COST AND CARBON REDUCTIONS THROUGH ALTERNATIVE PH CONTROL

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ABSTRACT

The costs of potable water treatment chemicals in New Zealand have been increasing year on year since 2020. The cost escalation has been driven by a reduction in New Zealand's domestic supply of chemicals, increased reliance on imported chemicals, and increased shipping costs. Carbon dioxide's (CO_2) rising costs and scarcity has affected the water treatment industry, as well as many other sectors (e.g., healthcare, food and beverage).

For Dunedin City Council (DCC), this has resulted in an almost 6-fold increase in the annual CO_2 costs at the Mount Grand Water Treatment Plant (WTP), one of its main WTPs. DCC have looked to review its chemical usage and the source of its chemicals to better understand supply chain logistics and national transport. Another key part of this review is the associated costs and carbon emissions, including potential mitigations.

DCC engaged Stantec to review and optimise its chemical usage at the Mount Grand WTP, and consider alternatives to CO_2. The Team worked collaboratively to first understand the current practice and rationale of chemical dosing. A baseline model of the Mount Grand WTP was developed using water solubility modelling software. Alternative pH control scenarios identified by DCC to reduce operational costs and embodied carbon were tested in the model.

This paper provides an overview of the methodology, results of the baseline and alternative scenario modelling, and a proposed staged approach to implement changes over the next 2-3 years. Annual operational cost savings and emission reductions are likely to be in the order of \$600,000 to \$1 million and 160-200 tCO_2e.

KEYWORDS

Carbon dioxide, water treatment, process optimisation, carbon emissions

PRESENTER PROFILE

Andrew Wong is a process engineer with water industry experience in Canada and New Zealand. He works primarily in water treatment plant process design, operation, troubleshooting, and optimization at both pilot- and full-scale.

1 INTRODUCTION

The costs of potable water treatment chemicals in New Zealand have been increasing year on year since 2020. The cost escalation has been driven by a reduction in New Zealand's domestic supply of chemicals, increased reliance on imported chemicals, and increased shipping costs. In particular, carbon dioxide's (CO_2) rising costs and scarcity has affected the water treatment industry, as well as many other sectors (e.g., healthcare, food and beverage). Concerns around the access to supply for water treatment have been addressed nationally by lobbying government.

For Dunedin City Council (DCC), this has resulted in an almost 6-fold increase in the annual CO_2 costs at the Mount Grand Water Treatment Plant (WTP), one of its main WTPs. DCC have looked to review its chemical usage and the source of its chemicals to better understand supply chain logistics and national transport. Another key part of this review is the associated costs and carbon emissions, including potential mitigations.

CO_2 behaves as a weak acid and is used to achieve fine pH adjustments, as well as add carbonate species to the water to increase buffering capacity (i.e., remineralisation). DCC engaged Stantec to review and optimise its chemical usage at the Mount Grand WTP, and consider alternatives to CO_2 to reduce operational costs.

Stantec worked collaboratively with operational staff to first understand the current practice and rationale of chemical dosing. Raw data (e.g., water quality, instrument data, operator log sheets) was collated and reviewed to create a baseline model of the Mount Grand WTP using water solubility modelling software. With the baseline model calibrated to operational data, the following scenarios identified by DCC were investigated to reduce operational costs and embodied carbon:

- Modification and optimisation of the current lime and CO_2 dosing system
- Replace lime and CO_2 with soda ash and sodium bicarbonate
- Replace lime and CO_2 with a limestone contactor

This paper provides an overview of the methodology, tools used as part of the assessment, results of the baseline and alternative scenario modelling, and proposed staged approach to implement over the next 2-3 years.

Based on the current chemical costs and carbon emission rates, the overall annual savings of the first stage (optimisation of the existing system) are likely to be in the order of \$600,000 and 160 tCO_2e, which can be readily implemented with limited capital investment. If additional chemical feed infrastructure is added, annual savings of the second stage (soda ash / sodium bicarbonate) are likely to be in the order of \$1 million and 200 tCO_2e.

1.1 MOUNT GRAND WATER TREATMENT PLANT

The Mount Grand WTP receives raw surface water from the Deep Stream and Deep Creek catchments located north-east of Dunedin City. It is DCC's largest plant with a design capacity of 44 MLD and is equipped with preliminary screening and clarification. Its main treatment process includes coagulation, flocculation, dissolved air flotation (DAF), rapid dual media filtration, chlorination, fluoridation, and pH / alkalinity adjustment. A simplified process flow diagram (PFD) of the main treatment process is illustrated in Figure 1.

