INNOVATIVE WASTEWATER TREATMENT SYSTEMS FOR EXTREME ALPINE ENVIRONMENTS

Dr Matt Savage (Apex Water Ltd)

ABSTRACT

Sewage treatment systems in the New Zealand alpine environment have a history of failure due to the biological systems utilised being unable to work effectively under the low temperatures and highly seasonal loads encountered.

With tightening regulatory compliance requirements, such failures are becoming less tolerable and a higher level of resilience must be engineered in to overcome these challenges.

A new treatment plant in Cardrona Valley servicing the village, Cardrona Alpine Resort Limited and a 500 house development at Mt Cardrona Station was built last year and has now worked through its first full winter.

The site is exposed to seasonal extremes in ambient temperature ranging from below -8°C to more than +30°C, resulting in wastewater temperatures too low for traditional biological treatment systems to function.

This was addressed by construction of a hybrid SBR / fixed biofilm reactor that utilised a novel thermodynamic solar heating system.

The SBR is operated at an extended sludge age to maximise nitrification and denitrification at low temperatures, and the fixed biofilm growing on bioblock media in the bottom of the reactors continues to nitrify down to a lower critical temperature than suspended growth biomass in the SBR.

After operating from July 2021 project completion through the 2021 – 2022 season, the plant was shown to successfully treat the influent to compliance with all consent parameters right down to the lowest recorded incoming sewage temperatures of 1.3°C.

Treated wastewater qualities of <4mg/L Total Nitrogen, <5mg/L BOD5, <25mg/L Suspended Solids and <1mg/L Total Coliforms are regularly achieved by this plant, therefore providing not only an increase in treatment capacity, but a significant improvement in treatment performance from the Baxter sewage treatment plant which previously served the village alone.

KEYWORDS

Sewage treatment, cold climate, consent compliance, alpine environment, seasonal, sustainable heating

INTRODUCTION

Located 550m above sea level, Cardrona Village is nestled in a valley between the Pisa and Cardrona mountain ranges. The village has undergone significant growth in recent years and an additional 500-house subdivision significantly larger than the village itself is currently under development at Mt Cardrona Station.

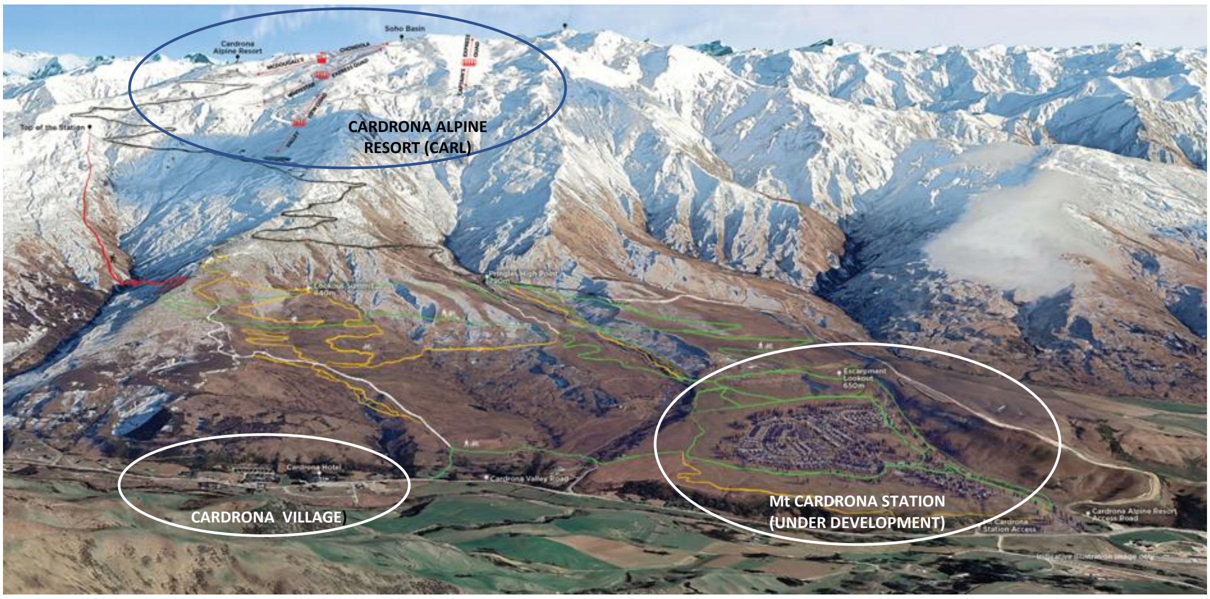

Figure 1 Cardrona Valley viewed from the east showing the three sources of influent to the new wastewater treatment plant (Mount Cardrona Station 2022)

