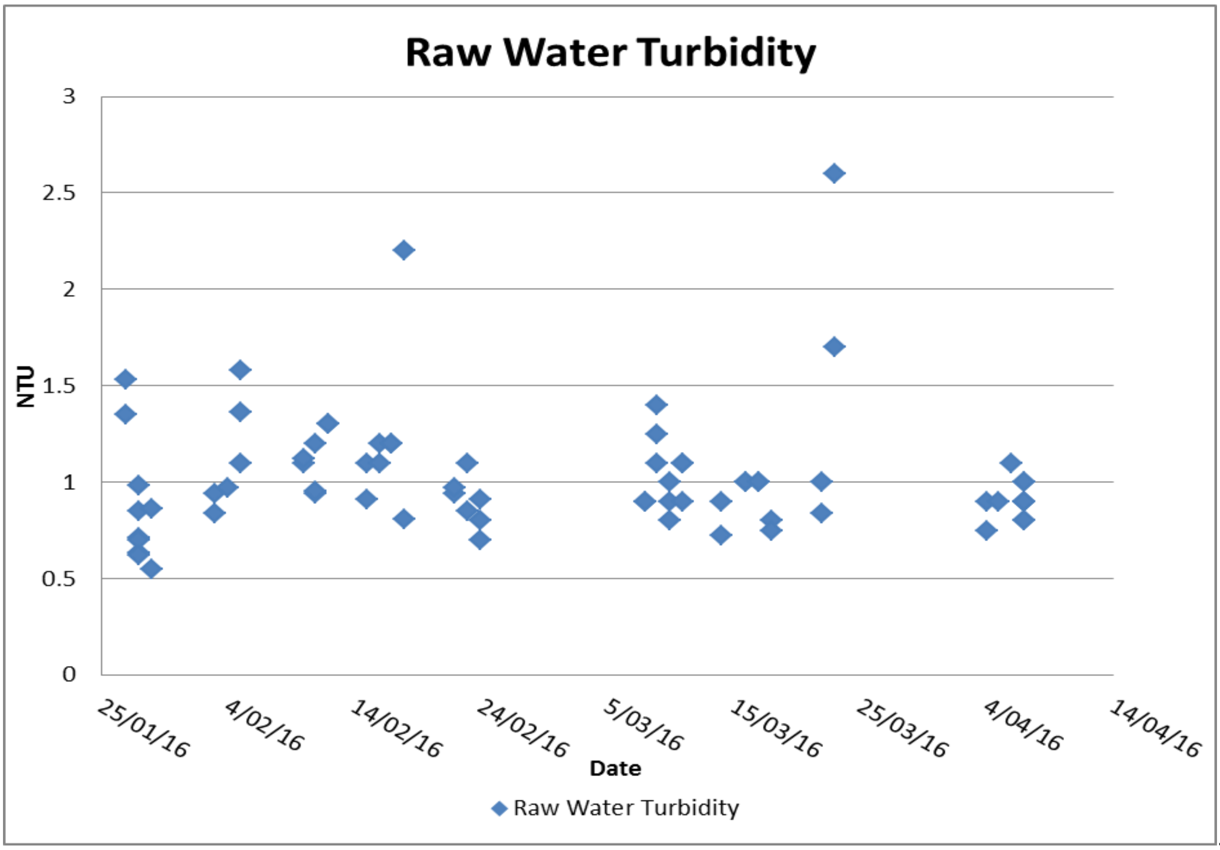
4 TRIAL RESULTS

During the operation, records were taken of the impact of flow changes and chemical dose rates. By varying these parameters separately, it was possible to determine the optimum settings for each parameter.

4.1 RAW WATER QUALITY

The data presented in Figure 2 below shows the variation in the raw water turbidity sampled throughout the day. During the trial, the raw water turbidity was relatively stable at around 1 NTU, with the exception of two occasions (18/02/16 and 23/03/16) where turbidity increased to over 2 NTU for a short period. Heavy rain was noted on the 18/02/16 occasion.

Figure 2 – Raw Water Turbidity



A summary of the range of recorded raw water parameters is shown in Table 2 below. A table of all raw water results is included in Appendix A.

Table 2: Summary of Raw Water Parameters

	Daytime Temperature ^{0}C	pH	Turbidity NTU	Total Algae Count Cells /ml
Minimum	15.0	7.0	0.55	62
Maximum	18.0	7.4	2.60	860
Average	16.2	7.2	1.03	282
Median	16.0	7.2	0.95	200

Grab samples of raw water were collected and analysed for total algae cell counts. The resuts are shown in Figures 3.1 and 3.2 below.

