UPGRADING A DIRECT FILTRATION TREATMENT PLANT WITH UV

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ABSTRACT

The township of Picton is served by two water treatment plants – Essons Valley and Speeds Road. The Essons Valley plant is a direct filtration plant constructed in 1994, and draws from a surface water dam source. The paper describes the upgrading of this plant with the addition of UV disinfection to meet the Drinking Water Standards for New Zealand, as well as a range of other upgrading measures to improve the plant's operability, serviceability and reliability. The paper illustrates the range of issues that need to be considered when upgrading small surface water treatment plants.

KEYWORDS

Picton, Essons Valley, water treatment, upgrading, Drinking Water Standards for New Zealand

1 INTRODUCTION

Picton, including Waikawa, has a population of approximately 4550 and is located in the Marlborough Sounds. Picton is well known as the South Island connection for the Cook Strait ferries. The town is also a popular summer holiday destination and hub for Queen Charlotte Sound.

Water is supplied to Picton from two separate sources, an aquifer at Speeds Road 12km to the south and the Waitohi Stream, Essons Valley just out of town to the southeast. Each source has its own water treatment plant (WTP). At Speeds Road the shallow groundwater is treated with chlorine and pH corrected with lime. Prior to the 2011 upgrade described in this paper, Essons Valley Water Treatment Plant (EVWTP) consisted of coagulation – direct filtration, chlorination and pH correction with lime. Barnes Dam which impounds water in the Waitohi Stream, supplies raw water to EVWTP through twin 2160 metre (m) long pipelines.

EVWTP did not comply with the Drinking Water Standards for New Zealand 2005 (revised 2008) (DWSNZ). Options were reviewed to upgrade the plant with consideration being given to affordability and reliability. EVWTP operates at 55 m of head from Barnes Dam and does not 'break' this pressure. A booster pump is required but only 19 m head is needed to deliver the treated water into the reticulation. It was hoped that the upgrade to the treatment plant would maintain pressure, thereby avoiding the energy loss that 'breaking pressure' would incur.

Barnes Dam catchment is steep and bush clad. There is no agriculture and no vehicle access. The resource consent for EVWTP permits a take of 34 litres per second (L/s). The plant operates at a fixed flow which is typically set just below the consent limit, giving a nominal capacity of 2,800 m^3/day. The shallow aquifer at Speeds Road operates at up to 57 L/s full capacity. The pumps at Speeds Road have to operate at 90 to 100 m head, making energy input much higher than at Essons Valley, however EVWTP requires more operator input and treatment chemicals. Consideration is given to operating costs when deciding how to operate the two WTPs. This will need revising and optimising when both WTPs are upgraded to meet the DWSNZ. Speeds Road bores are not secure, the aquifer is shallow, however given the good water quality, and from experience with other groundwater in the region, UV disinfection without filtration is likely to meet the DWSNZ.

Significant rainfall causes runoff and increase in turbidity in Barnes Dam. This invariably coincides with rainfall in Picton given the close proximity of Barnes Dam catchment. Rainfall in Picton reduces demand for garden watering. If raw water quality in Barnes Dam prevents EVWTP operating the Speeds Road WTP is used to supply the town.

A 3000 m³ reservoir has recently been constructed on Victoria Domain bringing the total treated water storage to 5800 m³. Figure 1 shows the reticulation and reservoir locations.