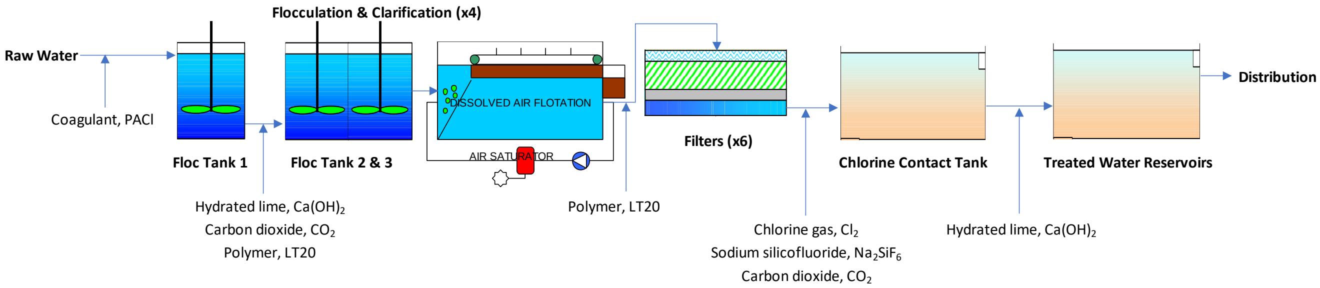


Figure 1: Mount Grand WTP simplified process flow diagram

A medium basicity polyaluminum chloride (PACl) is injected upstream of the flocculation tanks for coagulation. This PACl depresses the pH less than alum, so is a popular coagulant for low alkalinity waters such as this.

Hydrated lime ($Ca(OH)_2$) and CO_2 are injected between Floc Tank 1 and 2 for coagulation pH control. Lime addition serves two purposes: it is a base used primarily to increase the water pH due to its high hydroxide (OH^-) content, and adds calcium to the water which improves finished water stability and reduces the risk of corrosion by forming a protective layer of $CaCO_3$ on pipes in the network. Lime dosing is relatively inaccurate, making it hard to control the pH at a constant level with lime alone, therefore, CO_2 is used for fine pH control.

CO_2 is an acid, opposite to lime, but it is easy to dose accurately and commonly used to trim the pH to a control setpoint. The CO_2 also dissolves into the water to form H_2CO_3, a source of carbonate (CO_3) that will react with the calcium in the lime to form the protective layer of $CaCO_3$ as described above.

A high molecular weight non-ionic polymer (LT20) is added to Floc Tank 2 to develop a durable floc for clarification of the water in the DAF tanks. LT20 is also added as a filter aid to the clarified water prior to filtration. The filtered water is injected with chlorine gas (Cl_2) and fluoride (Na_2SiF_6).

To adjust the final treated water pH and make a stable, non-corrosive water, CO_2 is injected prior to the Chlorine Contact Tank and lime is added at the outlet of the Chlorine Contact Tank.

Raw water quality, plant performance, and treated water quality data from 2018 to 2023 was reviewed. It was found that the data from September 2018 to June 2021 was the most complete data set and illustrated consistent plant performance (i.e., negligible control setpoint changes). This allowed for the best agreement between the plant performance data and the baseline software model. A summary of the raw water quality data is provided in Table 1. Plant chemical dose rates, pH, and alkalinity data is summarised in Table 2.

Table 1: Mount Grand WTP raw water quality from 2018 to 2021

Parameter	Minimum	Maximum	Average	Unit
Plant Flow	0.2	35.6	22.9	ML/d
Temperature	2.2	20.3	9.9	°C
Turbidity	0.02	4	0.4	NTU
pH	4.95	12.65	6.45	
TDS	13	16	14.7	mg/L
Alkalinity	0.4	13.8	6.3	mg/L
Calcium	1.1	1.9	1.6	mg/L
Chloride	3.1	5.1	3.8	mg/L
Sulfate	0.3	0.8	0.5	mg/L
Magnesium	0.4	0.7	0.6	mg/L
UVA	0.01	0.7	0.2	cm^{-1}
DOC	1.8	4.4	2.5	mg/L

Table 2: Mount Grand WTP chemical doses, pH, and alkalinity from 2018 to 2021

Process Location	Parameter	Minimum	Maximum	Average	Unit
Pre-DAF	Coagulant dose	19.2	89.4	28.1	g/m^3
Pre-DAF	Lime dose	1.1	9	3.13	g/m^3
Pre-DAF	CO_2 dose	0.5	0.5	0.5	kg/h
Pre-DAF	Polymer dose	0.01	0.11	0.02	ppm
Floc Tank 1	Measured pH	3.06	12.9	4.9	
Floc Tank 2	Measured pH	5.23	7.38	6.23	
Post-filter	CO_2 dose	0.4	1,000	25.7	g/m^3
Post-CO_2	Measured pH (Chlorine Contact Tank)	2.24	5.48	3.94	
Post-lime	Measured pH	6.82	7.99	7.58	
Post-filter	Measured alkalinity	25.4	38	30.8	g $CaCO_3/m^3$

The CO_2 mass flow rate data recorded in SCADA was known to be unreliable. Instead, CO_2 bulk delivery data from 2022 was used as a baseline and summarised in Table 3. Review of the data revealed the variability in CO_2 usage.

Table 3: Mount Grand WTP 2022 CO_2 usage

Minimum	Maximum	Average	Median	Average Dose
80 kg/d	1,080 kg/d	390-700 kg/d	380-490 kg/d	16-35 mg/L

1.2 MODELLING SCENARIOS

A summary of the chemical dose modelling scenarios is presented in Table 4. The descriptions for Scenarios 1-3 are described as differences between each scenario and the Baseline model.

Even though the project objective was to reduce CO_2 usage, CO_2 injection was maintained at the pre-treatment stage of the model for all scenarios for the purposes of maintaining pH control accuracy. In the baseline model, the CO_2 used at the pre-treatment stage is less than 2% of the total plant usage, so this was not a major issue for optimisation.