Figure 3.1 – Raw Water Total Algae Counts

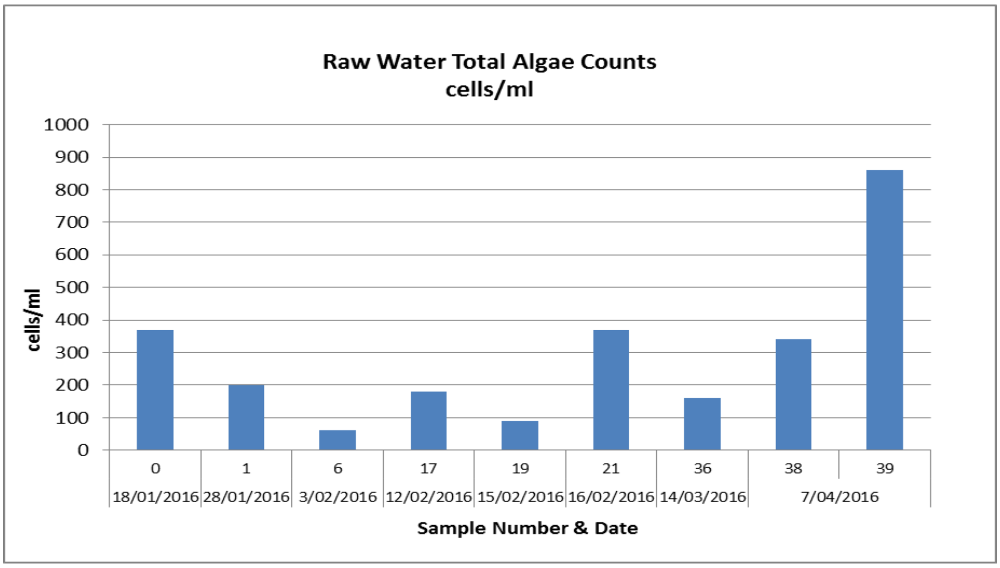
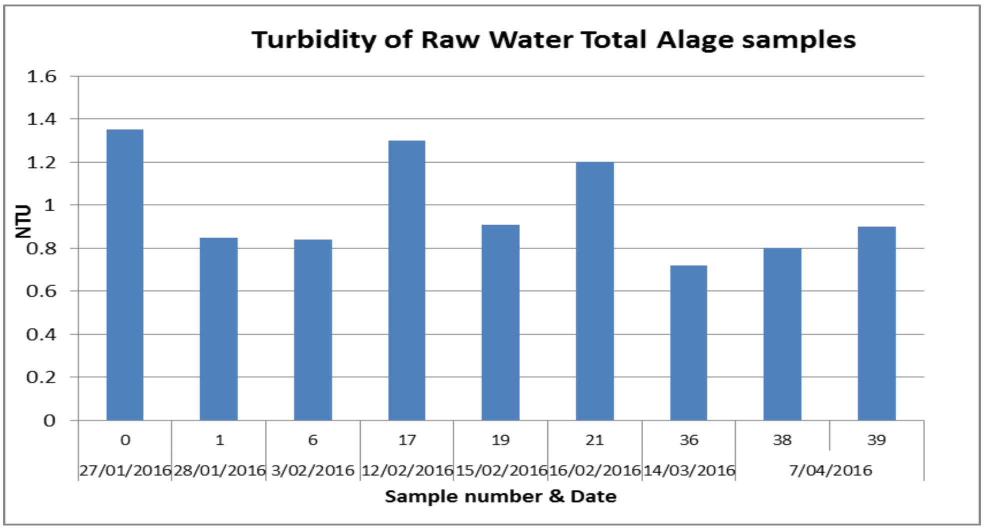


