Duvauchelle Wastewater Scheme

Design Flow Basis Update Report

Prepared for Christchurch City Council
Prepared by Beca Limited

13 February 2024

Contents

Appendices

Revision History

Revision Nº	Prepared By	Description	Date
1	Innes Duncan	Draft for Council Review	10/10/2023
2	Innes Duncan	Draft updated for revised flows	19/12/2023
3	Innes Duncan	Updated for Final Issue	13/02/2024

Document Acceptance

Action	Name	Signed	Date
Prepared by	Innes Duncan		13/02/2024
Reviewed by	Greg Offer		13/02/2024
Approved by	Greg Offer		13/02/2024
on behalf of	Beca Limited		

Executive Summary

This report presents an updated flow design basis (from previous work by Beca in 2020) and irrigation modelling outputs for the Duvauchelle Wastewater Scheme. Previous flow estimations were made with limited flow data (2-3 years) and prior to the I&I improvement work being complete and therefore had estimations factored in for anticipated future I&I reduction.

Long-term irrigation performance has been modelled using a synthetic long-time flow series. A relationship between the rainfall derived I&I portion of wastewater flow (RDII) and rainfall is determined and then extrapolated back against historical rainfall data from 1972 to present day. The RDII portion of the measured flows has been determined by subtracting dry weather flow (residential & commercial use) from the total flow. Review of water meter consumption data in the area has helped confirm the estimate of dry weather flow contributing to the daily wastewater flows. Climate change impacts based on Ministry for the Environment (MfE, 2018) guidance have been incorporated into the modelling as set out in the report.

Recent flow meter data from the relatively wet 2022 and 2023 periods has shown a delayed flow response for periods following rain events, which was not captured in the previous flow modelling work for the scheme. A tailing off RDII response (observed days following rain events) has now been incorporated into the model to capture this behaviour. This response is based on rainfall depth and a decay rate that represents the soil store flow observed.

Updated Irrigation Flows and Modelling

A comparison has been made between the synthetic 50-year irrigation flows and PS608 and 609 flow meter measurements from 2018 to 2023 to better understand differences in the synthesized flows against measured flows. The synthetic 50-year flows are considered to model Winter and early Spring flow volumes reasonably tightly against measured data, with annually averaged differences within +/- 5% - except for 2020 which was a particularly dry year. The average difference across all measured years is <3%.

Tabled below is a summary of the overflow recurrence modelled across the 51-year simulation period for each fixed onsite storage scenario. Note that ‘overflow seasons’ are reported below which indicate the number of irrigation seasons (i.e. years) that overflows occur in the model. Discrete overflow events and whether or not repeat overflows occur within an irrigation season are subject to a number of operational and regulatory aspects which need to be explored and defined at later project stages.

Irrigation Scenario Results - Storage Volumes and Overflow Seasons (PDP, 2023)

Scenario	Storage Volume (m^3)	Storage Overflow Seasons (51-years)
Scenario 1 8.2 ha tree dripper area + 6.36 ha course spray area	5,300	0
	4,000	5
	2,000	25
Scenario 2 8.2 ha Tree dripper area (no course spraying)	5,300	0
	4,000	5
	2,000	25
Scenario 3 6.4 ha tree dripper area + 6.36 ha course spray area	6,500	0
	4,000	17
	2,000	32
Scenario 4 6.4 ha tree dripper irrigation (no course spraying)	6,500	0
	4,000	17
	2,000	33

Utilising a smaller storage of 4,000m^3 and the preferred tree irrigation area of 6.4ha results in 17 modelled overflow seasons across the 51-year period. A further reduction in storage to 2,000m^3 (6.4ha) results in 32 modelled overflow seasons. Note that for a 2,000m^3 storage scenario the modelled overflow volumes are significant (often greater than the storage volume itself) and therefore draw-down and other operational approaches are unlikely to be able to avoid repeat overflow events within a season. Results for the 4,000m^3 storage scenarios suggest overflow volumes could likely be managed with operational approaches to avoid repeat overflows within a season.

Negligible differences were found between overflow recurrence with or without golf course spray irrigation (noting a minor improvement of 3% occurring only at the 2,000m^3 scenario and that this modelled event is over-estimated compared with measured data). This is due to the disposal of recycled water during winter months being the limiting factor that drives peak storage requirements. Also noting it is unlikely that the golf course would opt to irrigate their course during significant rainfall events in the summer.

Scheme Resilience and Overflows

It should be noted that the flows determined from this modelling exercise are a "best-fit" representation of the expected future performance of the Duvauchelle wastewater network. Differences between modelled and measured flows should be expected for future events due to the dynamics of network response that the model cannot fully account for. It is recommended that a sensible margin is allowed for when sizing infrastructure based on these results to account for modelling inaccuracy.

The design basis approach is based on the capacity and data from the current network and does not include conveyance of extreme events and/or overflows to the WWTP and irrigation to land system. An average recurrence Interval (ARI) resilience for the irrigation system cannot be determined without developing a network model and better understanding scheme and overflow performance during extreme events.

The climate change adjustments factored into the modelling are based on an overall probabilistic assessment by the Ministry for the Environment (MfE). The probabilistic approach cannot forecast extreme individual "black swan" rainfall events (i.e. extreme future rainfall events that are larger than those experienced over the time period of the modelling) or the associated network flow response. Such black swan events are expected to occur with increased frequency and can strike randomly in any location at any time. Council should expect that the design basis settings for the Duvauchelle Wastewater Scheme will be exceeded on occasions in the future. Consideration should be given to what happens during 'black swan' events and whether wastewater system responses pose any risks to the assets, the community or the environment.

1 Introduction

1.1 Background

Christchurch City Council (Council) are planning an upgrade to the Duvauchelle Wastewater Scheme to remove the existing harbour discharge and consent and commission a land disposal system, including wastewater treatment plant (WWTP) upgrades to meet irrigation water quality levels. The Duvauchelle Wastewater Scheme upgrade has been in development since 2018 and involves:

- Infiltration and ingress (I&I) reduction works (network upgrades)
- Upgrading of the existing Duvauchelle WWTP (tertiary treatment)
- New land disposal irrigation system (including buffering storage)

An optioneering exercise has been completed to assess the most suitable disposal system for the scheme with irrigation and storage on the Akaroa Golf Club (AGC) being the preferred disposal system largely due to moderate costs and the community stakeholder support for reuse benefits (Beca, Duvauchelle Wastewater Summary of Disposal and Reuse Options, 2022). The proposed land disposal system (at the time of this report) comprises of the following areas:

- Golf course playing areas – 6.4 ha spray irrigation (beneficial re-use when required by AGC)
- Woodland areas – 8.2 ha dripper irrigation under trees (when spray irrigation not beneficial)
- Discharge to covered tanks during wet weather conditions.