The village has historically been serviced by the Baxter sewage treatment plant, which is no longer able to cope with the load, and Cardrona Alpine Resort Limited (CARL) has previously treated and discharged their wastewater on site.

With the village having grown beyond the capacity of the current treatment plant and the addition of the new 500-house development, opportunity arose to both service growth in the village and centralise treatment of the wastewater from CARL's ski field facilities. The decision was therefore made to construct a centralised wastewater treatment plant (WWTP) to treat combined wastewater from all three sources.

	Cardrona Village	Mt Cardrona Station	Cardrona Alpine Resort	Combined
Average Annual Flow	78 m^3/day	178 m^3/day	50 m^3/day	305 m^3/day
Peak Dry Weather Flow	151 m^3/day	345 m^3/day	55 m^3/day	552 m^3/day
Peak Wet Weather Flow	302 m^3/day	691 m^3/day	110 m^3/day	1,103 m^3/day

Table 1 Design inflow for Cardrona WWTP

The plant was constructed by the developers of Mt Cardrona Station, and vested in Council (QLDC) after completion.

THE CHALLENGE

The key challenge in designing a biological treatment system for the Cardrona Valley is the extreme climate and accordingly low sewage temperatures.

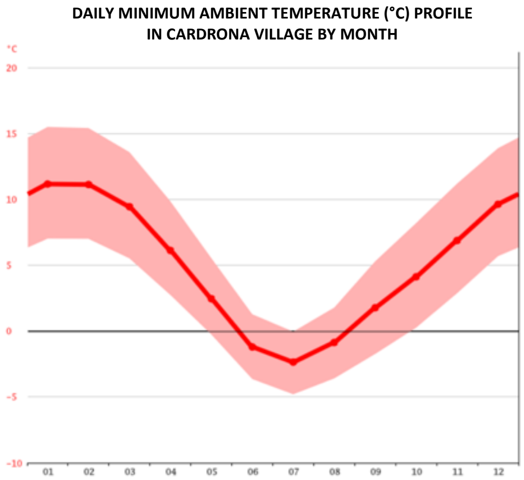

Figure 2 Annual Profile of daily minimum temperature of Cardrona Village by month (Climate-Data.org 2022)

The design envelope for the treatment plant was also heavily impacted by the large contribution of the local hotel / restaurant, and the relatively small permanent population. Pre-design sampling indicated an influent design envelope for the wastewater from the village with $cBOD_5$ concentrations peaking over 4,500mg/L and TN reaching over 150mg/L, which are approximately 20-times and 3-times the strength of domestic sewage respectively:

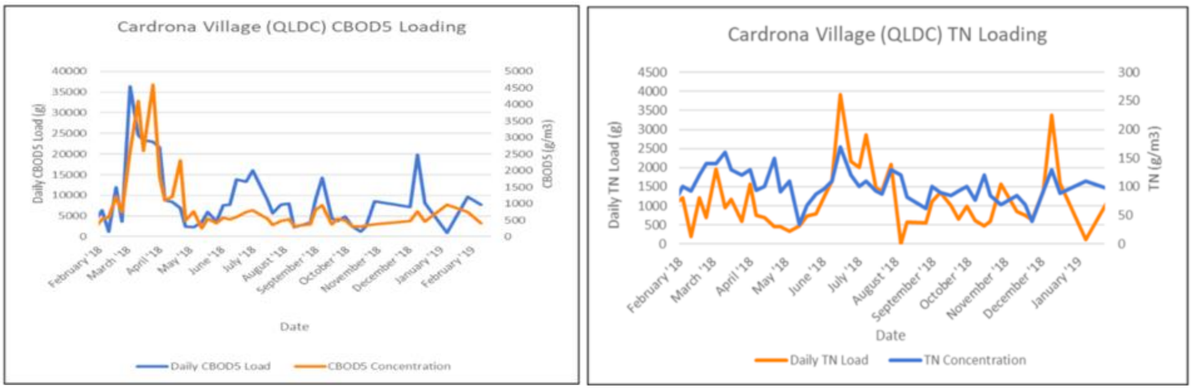

Figure 3 Influent characteristics specified for design of treatment plant for Cardrona Village wastewater