Table 4: Summary of process chemistry modelling scenarios

Scenario	Description
Baseline	• Flow rate: 23 MLD • Pre-treatment dosing: PACl, lime, CO_2 • Finished water dosing: Cl_2, Na_2SiF_6, CO_2, lime • Floc Tank 1 pH: 4.9 • Floc Tank 2 pH: 6.2 • Chlorine Contact Tank pH: 5.2 • Treated Water Reservoir pH: 7.6 • Treated Water Reservoir alkalinity: 30-40 mg/L
Scenario 1	• Relocate the filtered water CO_2 injection point to downstream of the finished water lime injection point • Treated Water Reservoir pH: 7.6
Scenario 2	• Replace finished water lime and CO_2 dosing with soda ash and sodium bicarbonate for pH and alkalinity control. • Chlorine Contact tank pH: 7.6
Scenario 3	• Replace finished water lime and CO_2 dosing with a limestone contactor for pH and alkalinity control.

2 CHEMICAL MODELLING APPROACH

Water chemistry modelling was conducted using Water!Pro™ software (Schott Engineering Associates, 2005), a water chemistry equilibrium model designed for water treatment chemistry analysis. It can be used to calculate pH and alkalinity resulting from the addition of a variety of water treatment chemicals, and is most useful at quantifying differences between chemical dosing scenarios.

Like other software packages, it assumes that the input data is correct and models "ideal conditions". The software cannot account for operational variation or plant inefficiencies, such as: instrument error, laboratory analytical error, incomplete blending / mixing, or variability in chemical feedstock quality or strength.

The following chemicals were investigated for pH and alkalinity adjustment: PACl, lime, CO_2, soda ash (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), and limestone ($CaCO_3$). Each of their impact on pH and alkalinity is described in Table 5.

Table 5: Effects of chemicals on pH and alkalinity

Chemical	Purpose	Effect on pH [a]	Effect on Alkalinity [b]
Polyaluminum chloride, PACl	Coagulation	Decrease	Decrease 0.2 mg/L as $CaCO_3$ per 1 mg/L as PACl
Carbon dioxide, CO_2	pH adjustment	Decrease	Neutral - No increase or decrease

Chemical	**Purpose**	**Effect on pH** [a]	**Effect on Alkalinity** [b]
Chlorine gas, Cl_2	Chlorination	Decrease	Decrease 1.35 mg/L as $CaCO_3$ per 1 mg/L as Cl_2
Sodium silicofluoride, Na_2SiF_6	Fluoridation	Decrease	Decrease 1 mg/L as $CaCO_3$ per 1 mg/L as Na_2SiF_6
Soda ash, Na_2CO_3	pH and alkalinity adjustment	Increase	Increase 0.9 mg/L as $CaCO_3$ per 1 mg/L as Na_2CO_3
Sodium bicarbonate, $NaHCO_3$	pH and alkalinity adjustment	Increase (a little)	Increase 0.6 mg/L as $CaCO_3$ per 1 mg/L as $NaHCO_3$
Hydrated lime, $Ca(OH)_2$	pH and alkalinity adjustment	Increase	Increase 1.35 mg/L as $CaCO_3$ per 1 mg/L as $Ca(OH)_2$
Limestone, $CaCO_3$	pH and alkalinity adjustment	Increase	Increase 1 mg/L as $CaCO_3$ per 1 mg/L as $CaCO_3$

Notes:
[a] The quantitative change in pH each chemical has depends on the receiving water quality.
[b] The change on alkalinity for each chemical is from Water!Pro™

2.1 FINISHED WATER QUALITY TARGETS

The finished water quality targets for Scenarios 1-3 (refer to Table 4) were set to the following values:

- pH equal to 7.6
- Alkalinity equal to 25 mg/L as $CaCO_3$

Water quality modeling was conducted to achieve proper coagulation pH at the pre-treatment process and to produce a chemically stable and non-corrosive finished water. The target finished water pH was 7.6 to conform with current practices.

A finished water alkalinity target of 25 mg/L as $CaCO_3$ was selected as this range has been shown to provide reasonable buffering capacity so that changes in water quality in the distribution system do not result in large changes in finished water pH.

2.2 LOW PH SETPOINTS

It was noted that the pH in Floc Tank 1 and the Chlorine Contact Tank is relatively low. However, no signs of significant concrete corrosion were reported.

Hypochlorous acid (HOCl) is the species that is responsible for bacteriological disinfection. HOCl exists in equilibrium with its corresponding base, OCl^-, depending on the pH as illustrated in Figure 2. When the pH is 5.2 there is 100% HOCl. When the pH is increased to 7 and 7.6, the fraction of HOCl decreases to 80% and 50% respectively. As the pH increases, the disinfection capacity of HOCl decreases.

However, from a compliance perspective, there is no loss of bacterial disinfection credit until the pH is greater than 8. There is also no additional bacterial disinfection credit provided to a water supplier if their chlorine disinfection process is operated at a pH less than 8.The Free Available Chlorine Equivalent (FACe) was calculated using the formula from Chapter 6 of the *Guidelines for Drinking-water*

Quality Management for New Zealand (Ministry of Health, 2017) and plotted in *Figure 3*.