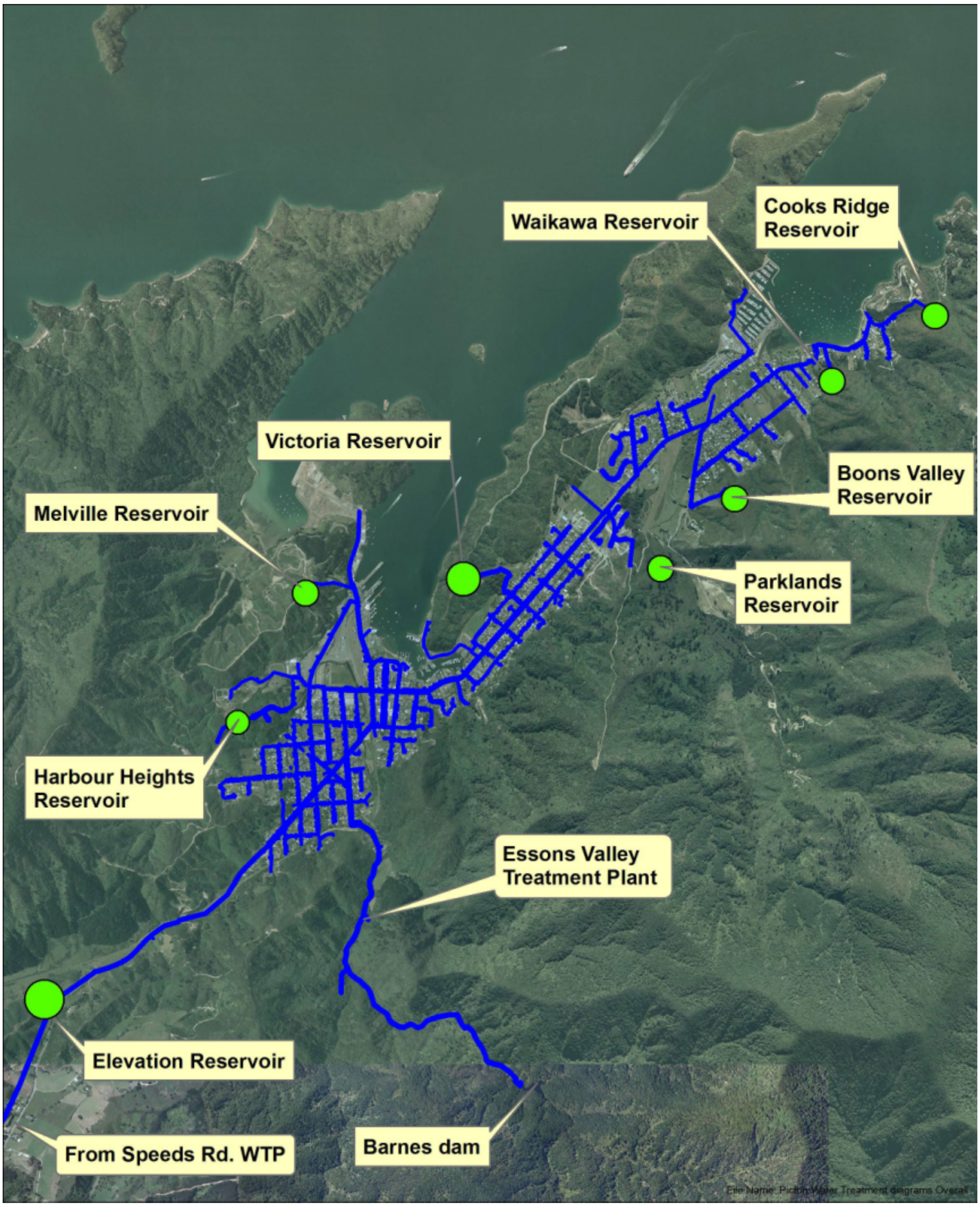

Figure 1: Picton Reticulation and Reservoirs

2 ESSONS VALLEY WTP PRE-UPGRADE

The Waitohi Stream was first used as a source of water for Picton in the 1890s. In 1952 the current 15 metre high concrete dam was built. The dam, known as Barnes Dam, has a 4.3 km² catchment. Treatment in the early years involved passing raw water through a coarse screen and chlorination.

In 1994 a filtration plant was built under a design and build contract. In 2002 the filter media was replaced using sand and thermally modified pumice and backwashing improved with a higher capacity pump. Filter performance and run time were improved.

Prior to the 2011 upgrade, EVWTP consisted of:

- Barnes Dam raw water storage
- Compressor and air line to the dam to control thermal stratification
- Coagulation and flocculation
- Four dual media pressurised filters
- Lime dosing
- Chlorine dosing
- Backwash facilities
- Booster pump

Figure 2 shows the location of the facilities. Barnes Dam is accessed via a 1.9 km walking track from the end of the vehicle access near the compressor shed. The power supply terminates at the compressor shed.