Even with the extreme strength of the wastewater measured, temperature remained the key design challenge for this plant, as it is widely accepted that nitrification becomes highly limiting below 10-15°C. Much of the design therefore focused on optimising the nitrification rate at low temperatures.

The design specification required was for successful treatment down to 7°C influent temperatures, but there was a low level of confidence that this would be the actual minimum temperature, based on low effluent flows during some of the coldest days of winter such as when the ski-field is closed due to poor weather resulting in low visitor numbers.

THE SOLUTION

A number of treatment technologies were evaluated in order to assess their suitability for addressing the challenges detailed above. These included Activated Sludge Process (ASP), Membrane Bioreactor (MBR), Recirculating Textile Reactor (RTF), Moving Bed Bioreactor (MBBR) and Sequencing Batch Reactor (SBR).

MBR and RTF were eliminated due to their sensitivity to low temperatures: MBR because the increased viscosity of water at low temperature significantly reduces membrane flux rates, and RTF due to the low thermal mass in the system making these reactors particularly susceptible to low winter night-time temperatures.

Activated sludge and MBBR were eliminated due to the highly seasonal flows and inflexibility of having fixed volume anoxic and aerobic processes under highly variable influent loading.

SBR was selected due to its high thermal mass, and inherent process flexibility:

The main advantages of SBR technology for this application include:

- The use of multiple variable volume reactors enables the total reaction volume to be reduced by up to 70% at times of low loading, such as during off season and early in the plant's operation before the subdivision is complete.
- The ratio of aeration to anoxic time to be adjusted based on the highly variable incoming nitrogen load.
- the settling time can be adjusted to match the settling characteristics of low temperature sludge which tends to be more bulky than is usually expected.
- The ratio of aerobic reaction time to anoxic reaction time to settling time can be adjusted on a day-to-day basis to suit the highly variable incoming wastewater quality.

The main disadvantages of SBR technology for this application include

- Suspended biomass has a higher critical nitrification temperature than attached biomass, therefore potentially limiting nitrification performance at the lowest temperatures expected.
- The SBR process has a larger footprint than an equivalent MBR or MBBR process.

In “Low Temperature Effects on the Nitrification in a Nitrogen Removal Fixed Biofilm Process Packed with SAC Media” (Se-Yong *et al*, 2013), the authors show that nitrification in low temperature suspended growth systems, such as SBRs or ASP can be compromised below 10°C with a risk of deflocculated activated sludge washing out with the clarified water. Biomass growing on fixed media however were shown to continue nitrifying down to temperatures as low as 5°C, with the reduction in specific nitrification rate only reducing by 41% when the operating temperature of the fixed media reactor was reduced from 20°C to 5°C

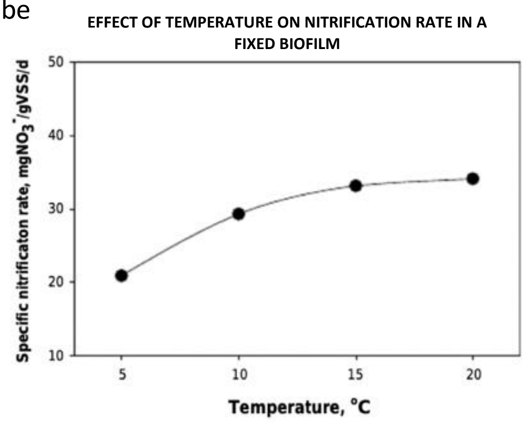

Figure 4 Specific nitrification rate in a fixed biofilm reactor as a function of temperature (Se-Yong et al, 2013),

Biowin® modelling of the proposed SBR process for Cardrona supported this finding with nitrification becoming the limiting step for consent compliance at temperatures below 10°C.