Refer to Appendix A for the overview concept plan for the proposed scheme.

The wastewater design flow from the catchment is an integral input for the scheme and is difficult to estimate due to the fluctuating population (the area is a holiday destination), significant I&I and limited flow metering records. Previous flow estimations have been determined using an inferred relationship between rainfall and WWTP flow based on limited flow meter data and then extrapolating back across historic rainfall records (back to 1972). Previous flow estimations were made with limited flow data (2-3 years) and prior to the I&I Improvement work being complete and therefore had estimations factored in for anticipated future I&I reduction.

The proposed I&I network improvement work began in 2020 and is now complete. Concept design for the WWTP upgrade has been completed and concept design for the spray and dripper irrigation system is still being progressed. In November 2023 Council has moved into the next stage of preparing the resource consent application (assessment of environmental effects) and aim to progress into detailed design in mid-2024.

1.2 Scope

The scope of this work is to update the design flow basis and irrigation requirements for the scheme, which comprises of:

- Updating, using the latest available data, the design flow basis for the Duvauchelle Wastewater Scheme.
- Reproduce the irrigation long-time flow series
- Rerun the irrigation models for this scheme to reassess irrigation area and storage volume requirements
- Update flow data for the WWTP upgrades

1.3 Updated Data

Additional and updated inputs provided by Council are:

- Latest PS608, 609 and WWTP flow meter data (2021-2023)
- Boundary water meter data (used to review assumed dry weather scheme flows)
- Rainfall data from the recently installed Duvauchelle Golf Course rain gauge

1.4 Irrigation Long-time Flow Series Approach

Long-term irrigation performance has been modelled using a synthetic long-time flow series. A relationship between the rainfall derived I&I portion of wastewater flow (RDII) and rainfall is determined and then extrapolated back against historical rainfall data from 1972 to present day. The RDII portion of the measured flows has been determined by subtracting dry weather flow (residential & commercial use) from the total flow. A tailing off RDII response (observed days following rain events) has also been modelled based on rainfall depth and a decay rate that represents the soil store flow observed. Review of water meter consumption data in the area has helped approximate the portion of dry weather flow contributing to the daily wastewater flows. This analysis and synthetic flow series has been developed by PDP – for further details around this approach and the results see Appendix B.

1.5 Rainfall and Evapotranspiration Data

The modelling process uses long-term daily climate data to both estimate the components of wet weather flow in the synthetic time series and calculate the soil moisture balance (SMB) for the irrigation modelling. Due to data availability the rainfall data used for this modelling is as follow:

- Onawe Duvauchelle Bay rainfall gauge (1972 – 2012)
- NIWA Virtual Climate Station Network (VCSN) station 20116 (reduced by 14%) (2012-2020)
- Duvauchelle CWS (Akaroa Golf Course) data from 2020 onwards

Note some rainfall data has been adjusted to better reflect local conditions. For further details around climate data and modifications see Appendix B.

VCSN Station 20116 has been used for the potential evapotranspiration (PET) data for the entire modelling period.

1.6 Future Climate Change Approach

As historic rainfall data is being used to model the future long-term performance of the irrigation system, it is important to consider potential changes to daily rainfall depths because of future climate change. Guidance from the Ministry for the Environment (MfE, 2018) suggests that while the Canterbury region is expected to experience no change in annual rainfall over the next 80 years, it is expecting seasonal increases and decreases in rainfall as shown below in Table 1.

Table 1 - Canterbury Climate Change Seasonal Rainfall (MfE Guidelines 2018)

Season	Precipitation change to 2031-2050	Precipitation change to 2081-2100
Summer	1%	8%
Autumn	3%	8%
Winter	-4%	-12%
Spring	1%	1%
Annual	0%	0%

A 3-8% increase in autumn rainfall depths may cause the irrigation cut-off trigger level to be reached more frequently and a greater volume of treated effluent needing to be stored (from additional I&I generated wastewater flow). Conversely, a 4-12% decrease in winter rainfall depths should reduce the likelihood of having to cease irrigation and store treated effluent. It is important to understand the impacts of this behaviour.

The rainfall long time-series was adjusted to reflect the above climate change predictions. The adjustment was made using a linear factor, making sure that the 'global' requirement of annual change of 0% and the seasonal requirement (1%, -4% and 3% respectively) are fulfilled. The linear adjustment consists of a slope and intercept which are from an algorithm. the algorithm iteratively draws from the normal distribution (for the slope) and from the intercept range (uniform distribution) until it finds seasonal adjustment parameters for every year that fulfil the seasonal and global requirements.

2 Updated Irrigation Design Flows

This section presents a summary of the method and results from the updated 2023 Irrigation long time flow series work performed by PDP – see Appendix B for further details.

2.1 Modelled I&I Relationship

Determining the relationship between RDII and rainfall is fundamental to producing the synthetic irrigation long timeseries flows. Key points around the RDII and rainfall relationship compared with earlier work[1]:

- 6 years of flow meter data available to infer relationship (previously only 3 years)
- Updated flow meter data included relatively wet years (added data points to the upper end of the trend)
- Previously work assumed a fixed winter groundwater component (GWII) that likely overestimated baseflow during drier winters. After reviewing the updated data set (with wetter years) a fixed winter GWII component is not considered appropriate and I&I (including both GWII and RDII) has been correlated with rainfall. This is considered to provide a better fit during winter months.
- The relationship is now based on Duvauchelle CWS rainfall data (2020-2023)
- Average Dry Weather Flow (ADWF) assumption from earlier work of 54m^3/d (off-peak) and 119m^3/d (peak summer) is still considered appropriate and has been retained. Water meter consumption data suggests winter residential and commercial usage is around the 40-50m^3/d which aligns with this assumption.
- Soil store flow component added which applies a decaying tail of wastewater flow beyond rainfall events to represent the soil store observed from the flow meter data.

Figure 1 shows the relationship inferred between I&I and rainfall for the updated 2018-2023 data set.