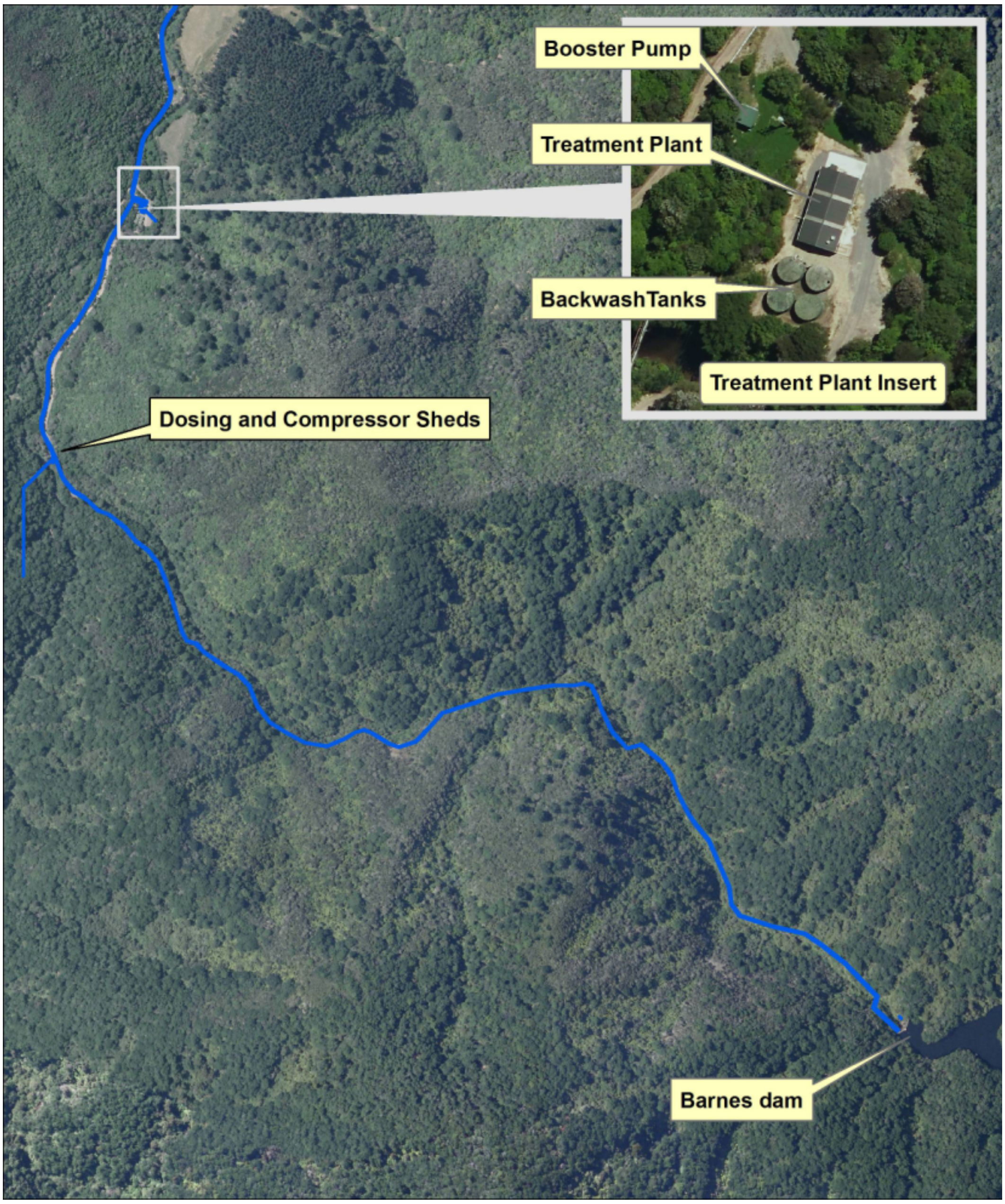

Figure 2: Essons Valley Water Treatment Plant and Barnes Dam

Four tanks are located next to the water treatment plant. Two store water for backwashing the filters while the other two hold the backwash wastewater. The wastewater is pumped to the town sewer at a controlled rate.