Figure 3.2 – Turbidity of Raw Water Total Algae Count Samples



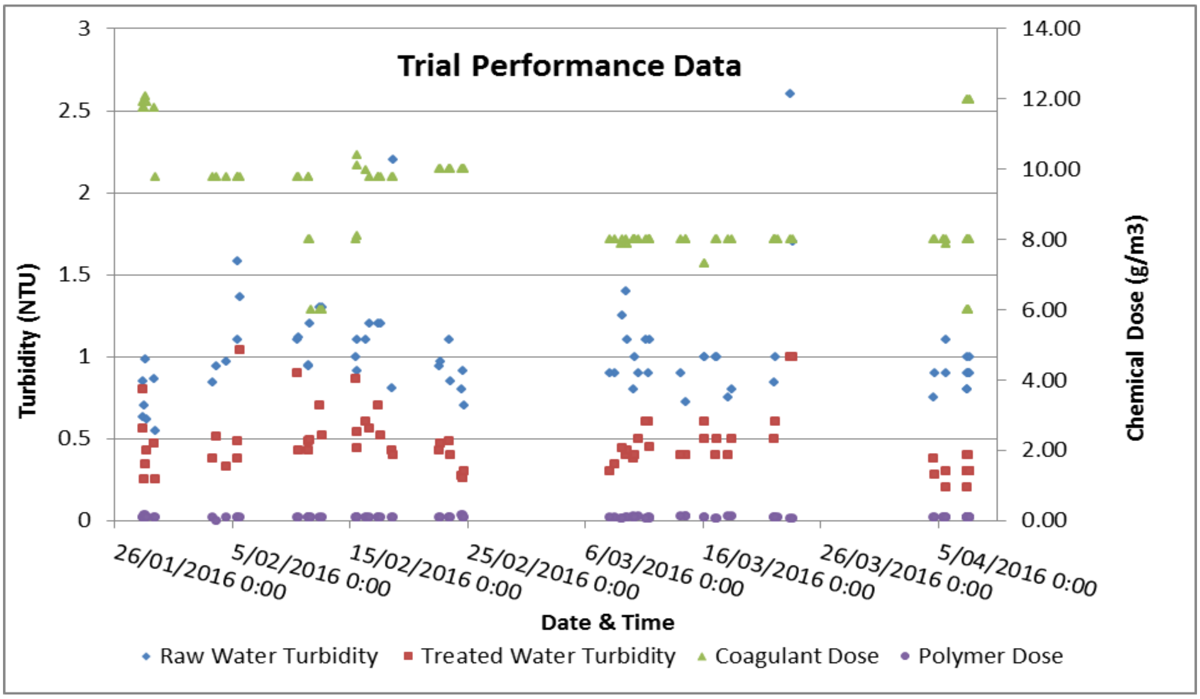
The majority of results were less than 400 cells/ml and less than 1 NTU. However it was suspected that algae number were variable throughout the day, so two set of samples were taken on 7/04/2016. Sample 38 (340 cells/ml) was taken at 10:00am in the morning, and sample 39 (860 cells/ml) at 1:40pm in the afternoon. These two samples demonstrate the wide variation in algae concentration that could possibly occur through the day. The significant increase in algae cell count on the afternoon of the 7/04/16 was due the prevalence of the cyanobacteria aphanocapsa.

4.2 ACTIFLO PERFORMANCE

Figure 4 below summarises Actiflo operating data collected. It was observed that the raw water turbidity could change rapidly. It is important to note that the algae concentrations were expected to fluctuate between morning and afternoon as the algae moved through the water column in response to sunlight, however these changes were not reflected in changes of inlet turbidity.

In order to manage these fluctuations it may be beneficial in a full scale plant to control the dose rates basis on other raw water quality data measures or operational parameters, such as stream current or spectral data.

Figure 4 – Trial Performance Data



The coagulant and polymer dose rates, plus the clarifier rise rate through the pilot plant, were also varied. These changes were made to determine their effects on performance, and are discussed in the sections below.

4.3 COAGULANT DOSING OPTIMISATION

The data presented in Figure 5 and Figure 6 below was collected to compare different dose rates and to further optimise the coagulant chemical usage. The PACL dosing changes were carried out at the maximum plant flow of $7.5m^3$/hr, corresponding to a clarifier rise rate of 60 m/hr. The results show that PACL dose rates of 8 g/m^3 and 10 g/m^3 both produced good quality settled water with algae counts of < 3 cells/ml, and with a turbidity of 0.4-0.5 NTU (raw water approx. 0.9 NTU) . It was observed that with 8 g/m^3 and 10 g/m^3 coagulant dosing, the floc from the coagulation process was forming properly. While coagulant dosing at 10 g/m^3 was good, 8 g/m^3 was considered to be optimum, with 97% algae removal and >50% turbidity removal.