[1] Duvauchelle WWTP Land Disposal Modelling – Updated WWTP Flow Series (PDP, 2020)

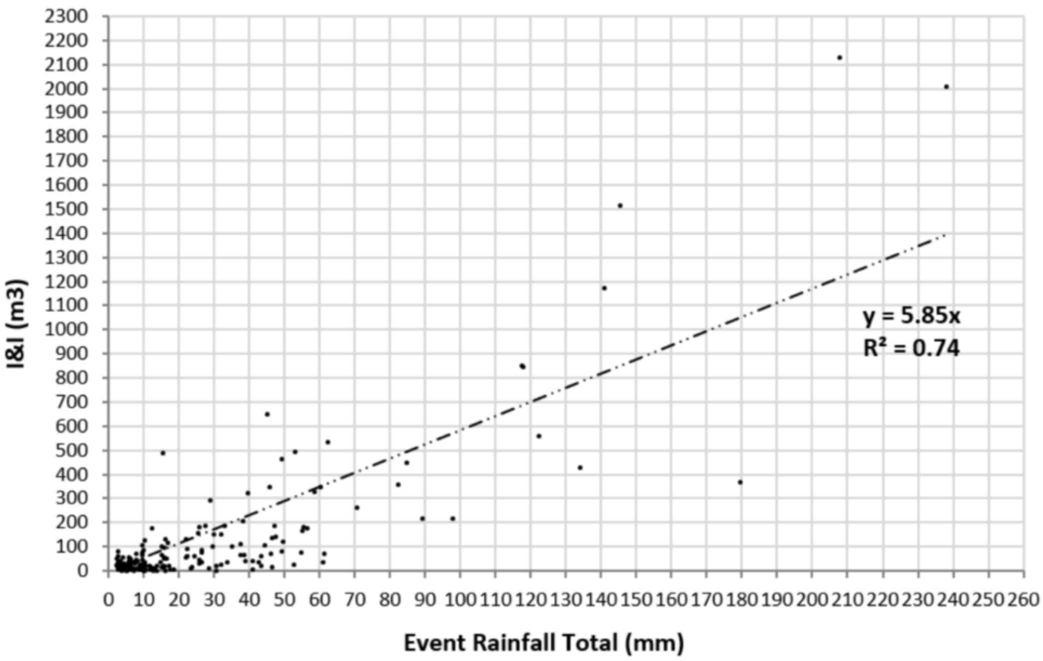


Figure 1 - I&I Portion of Measured Flows Against Rainfall (Event Based 2018-2023)

Figure 2 shows the comparison between modelled vs measured flows using the relationship determined from Figure 1.

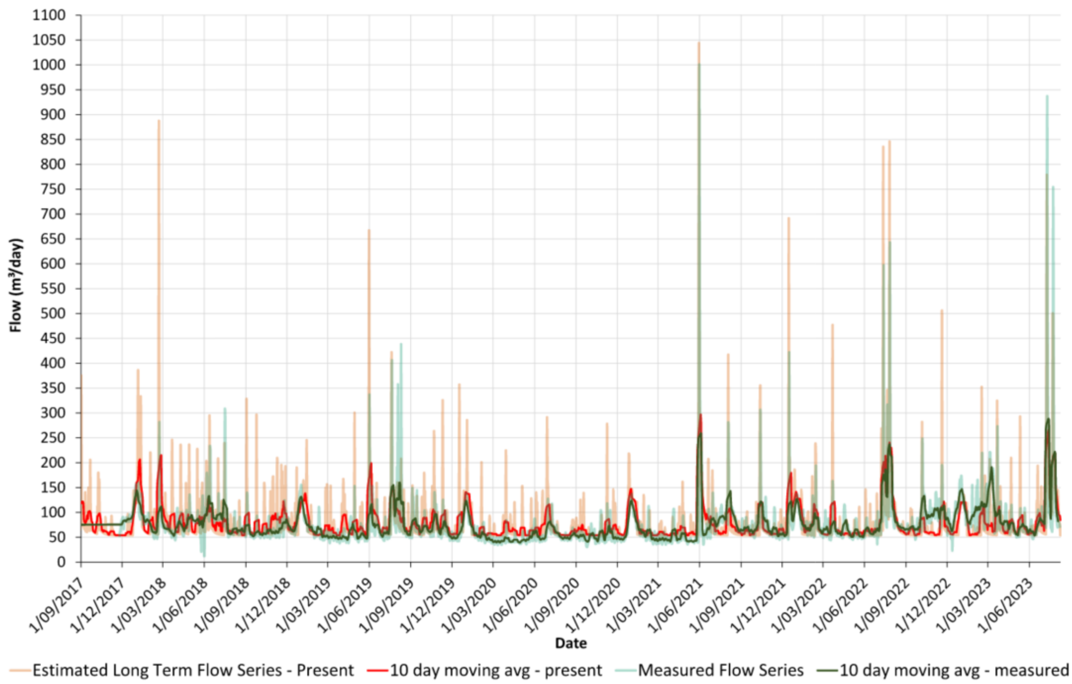


Figure 2 - Comparison of Modelled and Measured Flows

2.1.1 Comparison of Modelled Flows against Measured Flows

A comparison has been made between the synthetic 50-year irrigation flows and PS608 and 609 flow meter measurements from 2018 to 2023 to better understand differences in the modelled flows against measured flows. The modelled flows for this comparison have had non-climate change adjusted rainfall used and 2053 holiday growth removed – for fair comparison with measured data.

Time periods within the recent flowmeter data set are somewhat affected by the COVID pandemic. During the pandemic Akaroa visitors are known to have significantly reduced and therefore flowmeter readings are relatively low for certain periods. While Level 4 lockdown periods are considered to have had a severe impact on wastewater flow readings, baseflows through most of 2020 are significantly lower than the years preceding and following. It is however difficult to conclusively demonstrate population reductions outside of strict lockdown periods and it also understood that domestic tourism to the area may have even increased during some of these periods. Noting also that 2020 was a particularly dry year, it is difficult to exclude all of 2020 for comparative purposes.

Table 2 shows the modelled vs measured difference for the winter and early spring portions of the year that typically drive irrigation requirements.