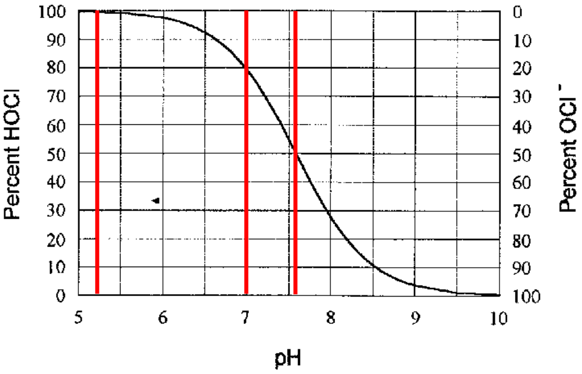


Figure 2: HOCl / OCl⁻ equilibrium diagram

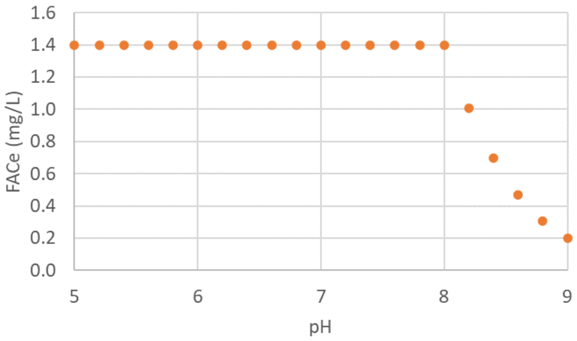


Figure 3: Free Available Chlorine Equivalent (FACe) vs pH with a chlorine dose of 1.4 mg/L

3 MODELLING RESULTS

3.1 BASELINE MODEL

The Baseline Model was developed using the raw water quality data presented in Table 1 and the technical chemical data provided by DCC. The Baseline Model was validated against the data presented in Table 2 and Table 3. A simplified PFD is presented in Figure 4 of the Mount Grant WTP illustrating the Baseline Model. The yellow boxes above the PFD present the water quality parameters and the green boxes below the PFD present the chemical dosages at various stages of the treatment process. The change in the Baseline Model pH and alkalinity through the treatment process is illustrated in Figure 5 and Figure 6, respectively.

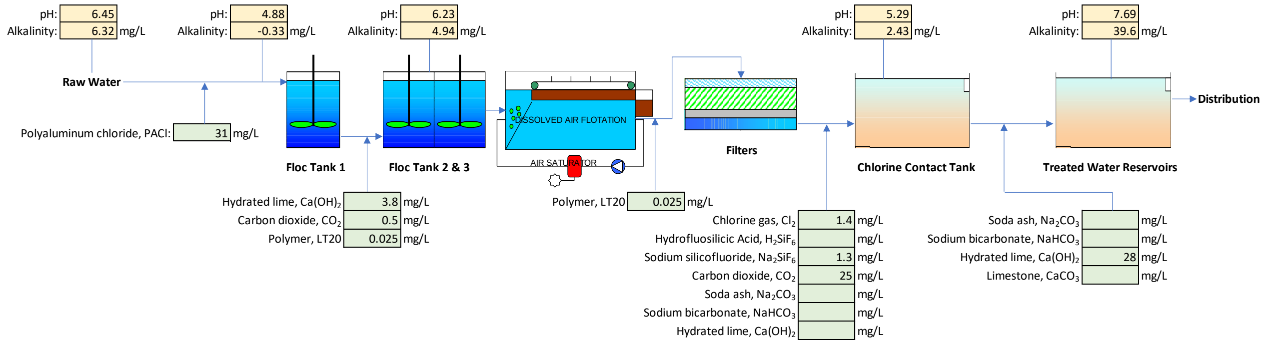


Figure 4: Baseline Model process flow diagram

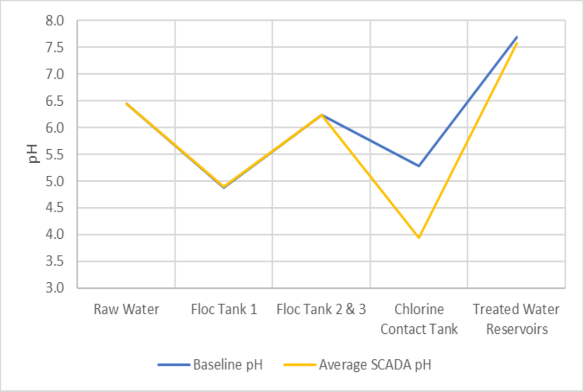


Figure 5: Baseline Model and average SCADA pH comparison

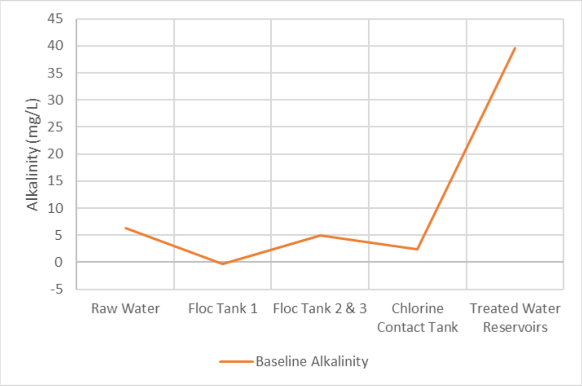


Figure 6: Baseline Model alkalinity through the treatment process

The Baseline Model achieved good agreement with Mount Grand WTP chemical dose and pH data as illustrated in Figure 5 and presented in Table 2. The Baseline Model finished water alkalinity was predicted to be approximately 40 mg/L as $CaCO_3$ compared to the average of 31 mg/L as $CaCO_3$ in Table 2. It was noted that lime accumulates in the Treated Water Reservoirs and is removed periodically as part of regular maintenance. The accumulated material may be undissolved lime or inert impurities. On this basis, a higher finished water alkalinity predicted by the model is not unreasonable.