No treated water is stored at the EVWTP, the water being boost pumped directly to the reticulation.

Operation of EVWTP pre 2011 was largely manual. The plant did shutdown automatically for high turbidity and other selected alarms and when the Elevation Reservoir reached its high level setpoint.

3 DRINKING WATER STANDARDS COMPLIANCE - ISSUES & OPTIONS

3.1 REQUIREMENTS OF THE DRINKING WATER STANDARDS

The Drinking Water Standards for NZ 2005 (revised 2008) (DWSNZ) specifies criteria for compliance for:

- Protozoa
- Bacteria

- Cyanotoxins
- Chemicals
- Radionuclides

Treated water from a surface water source must comply with the following to obtain an A grading according to the Public Health Grading of Community Drinking Water Supplies 2003.

- Protozoal compliance
- E.coli compliance
- Chemical (Priority 2) monitoring compliance
- Disinfection
- Record keeping
- Compliance with chemical (Priority 2) Maximum Allowable Values (MAV)
- Appropriate supervision
- Continuous quality control

3.2 PROTOZOA

3.2.1 PROTOZOA COMPLIANCE

Protozoa including Giardia and Cryptosporidium are Priority 1 under the DWSNZ due to their public health significance.

The Barnes Dam catchment is bush clad and has no agriculture. Based on Table 5.1a of DWSNZ the catchment requires a treatment log credit of 3, meaning the treatment process must provide 3 log removal or inactivation of the reference organism, Cryptosporidium.

The DWSNZ gives maximum log credits for various recognised water treatment processes and specifies performance requirements. The existing plant is classified as coagulation-direct filtration treatment process which can achieve 2.5 log credits subject to the following criteria being met for each filter:

- Continuous monitoring of turbidity
- Turbidity not greater than 0.3 NTU for more than 5% of the time over the compliance monitoring period
- Turbidity not greater than 0.5 NTU for more than 1% of the time
- Turbidity not greater than 1.0 NTU for the duration of any three minute period

An analysis of data from EVWTP for the period February 2006 to January 2007 showed that the turbidity exceeded 0.3 NTU 34% of the time the plant was running compared with a 5% limit. The 0.5 NTU limit was exceeded 3% of the time compared with the 1% limit. Clearly the plant was not meeting the requirements for a log credit of 2.5.

Table 1 summarises the maximum log credits that a range of treatment processes can achieve under the DWSNZ.

Table 1 - Treatment Process: Maximum Log Credits under DWSNZ 2005 (Revised 2008)

Treatment Process	Maximum Log Credits
Coagulation/clarification/filtration	3.0
Coagulation/direct filtration	2.5
Second-stage filtration	+0.5
Enhanced combined filtration	+0.5
Enhanced individual filtration	+1.0
Diatomaceous earth	2.5
Slow sand filtration (without coagulation)	2.5
Membrane filtration	4.0 (typical, manufacturer and test dependant)
Cartridge filtration	2.0
Bag filtration	1.0
Chlorine dioxide disinfection	3.0 – does dependant credit
Ozone disinfection	3.0 – dose dependant credit
UV disinfection (at 254 nm)	3.0 – does dependant credit

Only two options were considered to be cost effective for EVWTP, UV disinfection and improved filter performance. Microfiltration was also considered but discounted due to significantly higher cost.

3.2.2 UV DISINFECTION

UV reactors must be validated and the log credits assigned by one of the following:

- 3 log credits for reactors validated against DVGW technical standard W294, oNORM M5873-1, or NSF/ANSI 55-2002; or
- Up to 3 log credits following the requirements of the Ultraviolet Disinfection Guidance Manual (USEPA 2006b)

The turbidity of the water entering the UV reactor must not exceed:

- 1 NTU for more than 5% of every month.
- 2 NTU for the duration of any 3 minute period

3.2.3 UPGRADE EXISTING FILTERS

Upgrading of the existing coagulation and direct filtration could provide 2.5 log credits which is insufficient to meet the 3 log credits required. Up to one additional log credit could potentially be gained if the performance of the filters could be further improved to achieve enhanced individual filtration or up to 0.5 additional log credit for enhanced combined filtration. Monitoring and turbidity limits are more rigorous than for the 2.5 log credit for coagulation direct filtration.