Figure 5 – Coagulant Dose Rate Vs Treated Water Turbidity

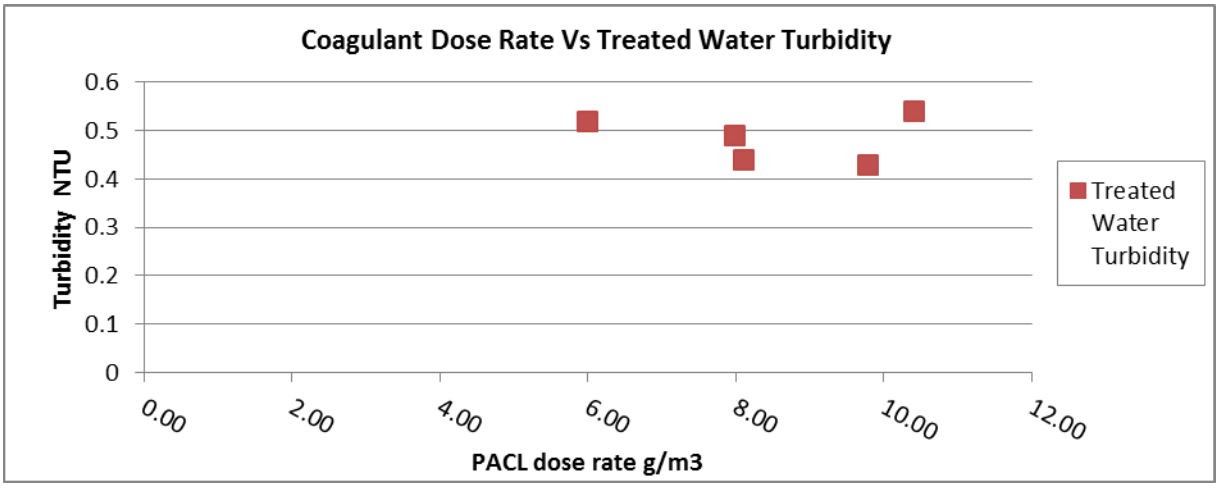
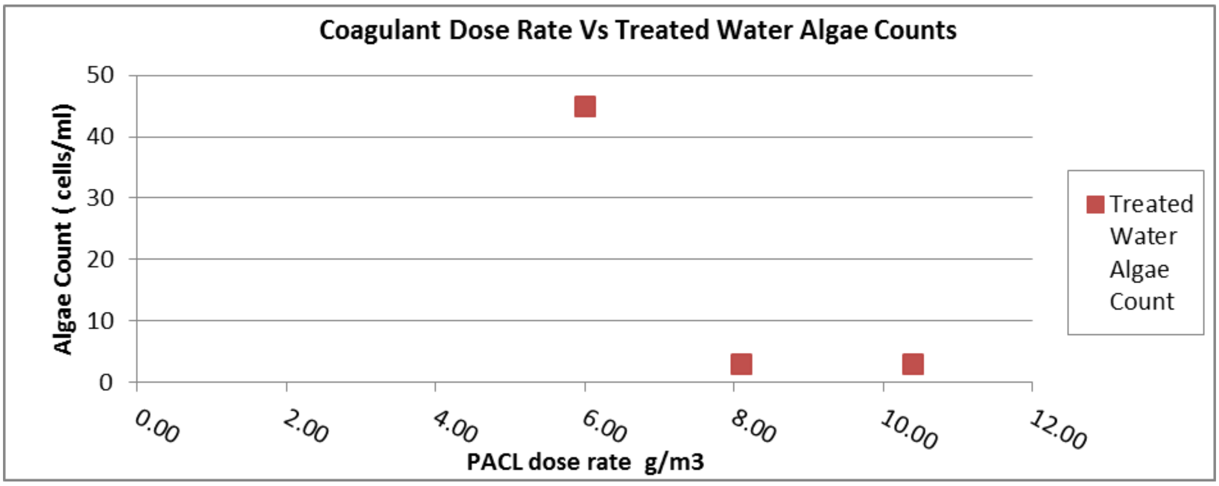


Figure 6 – Coagulant Dose Rate Vs Treated Water Algae Counts



4.4 RISE RATES

The plant was also operated at different flow rates to determine the impact that changes in clarifier rise rate would have on the settled water quality. Figures 7 and Figure 8 show the results whilst maintaining constant coagulant and polymer doses. All rise rate testing was carried out at dose rates of 10 g/m^3 PACL and 0.1 g/m^3 polymer A .