The Baseline Model estimated a CO_2 consumption rate of 585 kg/d, which generally aligns with the estimated consumption rates using the CO_2 bulk delivery data. This corresponds to a CO_2 dosage rate of 25.5 mg/L aligns with the dose setpoint in Table 3.

An estimate of the Baseline Model annual operating expenditure (OPEX) and embodied carbon associated with the chemical dosing is summarised in Table 6.

Table 6: Baseline Model chemical dosing OPEX and embodied carbon estimate

Total Annual Chemical Cost	**Annual CO_2 Cost**	**Annual Embodied Carbon**
\$1.9 million	\$1.2 million	2,480 tCO_2e

3.2 SCENARIO 1 – RELOCATE CO_2 INJECTION POINT

The results of the Scenario 1 modelling are summarised in Figure 7. The pH setpoint of the Chlorine Contact Tank was changed to 5.8 by relocating the CO_2 injection to downstream of the Chlorine Contact Tank and lime dosing point. The change in pH and alkalinity across the treatment process for Scenario 1 compared to the Baseline Model is illustrated in Figure 8 and Figure 9, respectively.

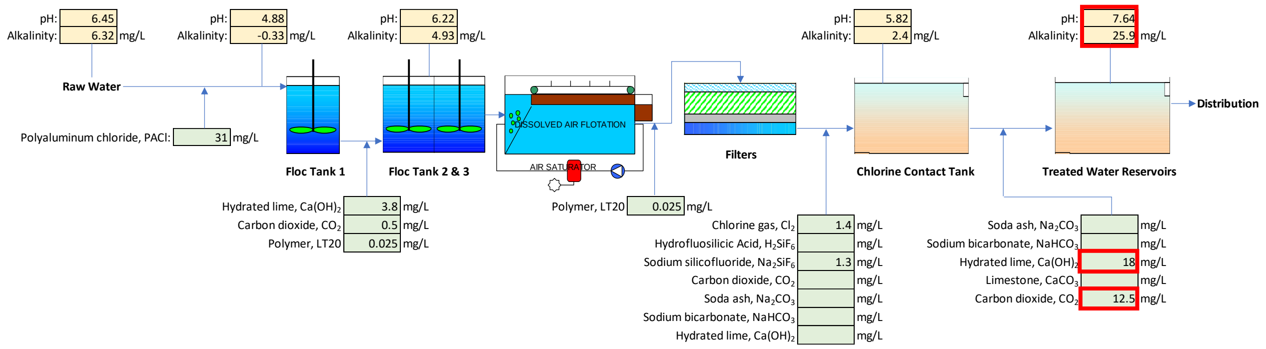


Figure 7: Scenario 1 PFD summary with changes made to Baseline highlighted in red

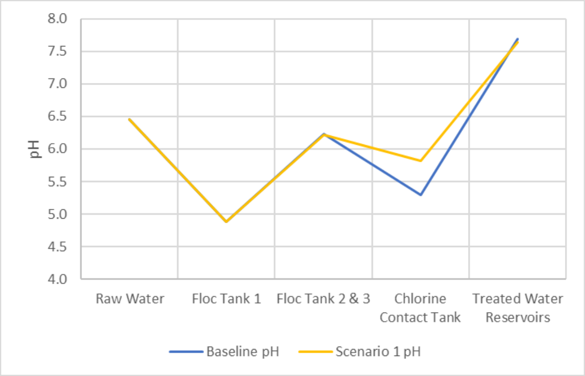


Figure 8: Scenario 1 and Baseline Model pH comparison

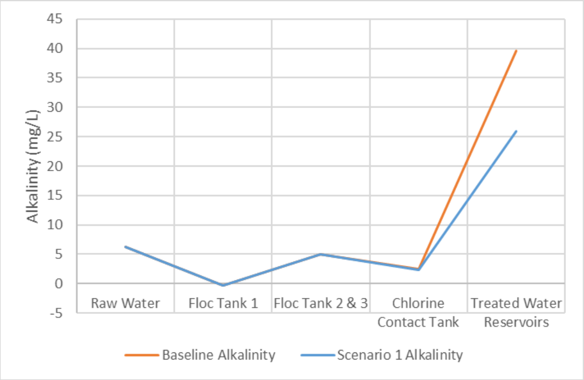


Figure 9: Scenario 1 and Baseline Model alkalinity comparison

Compared to the Baseline Model, eliminating the pH reduction to 5.2 at the Chlorine Contact Tank is estimated to decrease the lime and CO_2 usage by 36% and 50%, respectively. The finished water alkalinity is 25.9 mg/L as $CaCO_3$. The capital works required to implement Scenario 1 would include relocating the CO_2 injection point and modifications to the SCADA system (e.g., control page graphics, setpoint adjustment).