Figure 5 Bioblock media used in the SBR reactors

In order to combine the benefits of a fixed biofilm reactor with the versatility of the SBR solution, fixed biofilm media was incorporated into the SBR design by installing Bioblock media with a specific surface area of 250m^2/m^3 in the bottom of each SBR reactor. The bioblocks (Figure 5) are installed in modules of 48 blocks over each aeration lateral in the SBR to ensure aerobic nitrification occurs in the biofilm during aerations phases in the SBR. A top-down mixer is used to provide flow through the vertical flow paths in the media to facilitate denitrification during anoxic phases in the SBR.

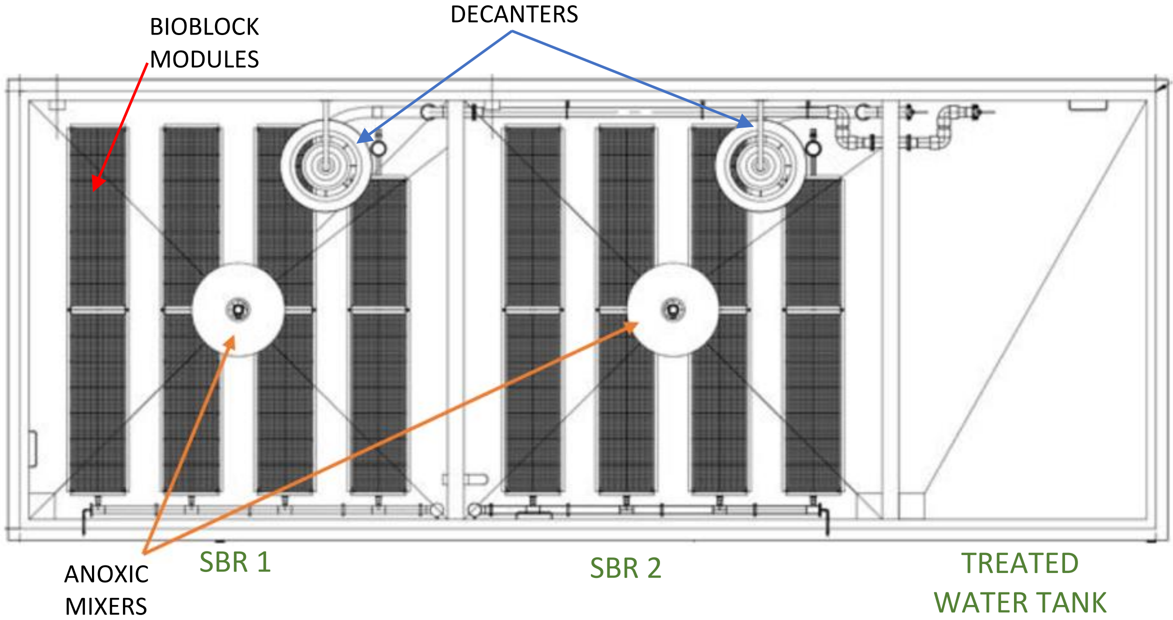

Figure 6 SBR layout incorporating Bioblock media

In total, approximately 24,000m^2 of biofilm support media was provided across the two SBR tanks.

In addition to the fixed biofilm media, the suspended growth biomass in the reactor is operated at a very high sludge age (>30 days) to maximise nitrification.

Figure 7 Bioblock installed in the bottom of the SBR tanks. In-tank heating coil shown to the right

Figure 8 Ski-field sewage storage pond from which discharge is sent to the Cardrona WWTP

In early years of operation, when flows into the treatment plant are low and largely consist of the existing flow from the village and a gradual discharge from the ski-field storage pond, the risk of incoming wastewater temperatures being below the 7°C design envelope limit were judged to be relatively high.

While heating sewage prior to treatment is usually considered too energy-intensive to be practical, for the Cardrona WWTP the projected sewage temperature is inversely related to flow into the plant. In the early years when flows are lowest (and therefore most practical to heat), the risk of the influent being too cold to treat is high. As the subdivision development comes on-line and flows increase (therefore making heating less practical), the wastewater temperature is also projected to increase above the minimum required for nitrification of the wastewater.