Figure 7 – Treated Turbidity Vs. Clarifier Rise Rate

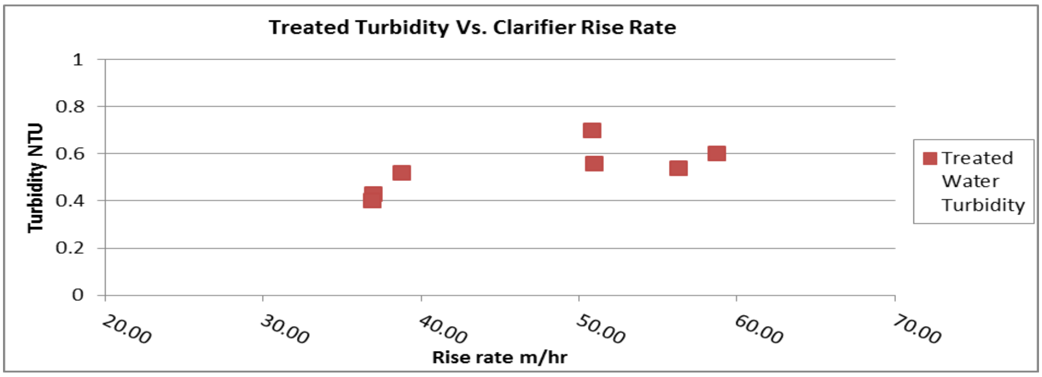
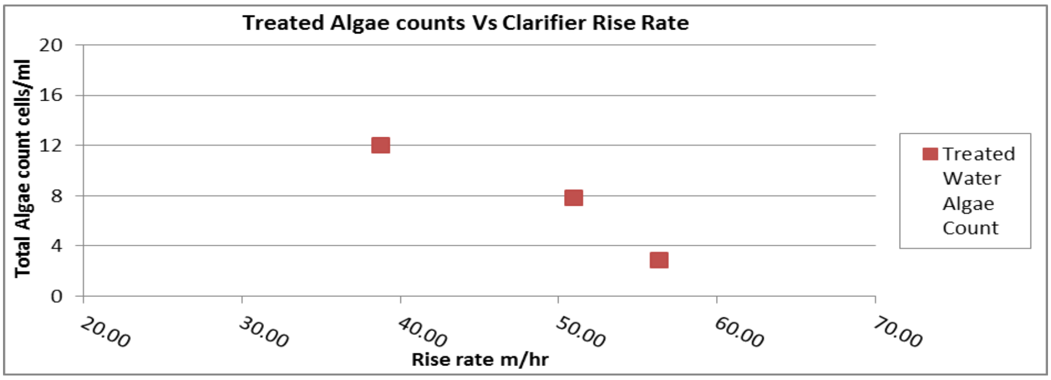