3.2.4 ALTERNATIVE PROTOZOA TREATMENT PROCESSES

Three cost effective alternatives were considered for protozoa compliance:

1. UV disinfection and improve coagulant dosing. Compliance by UV achieving 3 log credits.

2. Improve filtration performance and add UV. Compliance achieved by filtration 2.5 log credits plus UV 3 log credits ie; 5.5 log credits in total.

3. Improve filtration to enhanced combined filter performance, turbidity <0.15 NTU for 95% or more of the time, and improved monitoring. Compliance achieved by 3 log credits for enhanced filtration. Note there is no UV in this option.

3.2.5 ADOPTED PROTOZOA TREATMENT PROCESS

Given existing plant performance and the minimal depth of filter media, the third option for enhanced filtration was not considered further.

The first alternative was adopted for the following reasons:

- The most easily achievable alternative and lowest cost.

- A robust process with multiple barriers which gives good public health protection without the need for additional monitoring of the filtration process which alternative 2 would require.

3.3 BACTERIAL COMPLIANCE

Bacterial compliance can be achieved if chlorine is dosed continuously into the filtered water and 30 minutes contact time in a clearwater tank and/or pipeline is achieved before the first consumer. Alternatively if the protozoal compliance requirements are met with UV and the dose is 40 mJ/cm^2 or higher, then bacterial compliance is also achieved.

Upgrade for Bacterial Compliance

Because there was insufficient chlorine contact time and it would have been expensive to provide additional time, and the decision had been made to achieve protozoal compliance with UV, the method adopted for bacterial compliance in the upgrade was UV.

It is important to note that the wording in DWSNZ in relation to using UV to achieve bacterial compliance needs to be clearer if the UV reactor is validated under the USEPA “Ultraviolet Disinfection Guidance Manual”. Clause 4.3.5 of DWSNZ states: “If the protozoal compliance requirements are met with UV light using a dose equivalent to 40 mJ/cm2, bacterial compliance is automatically achieved, ….”. By “dose equivalent to” it means a “reduction equivalent dose” (RED) when using Bacillus subtilis or MS2 phage as the test organism”.

3.4 CYANOTOXINS

Cyanotoxins are the toxins produced by cyanobacteria (blue-green algae). The presence of cyanobacteria does not mean that cyanotoxins are present but they may be.

Algal blooms could lead to a proliferation of cyanobacteria with the potential for cyanotoxins. Blooms occur when sunlight, nutrients and temperature conditions become optimal. Such conditions have previously led to algal blooms in Barnes Dam and cyanobacteria have been detected.

The water in Barnes Dam can stratify and provide conditions conducive to algal blooms. Thermal stratification of the deeper water behind the dam can deplete the oxygen which can then allow contaminants including ammonia, phosphorus, iron and manganese to be released from sediments and this can lead to increased algal growth.

To prevent thermal stratification, a compressor supplies air through a 1760 m long pipeline to the dam to produce an air curtain. Due to the remoteness of the dam and the difficulties providing a reliable power supply there had never been any instrumentation or communications.

For over 10 years operators had routinely visited the dam to take DO and temperature measurements and take samples for laboratory analysis including phytoplankton counts.

Upgrade to Manage Cyanotoxins

The upgrade would reduce the frequency of operator visits to the dam with the introduction of a power supply, instruments and radio communication. This would ensure the operators would have some knowledge of water quality at the dam through SCADA (System Control and Data Acquisition).

A draft cyanobacteria management plan was lodged with the drinking water assessor.

3.5 CHEMICAL

Chemical compliance criteria in the DWSNZ are set to avoid determinands reaching concentrations that would pose a risk to public health. These are known as Priority 2 (P2). Priority 2a includes chemicals that could be introduced through the treatment process, Priority 2b includes chemicals present in the raw water that treatment doesn't remove and disinfection by-products and Priority 2c are chemicals arising from corrosion, primarily corrosion of household plumbing.