Table 2 – Averaged Difference on Synthetic 50-year Modelled Flows against Measured for June-September

Year	Measured Flows (m^3)	Model Flow (m^3)	Difference
2018	9,723	9,221	-5%
2019	10,529	10,664	1%
2020	*3,059*[1]	*3,702*[1]	*21%*[1]
2021	*5,222*[1]	*5,027*[1]	*-4%*[1]
2022	11,312	11,417	1%
2023	8,570	8,617	1%
		Average	***2.5%***

Note 1. Excludes periods considered worst effected by COVID lockdown Mar-July 2020 and Aug-Sept 2021.

The synthetic 50-year flows are considered to model Winter and early Spring flow volumes reasonably tightly against measured data, with annually averaged differences within +/- 5% - except for 2020 which was a particularly dry year. The average difference across all measured years is <3%.

Table 3 shows modelled vs measured annual differences from 2018 to 2023.

Table 3 – Averaged Difference on Synthetic 50-year Modelled Flows against Measured Annually

Year	Measured Flows (m^3)	Model Flow (m^3)	Difference
2018	30,941	34,160	10%
2019	28,207	32,176	14%
2020	*22,372*[1]	*27,581*[1]	*19%*[1]
2021	*14,578*[1]	*17,333*[1]	*9%*[1]
2022	24,961	27,100	-7%
2023	22,996	20,183	-12%
		Average	***5.5%***

Note 1. Excludes periods considered worst effected by COVID lockdown Mar-July 2020 and Aug-Sept 2021.

Annual volume comparison shows a wider range of difference generally sitting between +20% and -10%, however summer periods have unpredictable population fluctuations and summer periods are not critical to the irrigation performance and requirements.

While summer flows are acknowledged to over-estimate against measured, the wetter months average differences are considered to lie within a reasonable tolerance given the uncertainties and anomalies with measured readings.

2.2 Future 2052 Flow Series

Future 2052 design flows have been projected using future parameters however the only adjustment from present day is a predicted 33% increase in summer holiday period occupancy. Table 4 shows modelled future parameters with the previous 2020 work future parameters also shown for reference.

Table 4 - Future Flow Series Factors

Parameter	Previous Factor Used	Updated Factor
I&I	20% RDI Reduction	0% I&I Reduction
	20% GWI Reduction	
Water Treatment Plant Backwash	10 m^3/d inclusion	0 m^3/d inclusion
Holiday Flow	33% increase	33% increase
Non-Holiday Flow	0% increase	0% increase

Table 5 summarises the measured and modelled flow statistics.

Table 5 - Measured and Modelled LTS Flow Results (PDP, 2023)

	Measured (2017-2023)	Modelled (2017-2023)	Modelled (Future)
Average (m3/d)	76	80	82
Median (m3/d)	64	57	57
Max (m3/d)	1,001	1,040	1,147
Min (m3/d)	12	54	54

3 Irrigation Modelling

The updated irrigation long time series flows have been used to re-run the Soil Moisture Balance (SMB) Irrigation model for the Duvauchelle scheme. Rainfall and modelled treated effluent flows are applied to the proposed irrigation areas from which the SMB model determines application capacity to land and alternatively, how much water needs to be stored. For further details around the SMB modelling refer to Appendix C (PDP, 2023).

3.1 Irrigation Parameters

Key modelling parameters for the scheme are summarised in Table 6.

Table 6 - Irrigation Modelling Parameters

Parameter	Spray Irrigation (Golf Course Playing Area)	Tree Dripper Irrigation
Area	6.36 ha (tees, fairways, greens)*1	8.2 ha (max available) 6.4 ha (sensitivity)*2
Irrigation Season	Summer only*3	All year round
Application rate	5 mm/d	Summer – 2.8 mm/d Autumn – 1.5 mm/d Winter – 1.0 mm/d Spring – 1.5 mm/d
Irrigation efficiency	85%	100%
Irrigation cut-off rainfall trigger	30 mm / day	

Note 1 – Spray irrigation area based on information provided by Akaroa Golf Club (AGC) on preferred course irrigation area

Note 2 – 6.4 ha sensitivity area based on more easily accessible tree zones (i.e. excludes the tree areas within the course)

Note 3 – Additional sensitivity runs used for no spray irrigation at all to understand storage size reliance on spray areas

One of the key parameters for the modelling is the tree dripper irrigation area, which has been determined using guidance from the USEPA around land treatment of municipal wastewater[2] – key recommendations being:

- Exclude land with slope of greater than 19 degrees unless a site-specific geotechnical assessment confirms land as suitable
- Exclude land with slope of greater than 15 degrees for land downslope to coastline
- Exclude land with identified instability within or downhill of area
- Exclude land that, if it became unstable, could pose risk to downslope residences and infrastructure

A site walkover assessment has been carried out by a Beca Geotechnical Engineer and Irrigation Specialist (Andrew Brough) to assess the suitable tree irrigation area with consideration of the above guidance and site investigations – a total of 8.2 hectares of suitable irrigable area was determined (as shown in Appendix A). Based on site conditions (soil type, slope and hill facing direction) a minimum winter application rate of 1mm/day has been set (1.5mm/day in the shoulder seasons) as appropriate to not heighten the risk of land instability.

An irrigation cut-off trigger has been set that if 30 mm of rainfall falls during a day the irrigation system turns off and all treated effluent is stored onsite (the system will operate again after the next day with zero rainfall).

[2] Process Design Manual for Land Treatment of Municipal Wastewater, USEPA (2011)

This trigger level has been set based on the same factors as the application rates (soil type, slope and hill facing direction).

Other considerations for irrigable area are stream and coastline setback and landscape effects – for further details refer to the Disposal and Reuse Options Assessment work by Beca (2020)[3].

3.2 Irrigation Scenarios

Irrigation scenarios have been run to primarily understand the likely overflow recurrence with given on-site (covered) storage volumes. Note that a set of models has been run without course playing area spray irrigation to understand the schemes dependence on irrigating these areas (noting that course playing areas are only intended to be irrigated in the drier summer months). While 8.2 hectares of area has been identified as suitable for tree dripper irrigation, sensitivity has also been assessed on a reduced 6.4 hectares which represents the "more easily" irrigated areas around the top of the course without needing to irrigate tree areas within the central areas of the course.

Table 7 summarises the modelled overflow recurrence reported across the 51-year simulation period for each fixed onsite storage scenario. Note that 'overflow seasons' are reported below which indicate the number of irrigation seasons (i.e. years) that overflows occur in the model. Discrete overflow events and whether or not repeat overflows occur within an irrigation season are subject to a number of operational and regulatory aspects such as;

- how overflows will be managed (whether storage will be further drawn-down to provide capacity following an overflow) – how much and at what rate? etc.
- What will define an overflow 'event' – i.e. how many days between storage spilling defines a new event?