Figure 8 – Treated Algae Counts Vs Clarifier Rise Rate

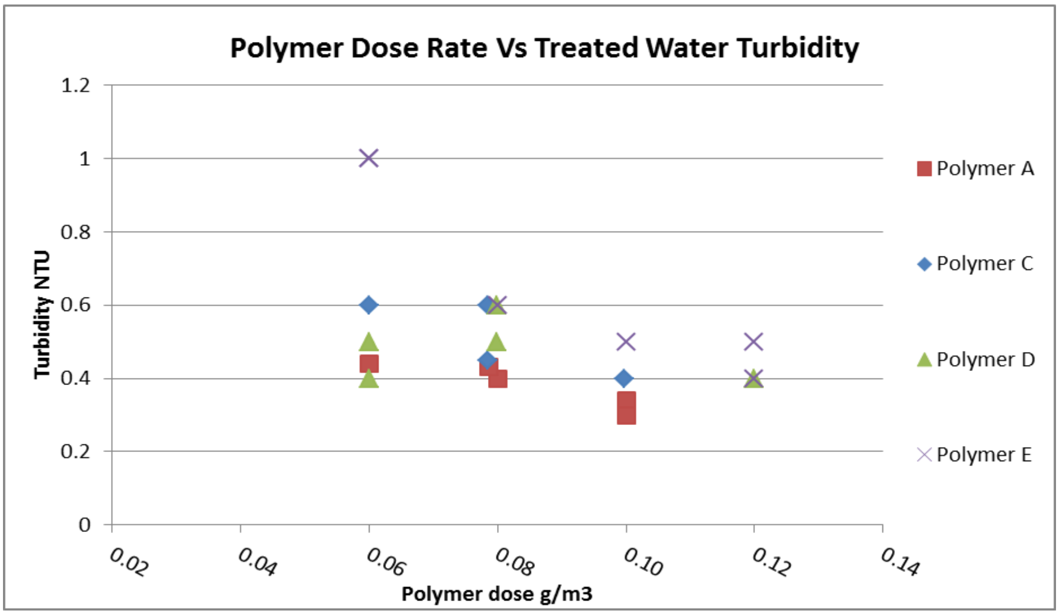


Increasing the rise rate from 40 to 60 m/hr slightly increased the turbidity from 0.4 NTU to 0.6 NTU. However turbidity removal rates for all rise rate tests were > 50%. Increasing the rise rate did not significantly affect the settled water algae counts, with algae cell counts all low and between 2.0 cells/ml and 12.0 cells/ml. The algae removal efficiency at 50 m/hr was 98% (raw water algae count 370 cells/ml). The Actiflo rise rates used during this test are much higher when compared to other conventional clarifier rise rates of 2 to 12m/hr (Ministry of Health, 2016).

4.5 POLYMER DOSING

The data presented in Figure 9 was collected to compare different polymer dose rates, and also compare other available polymers. With a smaller polymer pump installed, it was possible to accurately vary the polymer doses rate from 0.06 g/m^{3}to 0.12 g/m^3. This polymer testing was carried out with a coagulant dose rate of 8 g/m^3 and rise of approximately 50 m/hr.

Figure 9 – Polymer Dose Rate Vs Treated Water Turbidity

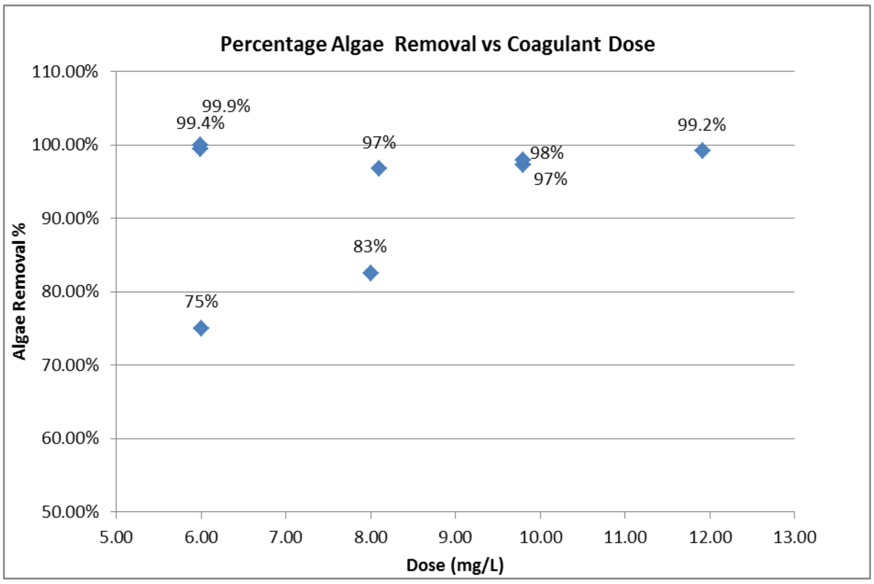


The results suggest that both floc formation and turbidity removal was best using Polymer A at a dose rate of 0.10 g/m^3. The floc formed was larger with polymer A, and a lowest turbidity of 0.3 NTU was achieved.

4.6 ALGAE REMOVAL

The data presented in Figure 10 shows variation in percentage algae removal with coagulant dose.

Figure 10 – Percentage Algae Removal vs Coagulant Dose



In general, doses of between 6 g/m^3 and 12 g/m^3 produced good algae removal rates of greater than 97%. The two lowest removal rates observed resulted from changes to operating parameters used to test the performance of the plant. The 75% removal was at the lowest coagulant dose rate of 6 g/m^3 and the highest rise rate of 60 m/hr. This suggests an increased dose rates is required to maintain settled water quality at higher rise rates. The 83% removal was the result of a change in polymer to Polymer C. With this polymer, the floc observed forming in the settling tank was not as dense when compared to that using Polymer A.

The lowest turbidity reduction of 6% was seen with the PACL dose of $12g/m^3$. This may be due to carry over of floc into the samples when it was collected, especially as the following sample had consistent turbidity reduction of 65%.

Sample results for total algae cell counts, and the related operating parameters, are summarised in Table 3.