Currently the Picton water supply has no P2 determinands that require specific monitoring.

4 OPERATIONAL AND PERFORMANCE ISSUES

4.1 IDENTIFYING THE ISSUES

The EVWTP was known to have operational and performance issues. To ensure the best outcome from the upgrade, all the issues with the plant were evaluated and decisions made on how to improve the operation and performance.

CH2M Beca engineers discussed the operation and performance of the plant with the operators, analysed the data from SCADA and made their own observations. From this came recommendations for improvements.

4.2 CHLORINE DOSING

Several issues were identified with the chlorine dosing system including potential under and overdosing at plant startup. Overdosing could be combined with higher turbidity at plant startup which could result in formation of disinfection by-products, including THMs (trihalomethanes).

4.2.1 CHLORINE SYSTEM UPGRADE

- Install a new chlorine analyser in the booster pump shed to allow some residence time from the dosing point immediately downstream of the UV reactor.

- Install new dosing line and dosing point.

4.3 FILTER RUN TIMES

An analysis of filter run times during 2006 showed that 44% of runs were less than one hour (ignoring runs that commenced and terminated almost immediately). Following backwashing the operator would operate the plant to waste before going 'online'. Frequently the plant would trip out on high turbidity within 30 minutes of producing water for supply. Of the filter runs that exceeded one hour, 38% ran for 1 to 10 hours and 57 % ran for 11 to 18 hours. Not all filter runs ended due to high turbidity. For example, EVWTP shuts down when high water level set point in the Elevation Reservoir is reached.

Analysis of typical summer and winter data from 2006 and 2007 is shown in table 2.

Table 2 – EVWTP Shutdown Causes

Shutdown for	% in Summer	% in Winter
Turbidity >0.5 NTU	37	31
Short run after backwash (turbidity >0.5 NTU)	33	17
Reservoir full	30	52

Filter Run Time Improvements

- Improve automated filter-to-waste.
- Filter resting following backwashing.

4.4 COAGULATION AND FLOCCULATION

Coagulant polyaluminium chloride (PACl) and coagulant aid Crystalfloc L3RC were being dosed to the raw water close to the filters in pipework with relatively high water velocity. A longer delay time was needed between the PACl and L3RC dosing points, with lower velocities to enhance coagulation.

Coagulation and Flocculation Upgrade

- Construct new dosing shed upstream of filter plant to give increased delay time.
- Dose coagulant into single pipeline for increased velocity before the raw water flow goes back to twin pipelines for low velocity, low turbulence prior to the filters.
- Install coagulant static mixer at the PACl dosing point (and upstream of the LR3C dosing point).
- Run trials to optimise performance and coagulant/coagulant aid ratio.

4.5 BACKWASH

This manual operation took the operator an hour or more. All four filters were backwashed with the treatment system shutdown. Approximately 20 m^3 of clean water was being used per filter over five minutes. This gave 5.9 bed volumes for 750 mm thick filter media.

Backwash Upgrade

Semi automatic operation using a programmable logic controller (PLC). All the valves for air scouring and backwashing are set manually by the operator. The operator acknowledges on the operator interface, the human machine interface (HMI), that the valves are correctly set before the control will move on to the next stage. Each filter is air scoured and backwashed before moving on to the next filter.

Air scour is time controlled.

Backwash is controlled by the PLC in the following manner. The operator sets the proportion of the backwash supply tank volume that each filter is to use, and the flow rate which the backwash pump will control at, plus a reduced flow rate at start up and shutdown of the backwash process.

The PLC control assists the operator and ensures consistent backwashing of all four filters.

4.6 FILTER-TO-WASTE

At start up following backwash the operator would run the plant to waste until the turbidity was less than 0.5 NTU, and then change over to supplying the reticulation. At this point the booster pump would start. Sometimes the turbidity would spike above 0.5 NTU and shut the plant down.

The backwash clean water tanks refilled with treated water from the reticulation.