The irrigation modelling undertaken does not capture the above resolution and therefore 'overflow seasons' have been reported and are discussed further below.

Table 7 - Irrigation Scenario Results - Storage Volumes and Overflow Seasons (PDP, 2023)[4]

Scenario	Storage Volume (m^3)	Storage Overflow Seasons (51-years)
Scenario 1 8.2 ha tree dripper area + 6.36 ha course spray area	5,300	0
	4,000	5
	2,000	25
Scenario 2 8.2 ha Tree dripper area (no course spraying)	5,300	0
	4,000	5
	2,000	25
Scenario 3 6.4 ha tree dripper area + 6.36 ha course spray area	6,500	0
	4,000	17
	2,000	32
Scenario 4 6.4 ha tree dripper irrigation (no course spraying)	6,500	0
	4,000	17
	2,000	33

[3] Duvauchelle Wastewater Summary of Disposal and Reuse Options, Beca (2020)

[4] Irrigation Model Results for Land Disposal of Recycled Water at Duvauchelle – Comparison of Areas, PDP (2023)

Irrigation model runs using the updated flow series and climate change adjusted rainfall data have suggested that to prevent any overflows from occurring during the 51-year modelled period, with the maximum available (and suitable) tree irrigation area (8.2ha), a covered storage volume of 5,300m^3 would be needed. Likewise, but utilising a smaller irrigation area of 6.4ha would require 6,500m^3 of storage to prevent overflows.

Utilising a smaller storage of 4,000m^3 and the preferred tree irrigation area of 6.4ha results in 17 modelled overflow seasons across the 51-year period. A further reduction in storage to 2,000m^3 (6.4ha) results in 32 modelled overflow seasons. Note that for the 2,000m^3 storage scenario the modelled overflow volumes are significant (often greater than the storage volume itself) and therefore draw-down and other operational approaches are unlikely to be able to avoid repeat overflow events within a season. For example, assuming no initial draw-down, and that a new overflow event is defined as an overflow occurring at least two days following the preceding overflow, the modelled 6.4ha tree irrigation scenario with 2,000m^3 storage suggests that up to 96 individual overflow events could occur (32 overflow seasons/years). Results for the 4,000m^3 scenarios suggest overflow volumes could likely be managed with operational approaches to avoid repeat overflows within a season.

There appears to be negligible difference between overflow recurrence with or without golf course spray irrigation (noting a minor improvement of 3% occurring only at the 2,000m^3 scenario and that this modelled event is over-estimated compared with measured data). This is due to the disposal of recycled water during winter months being the limiting factor that drives peak storage requirements. Also noting it is unlikely that the golf course would opt to irrigate their course during significant rainfall events in the summer.

The 1.8ha reduction sensitivity run (scenarios 3 and 4) require an additional 1,200m^3 of storage to avoid overflows. It should be noted that this is not a linear relationship. Any alternative area reduction scenarios should be modelled to confirm outcomes.

Note that consideration should be given to short-term water demands during establishment of the tree dripper plantations (assuming a large portion of the tree areas are replanted). It is expected that during the establishment years there will be a demand to preferentially irrigate the young trees during the summer which will likely significantly reduce the amount of treated effluent able to be utilised by the golf club for spray irrigation of the playing areas.

4 WWTP Flows

Modelled current and future flows relevant to the WWTP design and capacity are summarised in Table 8.

Table 8: Modelled Duvauchelle WWTP Daily Flow

<table>
<tr><th>WWTP Flows</th><th>Flow Parameter</th><th>Unit</th><th>Typical Domestic</th><th>Peak Summer</th></tr>
<tr><td></td><td></td><td>Period</td><td>Feb - December</td><td>31st Dec – 6th Jan</td></tr>
<tr><td rowspan="3">2023</td><td>Average Dry Weather Flow (ADWF)</td><td>m^3/d</td><td>54</td><td>119</td></tr>
<tr><td>Average Daily Flow (ADF)</td><td>m^3/d</td><td>80</td><td>136</td></tr>
<tr><td>Maximum Daily Flow (MDF)</td><td>m^3/d</td><td colspan="2">1,040</td></tr>
<tr><td rowspan="3">2053</td><td>Average Dry Weather Flow (ADWF)</td><td>m^3/d</td><td>54</td><td>158</td></tr>
<tr><td>Average Daily Flow (ADF)</td><td>m^3/d</td><td>82[*1]</td><td>175[*2]</td></tr>
<tr><td>Maximum Daily Flow (MDF)</td><td>m^3/d</td><td colspan="2">1,147</td></tr>
</table>

Note 1. Assumed no domestic population growth through to 2053 (CCC)

Note 2. 2053 flows have been modelled by applying a future 33% visitor growth factor (CCC).

5 Scheme Resilience

The Duvauchelle Wastewater Scheme is significantly smaller than the Akaroa scheme and there is no existing wastewater network model to derive design flows from. Flows for the scheme have been estimated using flow meter data from the WWTP and the two pump stations (PS608 and 609) that discharge into the WWTP. Overflow records (provided by Council) for the Duvauchelle Wastewater Scheme suggest overflows have occurred at least six times over the last two years:

- Three overflows at PS609 (July ’22, March ’23 and July ’23)
- Two overflows at the WWTP (May ’21 and Dec 21)
- One overflow at 35 Seafield Road, Duvauchelle (July ’21)

The flow basis for the scheme is derived from network conveyance data and does not include network overflows (extreme events). An average recurrence Interval (ARI) resilience for the irrigation system cannot be accurately determined without developing a network model and better understanding scheme and overflow performance during extreme events.

As with any critical Council infrastructure, consideration will be needed as to what happens during extreme ‘black swan’ events and whether wastewater system responses pose any risks to the assets, the community or the environment.

6 Data Accuracy and Flow Uncertainties

It should be noted that the flows determined from this modelling exercise are a simplistic “best-fit” prediction of the expected future performance of the Duvauchelle wastewater network. Differences between modelled and measured flows should be expected for future events due to the dynamics of network response that the model cannot fully account for. It is recommended that a sensible margin is allowed for when sizing infrastructure based on these results to account for modelling inaccuracy.