Table 3: Summary of Algae Removal and Operating Parameters

Date	Time	Raw Water Algae Cells/ml	Settled Water Algae Cells/ml	Algae Removal %	Rise Rate m/hr	PACL Dose g/m^3	Turbidity Reduction %
28/01/16	11:00	200	1.70	99.15	54	12	6
28/01/16	14:30	Not taken	6.40	N/A	57	12	65
29/01/16	11:00	Not taken	0.19	N/A	58	10	55
03/02/16	09:00	62	1.70	97.26	58	10	55
12/02/16	14:30	180	45.00	75.00	56	6	60
15/02/16	14:00	89	2.90	96.74	58	8	52
15/02/16	15:30	Not taken	2.90	N/A	56	10	51
16/02/16	15:00	370	7.80	97.89	51	10	53
17/02/16	14:00	Not taken	12.00	N/A	39	10	57
23/02/16	13:00	Not taken	14.00	N/A	53	10	53
14/03/16	12:00	160	28.00	82.50	49	8	44
07/04/16	10:15	340	2.00	99.41	44	6	75
07/04/16	13:00	860	0.55	99.94	44	6	56

The best turbidity and algae removal were obtained with a coagulant dose rate of 6 g/m^3 at the 44m/hr rise rate on the 07/04/16. The performance at the lower dose rate of 6 g/m^3 was also at a low rise rate, and 8 g/m^3 is still consider optimum as it provided the best performance (and therefore flexibility) at the higher rise rates of 50 to 60m/hr.

5 CONCLUSIONS

Key objectives for the trial were:

- To assess the ability of the Actiflo process in removing algae;
- To assess the ability of the Actiflo process at a variety of flows and therefore clarifier rise rates;
- To determine the best treatment combination of coagulant chemicals, and;
- To determine specific chemical dose rates for optimum plant performance.

The pilot plant trial was conducted with a range of chemical types and included evaluation of the optimum dose rates for PACL and polymer, and rise rates for the clarifier. These parameters are considered the most critical for sizing of a full scale plant. Additional settled water parameters monitored during the trial were pH, turbidity, and pre and post treatment algal cell count.

The trial enabled the following conclusions to be made;

- The Actiflo process produced a settled water of good quality for the duration of the trial, with a median algae reduction of 97.6 %, and median settled water turbidity reduction of 54.5%;
- These results were achieved over a variety of feed rate flows equivalent to a clarifier rise rates of 40 m/hr to 60 m/hr;
- The best results were achieved using a Poly Aluminum Chloride (PACL) coagulant and a mid molecular weight cationic polymer A;
- The optimum treatment chemical was a combination of the above coagulant and polymer, at dose rates of 8 g/m^3 and 0.1 g/m^3 respectively.

The trial was successful and proved the suitability of the Actiflo clarification technology for the removal of algae from the raw water abstracted at the Beacon Point Intake. The technology was able to adapt to the variety of raw water conditions, whilst continuing to produce a settled water of good quality.

ACKNOWLEDGEMENTS

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APPENDIX A- RESULTS OF RAW WATER ANAYLSIS