Filter-to-Waste Upgrading

- Redirect filter-to-waste water to the backwash supply tanks for filter backwashing.
- Fit large capacity overflow from backwash supply water tank to the stream.
- Obtain resource consent for discharge to the stream including the need to ensure chlorine dosing not active while operating filter-to-waste. Filter-to-waste is directed to the backwash supply tanks and if those tanks overfill, the overflow is piped to the stream.
- Automate the filter-to-waste process including automatic startup of the UV reactor, chlorination system, and lime dosing. Automatic changeover to supply the reticulation.

4.7 RAW WATER PIPELINES AND BARNES DAM

If the plant was operating when rainfall in the catchment caused the turbidity in the dam to rise, turbid water would be drawn into the twin 2160 m long 225 mm diameter raw water pipelines. With no online water quality monitoring at the dam the water in the raw water pipelines would rise in turbidity until the treatment plant could no longer treat it, at which point the plant would shut down. The raw water pipelines would then require manual scouring.

Raw Water Pipelines and Barnes Dam Improvements

- Add a scour so each raw water line can be separately manually scoured.
- Install turbidimeter, level transducer, power supply and communications to Barnes Dam.
- Install temperature sensors at the dam over a range of depths to monitor thermal stratification, and used to automatically start aeration of the dam when stratification is detected.

4.8 LIME DOSING

The lime system comprised a single tank and mixer with manual make up using 25 kg bags of hydrated lime, duty-standby dosing pumps and water flushing system. The water flushing system was of limited use and effectiveness.

Lime Dosing Upgrade

Install new dosing line and injection point.

5 PLANT UPGRADE

5.1 DWSNZ REQUIREMENTS

The primary driver for the upgrade was to comply with the DWSNZ for protozoa and bacteria. In addition the upgrade was to enable the treatment plant to be considered for an 'A' grading. This required improvements to be made as described in this section.

5.2 CHOSEN UPGRADE

The chosen upgrade was to improve filter performance and install a UV reactor after the filters. The UV would achieve the 3 log credits needed for protozoa compliance. The filters would not provide any log credits. The UV would also provide bacterial compliance with the chlorine dosing retained for reticulation residual.

The following outlines the key components of the upgrade:

- Improved monitoring of water quality parameters, including raw water turbidity measurement at Barnes Dam and at the new dosing shed.
- Power generation at the dam site to feed instruments and telemetry.
- Reconfiguration of filter-to-waste arrangement and addition of overflow and manual top-up line to the backwash supply tank.
- Additional health and safety measures including chlorine room ventilation and safety shower/eyewash facilities.
- Relocation and optimisation of coagulation/flocculation process.
- A new shed to house coagulant and coagulant aid dosing.
- New UV disinfection reactor to inactivate potential pathogens in the raw water and provide 3 log credits for Cryptosporidium inactivation under DWSNZ (a single duty unit). UV would also provide bacterial compliance.
- Reconfiguration of lime dosing to correct pH and reduce corrosivity of the water (minor modifications to the existing plant).
- Communications and control upgrades to support and integrate the above process units.
- Significant replacement of main panel, addition of PLC control, field instrumentation and instrumentation cabling.

5.3 WATER QUALITY MONITORING AND UV REACTOR

Prior to designing the upgrade, UV transmittance (UVT) and turbidity were monitored online to determine UV reactor performance requirements. The UV reactor was specified to achieve 3 log credit for Cryptosporidium inactivation at the plant design flow rate and for UVT of 80%/cm and greater. This provided some conservatism from the actual UVT measured but did not cause excessive oversizing of the UV reactor.

5.4 MONITORING

For compliance with the DWSNZ the following would be monitored continuously:

- UV transmittance (UVT)
- Turbidity
- UV intensity (UVI)
- Flow
- Lamp outage and faults
- Free available chlorine (FAC)
- pH

Additional monitoring was included in the upgrade to assist with plant operation.

6 PLANT CONTROL, COMMUNICATIONS AND DATAACQUISITION

6.1 PLANT CONTROL

Control is a mixture of semi automatic and automatic functions. Backwash is semi automatic, the cost of fully automating backwash was considered against the saving in operator time and was found to be uneconomic. Backwash automation would be relatively expensive because the plant has four individual filters and more than twenty valves would require actuators. The valves that would require actuation are fitted to unsupported solvent welded PVC pipework. The PVC pipework is considered unsuitable for unmanned automated valve actuation.