The climate change adjustments factored into the modelling are based on an overall probabilistic assessment by the MfE. The probabilistic approach cannot forecast extreme individual “black swan” rainfall events (i.e. extreme future rainfall events that are larger than those experienced over the time period of the modelling) or the associated network flow response. Recent black swan events include Cyclone Gabrielle and the extreme rainfall event that occurred at Akaroa on 24th of July 2023. Such black swan events are expected to occur with increased frequency and can strike randomly in any location at any time. As the modelling cannot anticipate them, Council should expect that the design basis flow settings for the Duvauchelle Wastewater Scheme will be exceeded on occasions in future.

7 Summary

The Duvauchelle Wastewater Scheme design flow basis has been updated using the latest flow meter data through to July 2023. The inferred relationship between RDII and rainfall has been adjusted based on the additional data and has had the fixed GWI component (from previous 2020 work) removed as considered a more appropriate fit with measured and modelled flows. Further modifications to the flow basis include removal of the fixed 10m^3/d Duvauchelle Water Treatment Plant backwash (as no longer proposed) and removal of the 20% future I&I reduction factor as updated data now largely reflects physical I&I improvement works to the network. An allowance has also been made for soil store slow response following rainfall events.

A comparison has been made between the synthetic 50-year irrigation flows and PS608 and 609 flow meter measurements from 2018 to 2023 to better understand differences in the synthesized flows against measured flows. The synthetic 50-year flows are considered to model Winter and early Spring flow volumes reasonably tightly against measured data, with annually averaged differences within +/- 5% - except for 2020 which was a particularly dry year. The average difference across all measured years is <3%

Utilising a smaller storage of 4,000m^3 and the preferred tree irrigation area of 6.4ha results in 17 modelled overflow seasons across the 51-year period. A further reduction in storage to 2,000m^3 (6.4ha) results in 32 modelled overflow seasons. Note that at the 2,000m^3 storage scenario the modelled overflow volumes are significant (often greater than the storage volume itself) and therefore draw-down and other operational approaches are unlikely to be able to avoid repeat overflow events within a season. Results for the 4,000m^3 scenarios suggest overflow volumes could likely be managed with operational approaches to avoid repeat overflows within a season.

Negligible difference was found between overflow recurrence with or without golf course spray irrigation (noting a minor improvement of 3% occurring only at the 2,000m^3 scenario and that this modelled event is over-estimated compared with measured data). This is due to the disposal of recycled water during winter months being the limiting factor that drives peak storage requirements. Also noting it is unlikely that the golf course would opt to irrigate their course during significant rainfall events in the summer.

The design basis approach for this scheme upgrade work is based on the capacity of the current network and does not include conveyance of extreme events and/or overflows to the WWTP and irrigation to land system. An average recurrence Interval (ARI) resilience for the irrigation system cannot be accurately determined without developing a network model and better understanding scheme and overflow performance during extreme events. As with any critical Council infrastructure, consideration will be needed as to what happens during extreme 'black swan' events and whether wastewater system responses pose any risks to the assets, the community or the environment.

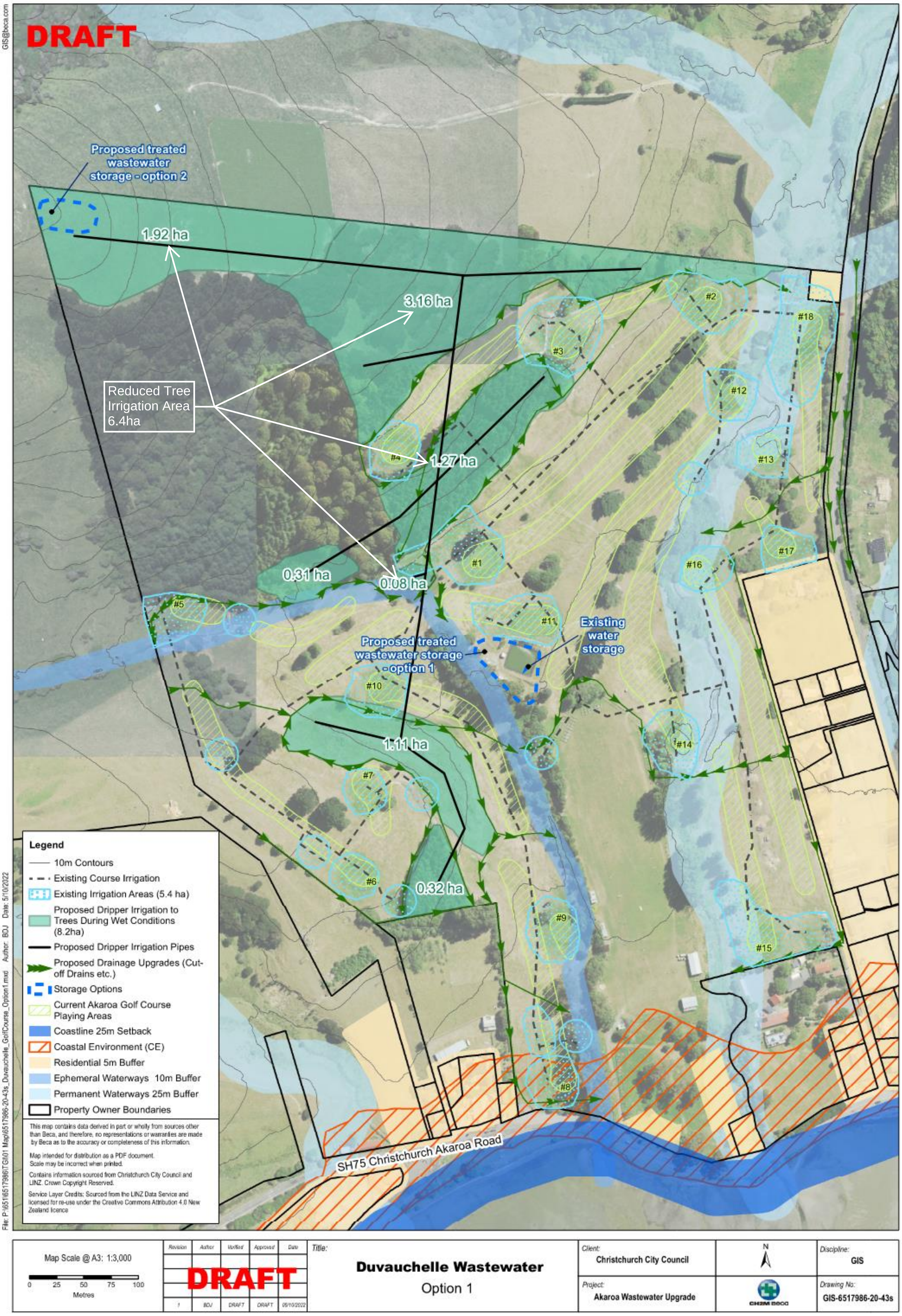
It should be noted that the flows determined from this modelling exercise are a simplistic "best-fit" prediction of future performance of the Duvauchelle wastewater network. Differences between modelled and measured flows should be expected for future events due to the dynamics of network response that the model cannot fully account for. It is recommended that a sensible margin is allowed for when sizing infrastructure based on these results to account for modelling inaccuracy.