Based on this flow profile, the decision was made to insulate the buried walls and base of the SBR tanks, and heat the wastewater. Direct electric heating was eliminated as inefficient, gas heating was unacceptable due to the increased greenhouse gas emissions that would result, and thermal solar heating would be ineffective at the time of year when needed most.

Figure 9 Solar thermodynamic panels on the roof of the treatment plant building

Further research identified a novel type of water heating that combines the benefits of solar thermal water heating with those of a heat pump. Known as solar thermodynamic heating, this method employs solar panels on the roof of the treatment plant building, but instead of circulating the water to be heated through the solar panels, a refrigerant at -25°C is circulated through the panels. After evaporating in the solar panels, this refrigerant is returned to a heat pump unit, which compresses the refrigerant gas and condenses it in a heat exchanger. This is then used to heat a water circulation loop which in turn heats the reactor tanks via submerged heating coils (right hand side of Figure 7).

Because the solar panels operate at -25°C, they are able to extract heat from -5°C air, *even at night-time*, albeit with less efficiency than in full sunlight. Theoretically the panels can even extract heat from snow sitting on the panels but, due to the insulating properties of snow, this is the one condition that they do struggle with. For this reason, a back-up hot water heat-pump is installed in the heating loop that can be used when the panels are buried in snow.

RESULTS

As suspected during the design phase, the first full winter of operation showed that minimum influent temperatures were significantly lower than the 7°C initially projected. Especially low sewage flows due to the Covid lockdowns are likely to have contributed significantly to this in 2021:

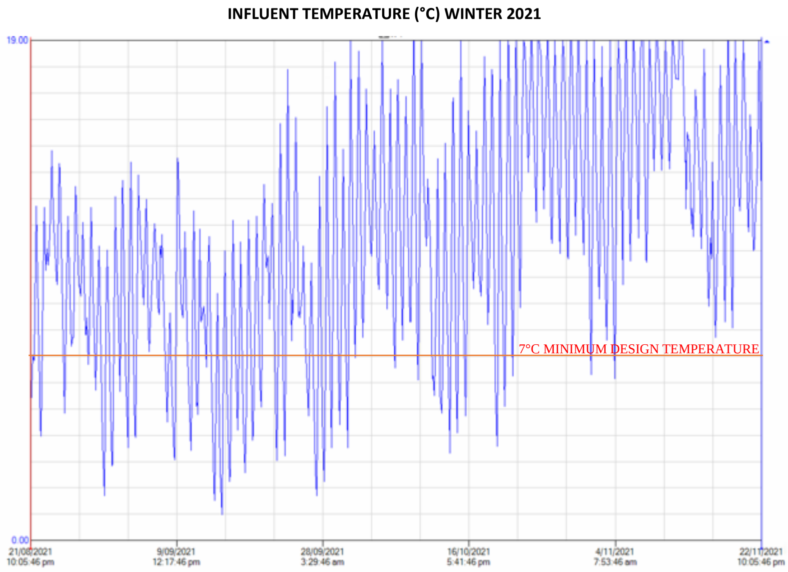

Figure 10 Influent temperature profile from commissioning completion in Aug 2021 through first winter of operation