Date	Time	Lab Sample No	Turbidity NTU	Daytime Temperature ^{0} C	pH	Total Algae Count Cells /ml
18/01/16	N/A	0	1.24	Not taken	7.30	370
27/01/16	13:00	n/a	1.35	Not taken	Not taken	Not taken
27/01/16	15:30	n/a	1.53	Not taken	7.08	Not taken
27/01/16	07:12	n/a	0.71	Not taken	7.05	Not taken
28/01/16	08:30	n/a	0.63	Not taken	7.17	Not taken
28/01/16	11:00	1	0.85	Not taken	7.00	200
28/01/16	13:00	n/a	0.70	Not taken	7.00	Not taken
28/01/16	14:30	n/a	0.98	Not taken	7.00	Not taken
28/01/16	16:30	n/a	0.62	Not taken	7.00	Not taken
29/01/16	09:30	n/a	0.86	Not taken	7.00	Not taken
29/01/16	11:00	n/a	0.55	Not taken	7.10	Not taken
3/02/16	09:00	6	0.84	Not taken	7.20	62
3/02/16	15:30	n/a	0.94	Not taken	7.20	Not taken
4/02/16	13:00	n/a	0.97	Not taken	7.20	Not taken
5/02/16	11:00	n/a	1.58	17.3	7.20	Not taken
5/02/16	11:30	n/a	1.10	Not taken	7.20	Not taken
5/02/16	15:00	n/a	1.36	16.6	7.20	Not taken
10/02/16	12:45	n/a	1.10	16.6	7.22	Not taken
10/02/16	15:00	n/a	1.12	16.7	7.20	Not taken
11/02/16	11:00	n/a	0.94	17.0	7.20	Not taken
11/02/16	11:45	n/a	0.95	17.0	7.20	Not taken
11/02/16	14:45	n/a	1.20	17.0	7.23	Not taken
12/02/16	11:30	n/a	1.30	17.0	7.35	Not taken
12/02/16	14:30	17	1.30	18.0	7.34	180
15/02/16	14:00	19	0.91	Not taken	7.26	89
15/02/16	15:30	n/a	1.10	18.0	7.23	Not taken
16/02/16	09:20	n/a	1.10	18.0	7.20	Not taken
16/02/16	15:00	21	1.20	18.0	7.30	370
17/02/16	09:40	n/a	1.20	17.0	7.26	Not taken
17/02/16	14:00	n/a	1.20	18.0	7.20	Not taken
18/02/16	13:15	n/a	0.81	18.0	7.20	Not taken
18/02/16	15:15	n/a	2.20	17.5	7.20	Not taken
22/02/16	13:00	n/a	0.94	16.5	7.14	Not taken
22/02/16	15:30	n/a	0.97	16.0	7.10	Not taken
23/02/16	9:30	n/a	1.10	16.0	7.10	Not taken
23/02/16	13:00	n/a	0.85	16.0	7.10	Not taken
24/02/16	12:00	n/a	0.80	17.0	7.10	Not taken
24/02/16	13:50	n/a	0.91	17.0	7.10	Not taken
24/02/16	15:30	n/a	0.70	17.0	7.10	Not taken
8/03/16	12:30	n/a	0.90	17.0	7.10	Not taken
8/03/16	15:00	n/a	0.90	16.0	7.20	Not taken
9/03/16	10:30	n/a	1.40	15.0	7.10	Not taken

Date	Time	Lab Sample No	Turbidity NTU	Daytime Temperature ^{0} C	pH	Total Algae Count Cells /ml
9/03/16	12:50	n/a	1.10	16.0	7.10	Not taken
9/03/16	15:45	n/a	1.25	16.0	7.10	Not taken
10/03/16	11:15	n/a	0.90	16.0	7.10	Not taken
10/03/16	13:30	n/a	0.80	Not taken	7.10	Not taken
10/03/16	15:40	n/a	1.00	Not taken	7.10	Not taken
11/03/16	08:45	n/a	0.90	15.0	7.20	Not taken
11/03/16	11:40	n/a	1.10	16.0	7.20	Not taken
11/03/16	15:25	n/a	1.10	Not taken	7.20	Not taken
14/03/16	12:00	36	0.72	Not taken	7.10	160
14/03/16	15:20	n/a	0.90	16.0	7.20	Not taken
16/03/16	14:15	n/a	1.00	15.0	7.20	Not taken
16/03/16	15:30	n/a	1.00	15.0	7.20	Not taken
17/03/16	14:15	n/a	1.00	15.0	7.10	Not taken
17/03/16	15:30	n/a	1.00	15.0	7.20	Not taken
18/03/16	11:30	n/a	0.80	Not taken	7.20	Not taken
18/03/16	14:30	n/a	0.75	16.0	7.30	Not taken
22/03/16	14:00	n/a	0.84	16.0	7.25	Not taken
22/03/16	15:40	n/a	1.00	16.0	7.30	Not taken
23/03/16	10:00	n/a	2.60	Not taken	7.30	Not taken
23/03/16	13:45	n/a	1.70	16.0	7.20	Not taken
4/04/16	13:00	n/a	0.75	Not taken	7.30	Not taken
4/04/16	15:30	n/a	0.90	15.0	7.30	Not taken
5/04/16	15:30	n/a	0.90	15.0	7.30	Not taken
6/04/16	15:30	n/a	1.10	Not taken	7.30	Not taken
7/04/16	09:30	n/a	0.80	15.0	7.40	Not taken
7/04/16	10:15	38	0.80	15.0	7.40	340
7/04/16	11:00	n/a	0.90	15.0	7.30	Not taken
7/04/16	11:40	n/a	1.00	15.0	7.20	Not taken
7/04/16	13:00	39	0.90	Not taken	7.40	860
7/04/16	13:40	n/a	0.90	15.0	7.40	Not taken
7/04/16	14:30	n/a	0.90	15.0	7.30	Not taken
7/04/16	15:20	n/a	1.00	15.0	7.20	Not taken