A

Appendix A – Duvauchelle Wastewater Scheme - Overview Concept

Sensitivity: General

Attachment 1 – Option 1 Overview Plan



B

Appendix B – Duvauchelle WWTP Land Disposal Modelling – Updated WWTP Flow Series (2023)

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18 December 2023

Innes Duncan
Senior Civil Engineer
Beca
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Dear Innes

DUVAUCHELLE WWTP LAND DISPOSAL MODELLING – UPDATED WWTP FLOW SERIES

1.0 Introduction

Beca Ltd is investigating options for the disposal of recycled water from the Duvauchelle wastewater treatment plant (WWTP) for Christchurch City Council (CCC). As part of this project, Pattle Delamore Partners Ltd (PDP) have been engaged by Beca to develop a soil moisture balance model (SMB) for the irrigation of recycled water to land at the Akaroa Golf Club (Golf Club) located in Duvauchelle.

Previous modelling (Pattle Delamore Partners Ltd, December 2020) has been based on measured flow data recorded at the outlet of the Wastewater Treatment Plant (WWTP). Data was used from the period 1 December 2017 to 21 October 2020. Subsequent flow data is now available, allowing this data series to be extended to 7 August 2023. PDP have been requested to update the model to incorporate this new data.

As per previous work[1], PDP have created an adjusted flow series to account for the internal pipework configuration of the WWTP causing the measured outlet flows to be overstated at times. As a part of this, PDP have been informed that work was undertaken in mid-2021 to fix the overstatement of flows. This has been accounted for when creating the adjusted flow series, with key dates/methods described within this letter.

The adjusted flow series is used to derive the following:

- A relationship between rainfall and rainfall derived inflow and infiltration (RDII) entering the wastewater network, and
- A relationship between RDII and a soil store component, taken to represent the portion of the rainfall considered to be held within the soil where it slowly enters the wastewater network via inflow and infiltration. This is observed as a tail to the immediate RDII response.

[1] Letter to Beca Dated 15th December 2020, "Duvauchelle WWTP Land Disposal Modelling – Updated Flow Series", Pattle Delamore Partners Ltd

A synthetic flow series was generated for a 51-year time period by applying the above relationships to historic rainfall data which had been adjusted for projected climate change effects (adjustment for climate change completed by Beca). This synthetic flow series is used to model the disposal of the recycled water to land by irrigation. The irrigation model uses a daily timestep and models the SMB over the 51-year period.

This letter has been prepared to describe the work done to prepare an adjusted flow series for use in estimating the I&I component in the long-term irrigation model. A long-term WWTP outflow series has been developed to be incorporated into the SMB model.

2.0 Available Flow Data

The adjusted flow series is built on multiple sets of flow data. These can be split into two categories:

- Pump station (PS) flow data (PS608 and PS609) from 22 November 2018 to 7 August 2023; and,
- WWTP flow data from 25 November 2017 to 7 August 2023.

Prior to 2021, the flow meter for the WWTP outlet was understood to be located upstream of an offtake which recirculates flow back into the WWTP. This resulted in an overestimate of the volume being discharged as a proportion is diverted back through the treatment plant. CCC advised that the flow meter was relocated in mid-2021, however, no specific date was provided. From the data, PDP estimates the change to have occurred around 27 June 2021.

CCC has indicated that the measured pump station flow is therefore a more accurate measure of the true flow through the WWTP. The pump stations are therefore considered more appropriate to estimate the I&I contribution for the long-term flow series. However, the WWTP flow records are available for a longer period, so are more useful for understanding the effect of rainfall on flow at the WWTP (inflow and infiltration). PDP have been asked to derive a relationship between the pump station flow data and the WWTP outflow data. The relationship will be used to adjust the WWTP flows where the pump station flows were not available. To avoid the recent data skewing the relationship between WWTP and pump station flows, data post-27 June 2021 has not been included when determining this relationship.

The source of each data series is further discussed in the sections below.

In addition, CCC provided Beca with data from potable water consumption data sourced from flow meters in the water network. The meters were read at varying frequencies, typically 3-6 monthly. This data was used as a comparison and check against the wastewater flow data.

2.1 Pump Station Flow Data

All wastewater flow entering the treatment plant passes through one of two pump stations (PS608 and PS609). The flows from both pump stations were summed to get a total flow rate entering the WWTP.

Flow data from these pump stations is available from 22 November 2018 to 7 August 2023. The data was provided as a mix of daily flows; and as SCADA outputs (pump start & stop times, instantaneous flows along with cumulative totals for each 24-hour period).

2.2 WWTP Flow Data

WWTP daily flow data had previously been provided from 1 December 2017 to 21 October 2020. As a part of this work, Beca has provided an extended series with daily flow data from 25 November 2017 up until 7 August 2023. As minimal difference was seen between the two series within the period of overlap, the extended series provided by Beca was used going forward.

Some “cleaning” of the data was completed at obvious outlier dates. This included days with negative flows and days of zero flows, immediately followed by extremely high volumes. As the Beca provided daily flow data is based on a Totaliser value, this was not unexpected with potential reading errors/meter resets. Outlier values were removed and not replaced.

3.0 Measured Flow Series

The two datasets (WWTP and PS flows) were reviewed to assess differences.

Some differences between the flow recorded at the inlet and outlet of the WWTP can be expected. These can be expected to be due to factors such as:

- The standard range of accuracy associated with each of the flow recording devices;
- The time lag within the system between the pump station and the WWTP recorders;
- Liquid removed through the solids stream of the WWTP;
- Additional rainfall on the WWTP tanks; and
- Flow recirculated back through the WWTP.