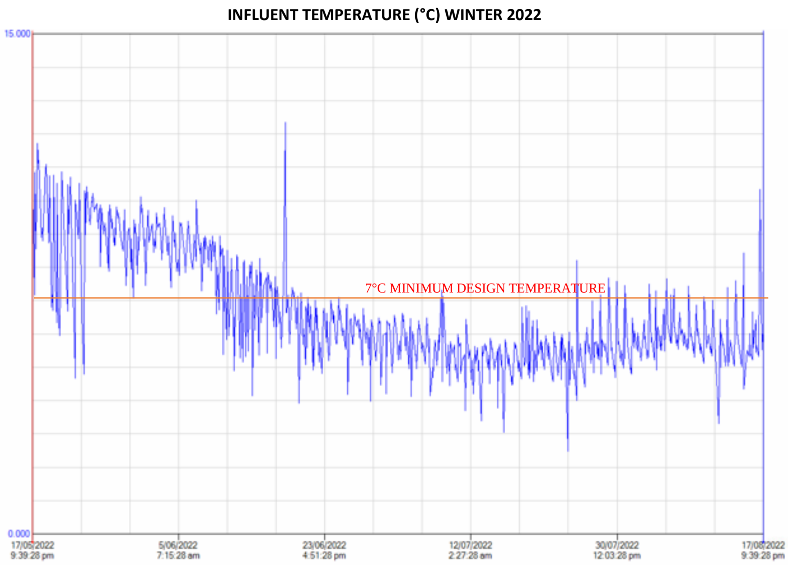

Figure 11 Influent temperature profile - Winter 2022

As can be seen from Figure 10 andFigure 11 above, minimum influent temperatures of approximately 1.3°C were reached in the winter of 2021 and 2.5°C in winter 2022. The reduced diurnal scatter in 2022 corresponds with higher inflow into the plant than during the 2021 Covid pandemic lockdowns. During both seasons, the minimum influent temperature was below the design envelope of 7°C for significant portions of the winter.

Despite the low influent temperature, the hybrid solar thermodynamic heating system was able to maintain the reactor temperature above the critical nitrification temperature under all operating conditions. This included through July 2022, when the solar panels were covered in snow for an entire week and ambient temperatures on the site repeatedly dropped below -8°C, which is significantly below the range indicated by historical climate data records for Cardrona (Figure 2).

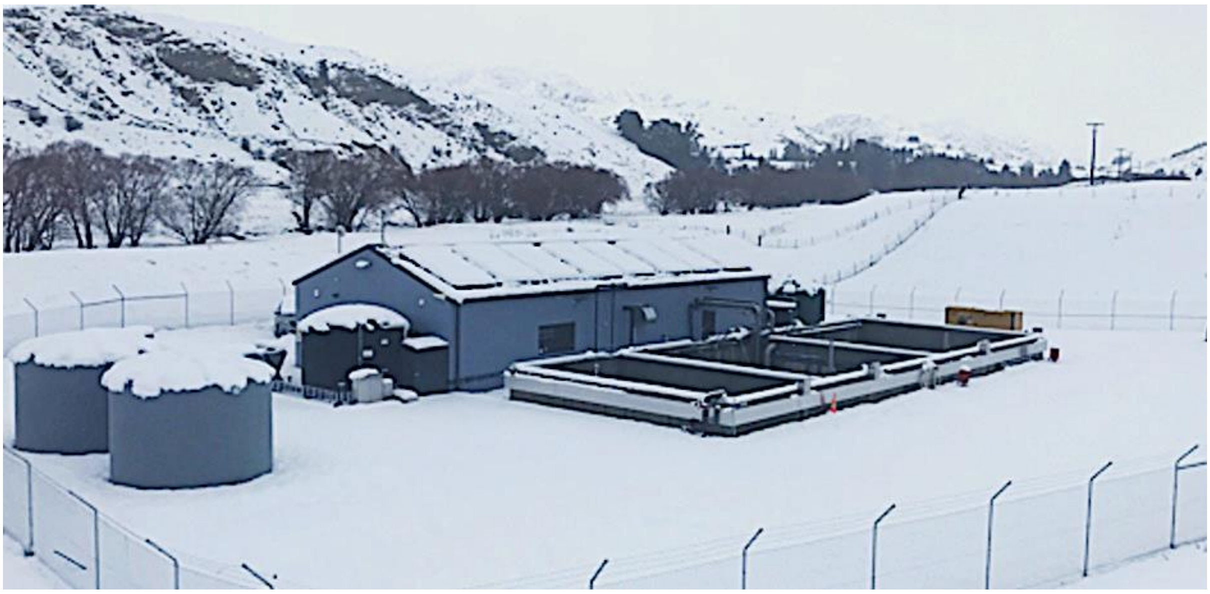

Figure 12 Cardrona wastewater treatment plant (including solar panels) buried in snow - July 2022