Following backwash the operator is required to confirm valves are correctly set on the HMI before selecting WTP operation. Once selected, the filter-to-waste and then the change over from filter-to-waste to online (to the reticulation) is automatically controlled by the PLC. Shutdown of the plant is automatic based on alarm conditions occurring or high Elevation Reservoir water level.

The plant will also start automatically on low water level setpoint in the Elevation Reservoir if the previous plant stop was on reservoir high level and water quality at the time was within acceptable limits ie; the plant did not stop on high turbidity or other alarm conditions. In this instance and if raw water turbidities are acceptable, the plant will automatically go to filter-to-waste and then online.

6.2 FILTER-TO-WASTE REUSE

Filter-to-waste when the filters are being run offline in preparation for going online, is directed to the clear water backwash tanks to be used for backwashing. This makes use of water which would have previously been discharged to the stream. The clear water backwash tanks have a large capacity high level overflow to the stream to prevent overfilling

6.3 RAW WATER TURBIDITY

Raw water turbidimeters are installed at the dosing shed and at Barnes Dam. Each meter has high and high-high alarms. The high alarms warn the operator of rising turbidity. The high-high alarms shut down the plant, although the operator may elect to override either or both so the plant remains operating. The concept of plant shutdown is to prevent the substantial length of raw water pipelines from filling with turbid water.

6.4 BARNES DAM TEMPERATURE AND LEVEL

Five temperature sensors are suspended into the water at the dam. Sensors are separated 1.25 m vertically. A level transducer is also submerged in the water. The PLC at the water treatment plant checks the temperature differential across each pair of submerged sensors. If the absolute difference of any pair exceeds a setpoint value and the thermocline control is selected, the compressor will run according to the option chosen on the HMI to deliver air into the dam to prevent a thermocline developing.

The level sensor also allows the PLC to calculate and display the remaining volume of water.

6.5 BARNES DAM POWER SUPPLY AND COMMUNICATIONS

The dosing shed communicates with the main water treatment plant building by Ethernet over fibre optic cable. The dosing shed has a duplicate HMI to that in the MCC room at the main treatment plant building.

Radios at the main water treatment plant and Barnes Dam send data to, and receive data from, the base at Council's office in Blenheim. This enables communications between the dam and the treatment plant.

Power supply is from solar panels and using the existing compressed air system to the dam to operate an air motor driving a generator. The two power sources charge a battery bank. The control offers the operator a range of options for sharing the air supply between battery charging and thermocline control in the dam.

Like most remote Council facilities there has been a history of vandalism at the Barnes Dam site. To reduce the risks of damage to, or theft of, the new equipment there is a locked gate at the top of the stairs to prevent access to the dam crest. The equipment other than the solar panels and instrumentation is housed in a locked chainlink enclosure. The solar panels are mounted high on a pole on the dam crest to be out of reach of anyone who does gain access. There are two battery powered security cameras operated by motion sensors. It is hoped the cameras will act as a deterrent.

7 PERFORMANCE

Since the completion of the upgrading the plant performance has improved considerably. Runs of less than one hour (including aborted starts) have reduced by 60%. The short runs are now rarely to do with turbidity, but are most often to do with chlorine or pH, and occasionally the UV. There is still scope to fine tune the start up control to further reduce the number of stoppages and increase the plant's utilisation.

The total cost of the upgrading was $1.5 million, considerably less than the cost of a new plant of this capacity.

8 CONCLUSIONS

This case study shows that filtration plants that struggle to meet the DWSNZ protozoal compliance criteria for turbidity can be cost-effectively brought into compliance by the addition of a UV disinfection step. The filtration process then essentially acts as a pre-treatment step to meet the DWSNZ requirements for the UV feedwater quality.

While such plant upgrading work is often triggered by the need to achieve DWSNZ compliance, the case study shows that there can be many other issues that also must be addressed in order to meet operability, serviceability and reliability needs.

ACKNOWLEDGEMENTS

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