An estimate of the annual OPEX and embodied carbon associated with Scenario 1 is summarised in Table 7.

Table 7: Scenario 1 chemical dosing OPEX and embodied carbon estimate

Total Annual Chemical Cost	Annual CO_2 Cost	Annual Embodied Carbon
$1.3 million	$0.6 million	2,320 tCO_2e

Compared to the Baseline Model, Scenario 1 is estimated to reduce the annual chemical costs by approximately $630,000; annual cost savings from the reduction of lime and CO_2 usage are estimated to be $40,000 and $590,000, respectively. Scenario 1 reduces the annual embodied carbon from chemical usage by 160 tCO_2e compared to the Baseline Model.

3.3 SCENARIO 2 – SODA ASH & SODIUM BICARBONATE

The results of the Scenario 2 modelling are summarised in Figure 10. The pH setpoint of the Chlorine Contact Tank was changed to 7.6 by dosing soda ash upstream of the Chlorine Contact Tank for coarse pH and alkalinity control. Fine adjustment of the finished water pH and alkalinity was achieved by dosing sodium bicarbonate downstream of the Chlorine Contact Tank. Both soda ash and sodium bicarbonate could be added at the same location either upstream or downstream of the Chlorine Contact Tank. The change in pH and alkalinity across the treatment process for Scenario 2 compared to the Baseline Model is illustrated in Figure 11 and Figure 12, respectively.

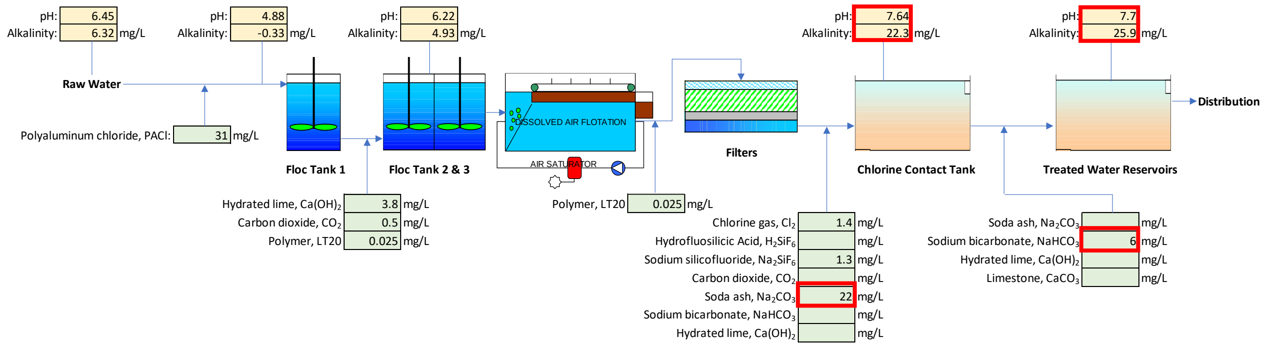
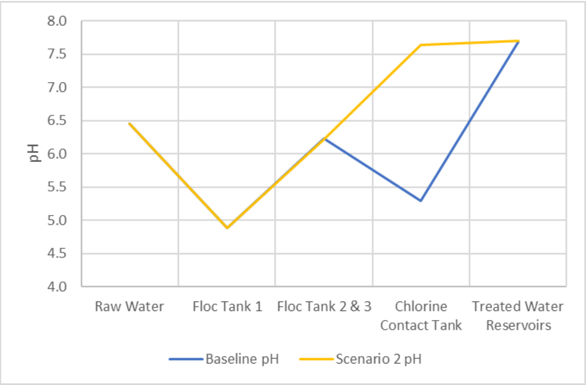


Figure 10: Scenario 2 PFD summary with changes made to Baseline highlighted in red



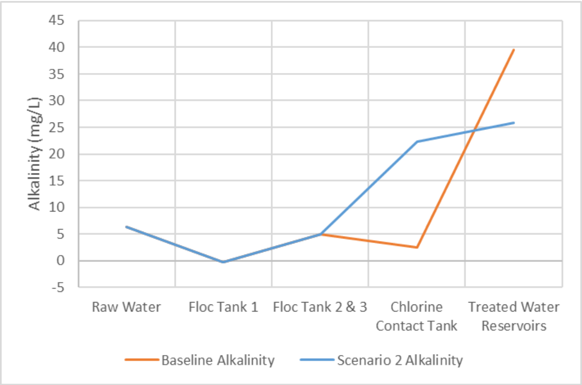


Figure 11: Scenario 2 and Baseline Model pH comparison

Figure 12: Scenario 2 and Baseline Model alkalinity comparison

Soda ash increased the pH and alkalinity of the Chlorine Contact Tank to 7.64 and 22.3 mg/L as $CaCO_3$, respectively. Sodium bicarbonate increased the pH and alkalinity of the finished water to 7.7 and 25.9 mg/L as $CaCO_3$, respectively. The capital works required to implement Scenario 2 would include: new soda ash and sodium bicarbonate handling, batching, and dosing systems, as well as modifications to the SCADA system (e.g., control page graphics, batching logic, dose control logic, setpoint adjustment). Maintaining the CO_2 dosing system is recommended for fine pH control and to mitigate pH overshoot. It is anticipated that Scenario 2 would require more CAPEX to implement than Scenario 1, but reduces the reliance on CO_2 at the Mount Grand WTP.