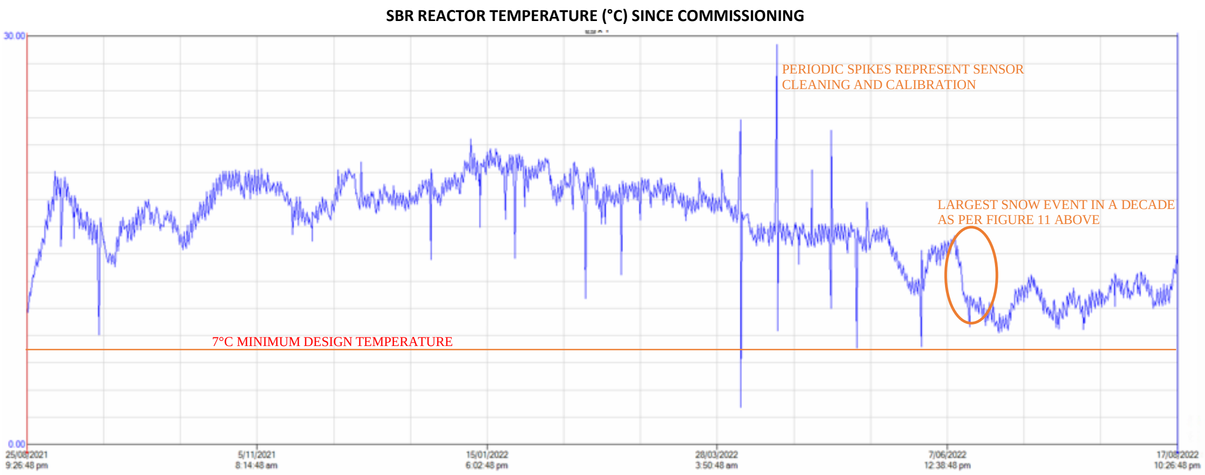

Figure 13 SBR Reactor temperature winter 2021 - winter 2022 (spikes indicate sensor exposure to ambient temperatures during cleaning or calibration)

Throughout this period, the plant performed beyond expectations, with all consent parameters complied with and a median total nitrogen concentration of 6.4mg/L in the treated water. This is approximately 80% lower than the consented median of 30mg/L.