An estimate of the annual OPEX and embodied carbon associated with Scenario 2 is summarised in Table 8.

Table 8: Scenario 2 chemical dosing OPEX and embodied carbon estimate

Total Annual Chemical Cost	Annual CO_2 Cost	Annual Embodied Carbon
\$1.0 million	\$0.03 million	2,290 tCO_2e

Compared to the Baseline Model, Scenario 2 is estimated to reduce the annual chemical costs and embodied carbon by approximately \$990,000 and 190 tCO_2e, respectively. If implemented, the CO_2 usage and cost are expected to be higher than estimated as finished water CO_2 trim after the soda ash and sodium bicarbonate dosing was not modelled.

3.4 SCENARIO 3 – LIMESTONE CONTACTOR

Results of the Scenario 3 modelling are summarised in Figure 13. pH and alkalinity adjustment was moved to downstream of the Chlorine Contact Tank and achieved with a Limestone Contactor. The pH is decreased from 6.2 to 5.8 following chlorination and fluoridation. The change in pH and alkalinity across the treatment process for Scenario 4 compared to the Baseline Model is illustrated in Figure 14 and Figure 15, respectively.

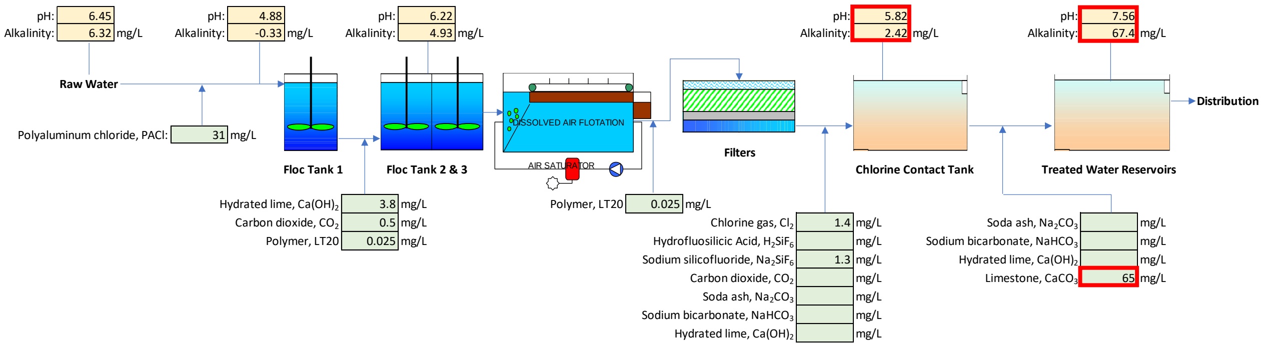
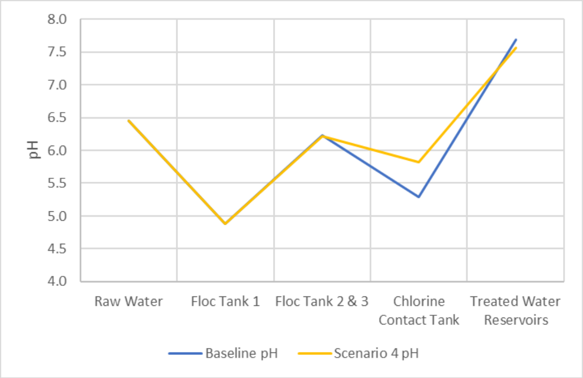


Figure 13: Scenario 3 PFD summary with changes made to Baseline highlighted in red



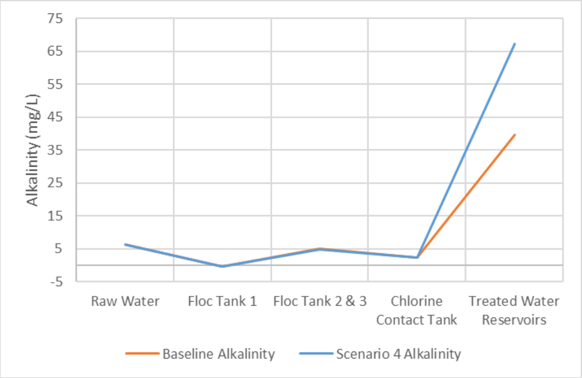


Figure 14: Scenario 3 and Baseline Model pH comparison

Figure 15: Scenario 3 and Baseline Model alkalinity comparison

The limestone contactor increases the pH and alkalinity of the finished water through the dissolution of limestone chip. An equivalent dose of 65 mg/L of $CaCO_3$ required to raise the finished water pH to 7.6, and results in an approximate alkalinity of 70 mg/L as $CaCO_3$.

For finished water conditioning, the limestone contactor is installed after the disinfection processes are complete, as it typically increases the finished water turbidity; an increase in turbidity negatively impacts the effectiveness of disinfection processes. Controlling the finished water pH and alkalinity using a limestone contactor can be challenging and would be achieved by varying its flow rate and corresponding contact time. Flow rate adjustments would be required as limestone is dissolved or topped up.

The capital works required to implement Scenario 3 would include: six limestone contactor basins (7 m x 7 m x 2 m) contained inside a building to protect the finished water from contamination, feed pump station with adequate storage volume to mitigate site constraints and plant hydraulics, backwash system, limestone chip handling facilities (e.g., media wash down, truck unloading, contactor loading), piping modifications, and SCADA system modifications (e.g., control page graphics, flow control logic, media level monitoring, loading / unloading). Maintaining the CO_2 dosing system is recommended for fine pH control and mitigate pH overshoot. It is anticipated that Scenario 3 would require the highest CAPEX to implement of the options investigated, but reduces the reliance on CO_2 at the Mount Grand WTP. A schematic of a limestone contactor is illustrated in Figure 16.

An estimate of the annual OPEX and embodied carbon associated with Scenario 3 is summarised in Table 9.

Table 9: Scenario 3 chemical dosing OPEX and embodied carbon estimate

Total Annual Chemical Cost	**Annual CO_2 Cost**	**Annual Embodied Carbon**
\$0.7 million	\$0.03 million	2,350 tCO_2e

Compared to the Baseline Model, Scenario 3 is estimated to reduce the annual chemical costs and embodied carbon by approximately \$1,200,000 and 130 tCO_2e, respectively. If implemented, the CO_2 usage and cost are expected to higher than estimated as finished water CO_2 trim after the limestone contactor was not modelled.

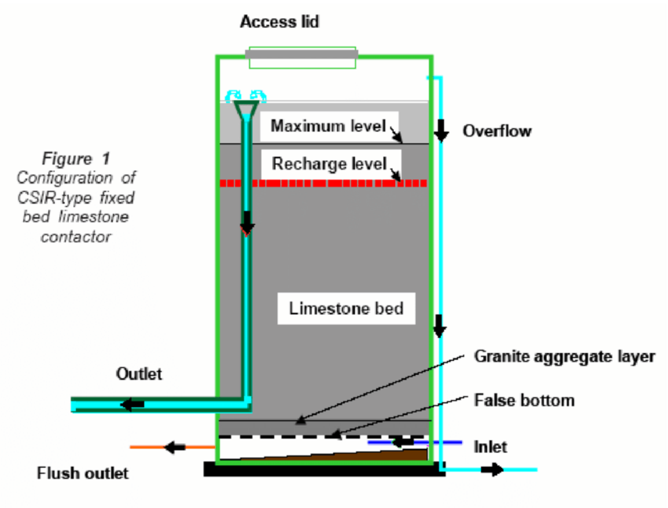


Figure 16: Limestone contactor schematic (Batson, 2008)

3.5 SUMMARY

A summary of the Mount Grand WTP chemical dosing scenario modelling results as compared to the Baseline Model is presented in Table 10.

Table 10: Scenario modelling chemical dosing OPEX and embodied carbon estimates compared to Baseline

Scenario	**Required Capital Works (CAPEX / tCO_2e not estimated)**	**Change in Annual OPEX and tCO_2e**
Scenario 1	• Relocate CO_2 injection location • SCADA modifications: graphics, setpoints	• Reduce by $630,000 • Reduce by 160 tCO_2e
Scenario 2	• New soda ash and sodium bicarbonate handling, batching, and dosing systems • SCADA modifications: graphics, batching logic, dosing logic, setpoints • Maintain CO_2 dosing for fine pH control	• Reduce by $990,000 • Reduce by 190 tCO_2e
Scenario 3	• Six limestone contactor basins (7 m x 7 m x 2 m) inside new building • Feed pumping station and backwash system • Limestone chip handling facilities • SCADA modifications: graphics, control logic, setpoints	• Reduce by $1,200,000 • Reduce by 130 tCO_2e

4 CONCLUSIONS

The following key conclusions and recommendations are provided from the results of the modelling:

- Scenarios 1, 2, and 3 are technically feasible and yields finished water quality similar to the Baseline Model and current operational practices.
- Scenario 1 requires the lowest CAPEX and the shortest time to implement, reduces both OPEX and embodied carbon, results in minor changes to the existing treatment process, and reduces CO_2 usage by 50%
- Scenario 2 requires moderate CAPEX to implement, reduces both OPEX and embodied carbon, results in moderate changes to the existing treatment process, and reduces reliance on CO_2 (i.e., fine pH adjustment)
- Scenario 3 requires the highest CAPEX to implement, reduces OPEX and embodied carbon, results in significant changes to the existing treatment process, and reduces reliance on CO_2 (i.e., fine pH adjustment)
- A staged implementation approach is recommended:
    - Implement Scenario 1 in the short-term to reduce OPEX and embodied carbon emissions.
    - Implement Scenario 2 in the medium-term to further reduce OPEX and embodied carbon emissions and reduce the operational reliance of CO_2.

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5 REFERENCES

Batson, R. G., 2008. *The Generation of Design Parameters for the use of the Limestone Teeter Bed Reactor for Potable Water Stabilisation and the Treatment of Cape Coloured Waters,* Cape Town: Water Research Commission.

Ministry of Health, 2017. *Guidelines for Drinking-water Quality Management for New Zealand,* Wellington: Ministry of Health.

Schott Engineering Associates, 2005. *Water!Pro.* [Online] Available at: http://schotteng.com/WaterPro%20Schott-1.htm