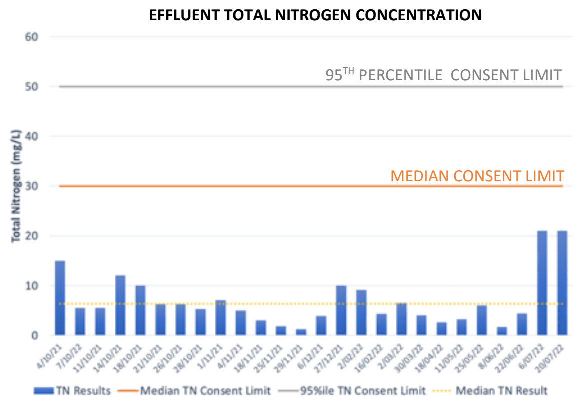

Figure 14 TN Results

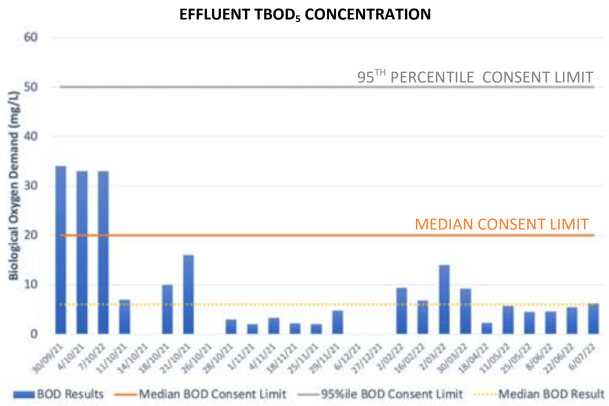

Figure 15 TBOD$_5$ Results

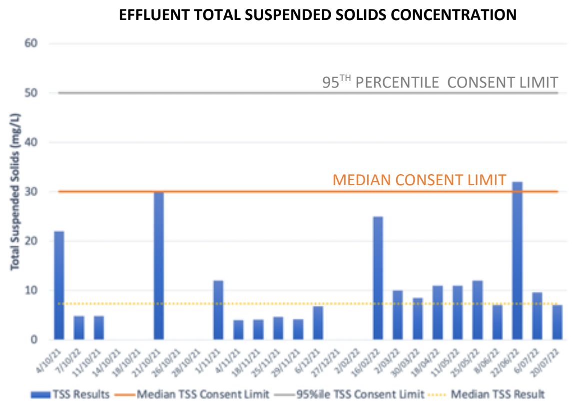

Figure 16 TSS Results

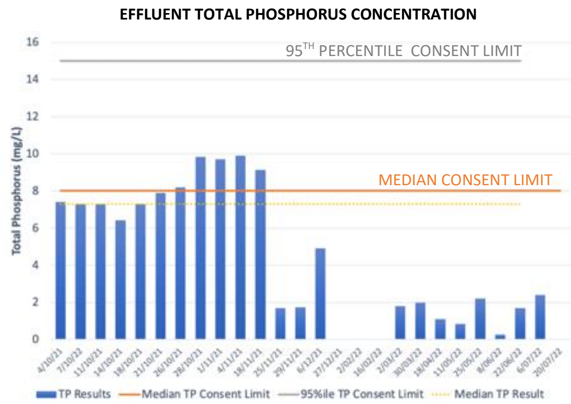

Figure 17 TP Results

As can be noted from Figure 14 above, this plant has maintained a high level of nitrogen removal through two winters.

In order to accommodate low flows prior to the Mt Cardrona Station development being completed, these results were achieved by using only one of the two SBR tanks and operating that at approximately half of its full design volume.

The wastewater from the treatment plant is applied to a seven hectare lucerne plot via sub-surface drip irrigation buried at an average depth of 300mm to avoid issues with ground freezing. Analysis of the lucerne harvest in the first growing season showed that the crop actually suffered significant nitrogen deficiency due to the higher-than-expected level of treatment. In July 2022 the decision was therefore reluctantly made to intentionally reduce the amount of nitrogen removal to avoid the need to apply supplemental fertiliser to maintain crop health.

Interestingly some of the most significant operational challenges with the plant arose from two external factors which were not the focus of the design. The first was a significant algal bloom in the CARL sewage storage pond due to the unseasonably hot sunny 2021-2022 summer, which required Poly Aluminium Chloride (PAC) to be dosed to coagulate algae and keep treated water suspended solids levels in compliance. The second issue involved flooding of clay-laden stormwater into the plant during an extreme rainfall event, which again was handled by dosing PAC to avoid breaching solids discharge limits.

CONCLUSION

The design presented was successfully executed and, after the first year of operation has been shown to efficiently moderate reactor temperature under severe winter conditions with influent temperatures down to 1.3°C. Near full nitrification was maintained even when the largest snow event in 10 years caused the reactor temperature to drop as low as 8.2°C.

Solar thermodynamic heating represents a viable low-carbon-emission alternative to fossil-fuel heating of wastewater in extreme cold climate environments.

After a treated effluent result of 1.7mg/L TN was achieved mid-winter 2022, and a result of 4.4mg/L TN was achieved after the major snow event discussed above, the decision was made to intentionally increase the level of nitrogen in the treated water to optimise crop health in the irrigation field. This is reflected in the last two nitrogen results presented in Figure 14.

Poly Aluminium Chloride dosing had to be retrofitted to the plant to provide for coagulation of unexpected high loads of algae and clay in the influent that were unable to settle in the SBR system. Care was required not to dose too much PAC and strip out all free phosphorus from the reactor therefore limiting biological growth and removal of other contaminants. These unexpected contaminants further supported hybrid SBR as the correct technology choice, due to the ease and speed with which the process could be adapted to treat these.

The learnings from this project have already been incorporated into multiple other projects in the area including sewage treatment plants for Coronet Peak Ski Area, Lake Hawea village, the Southern Hemisphere Proving Grounds on the Pisa range, and Scapegrace's new distillery near Cromwell.

Going forward these findings will have significant application to upgrades of plants throughout the North Island's central plateau, the wider South Island high country and potentially even the redevelopment of Scott Base.

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