The flow records from the combined pump stations and the WWTP outlet are shown in Figure 1.

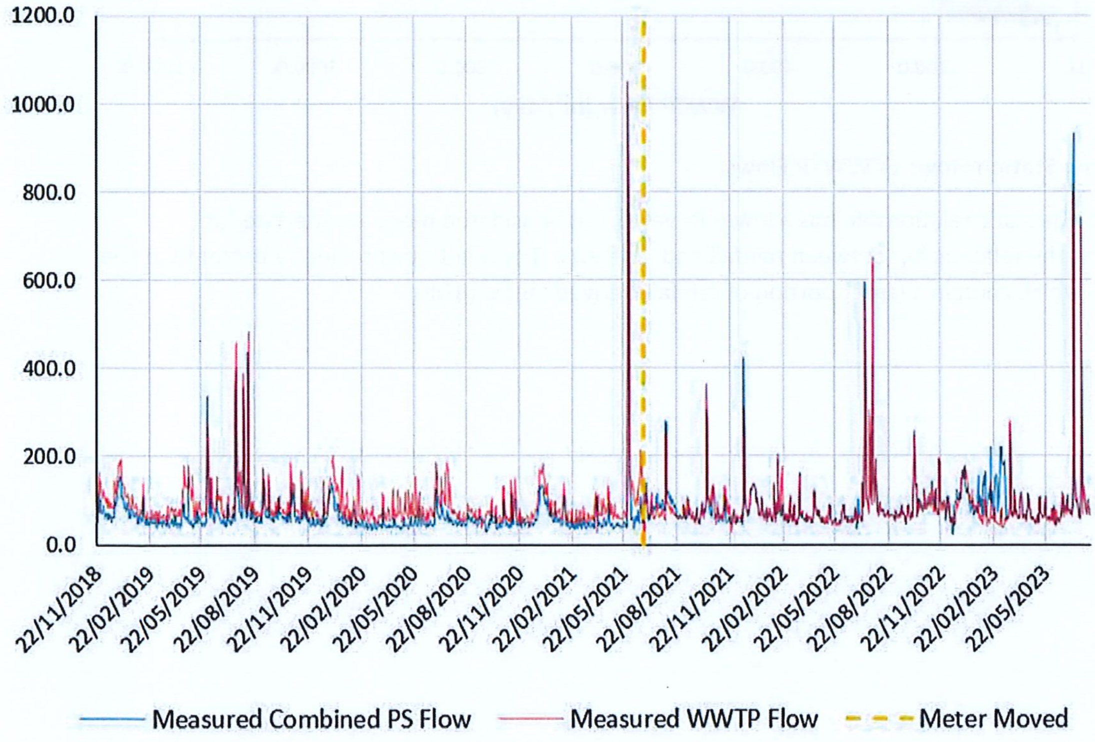

Figure 1: Combined Pump Station Flow vs WWTP Flow, Showing Estimated Date when Meter was Moved.

The measurements from the WWTP are consistently higher than the combined pump station flows prior to June 2021. The difference during dry weather is approximately 20 m^3/day. This offset during dry weather flow is consistent with the understanding that the WWTP flow meter is counting a recirculation flow.

During wet weather, the peaks in flow are more pronounced at the WWTP than at the pump stations. The flow patterns from the two series do not always closely match. On some occasions there are peaks in the WWTP flow that are not present in the pump station flow – an example is around 19 July 2020.

Figure 2 shows the two flow datasets plotted against each other. Two relationships have been derived, a linear relationship with the y-intercept set at 0, and a second-order quadratic relationship.

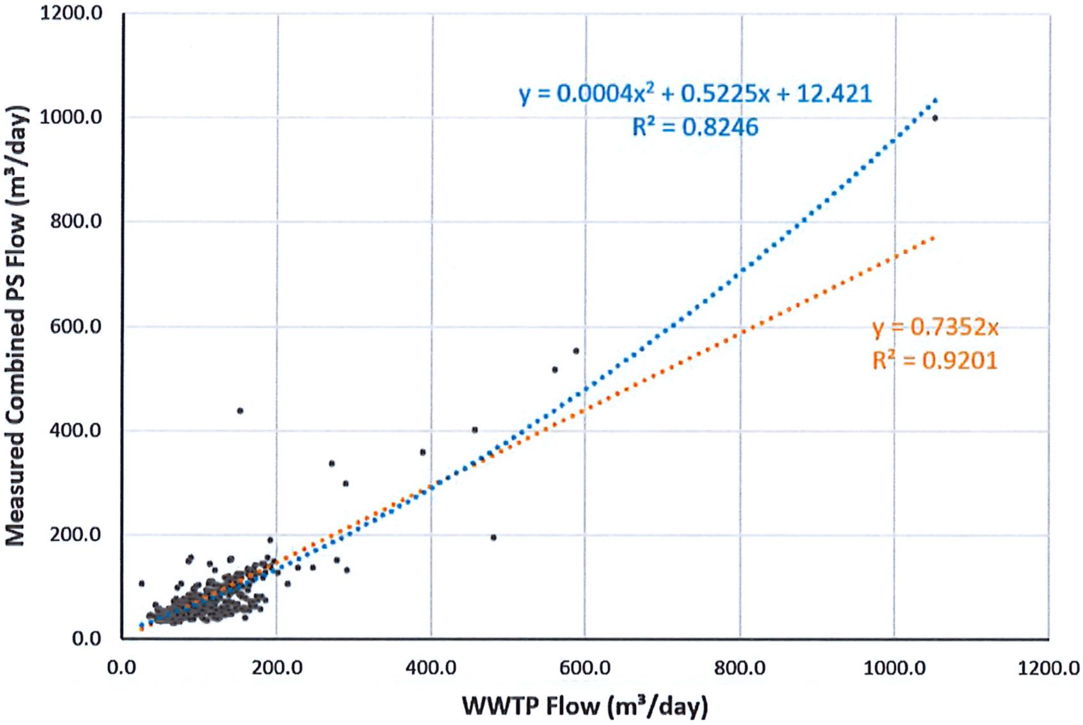

Figure 2: Pump Station Flows vs WWTP Flows.

Although the quadratic relationship has a lower R^2 value, it is considered more appropriate for understanding the relationship between rainfall and I&I flows. The quadratic provides a better fit at the higher flows, which contain a larger portion of rainfall-derived inflow (RDII).

Figure 3 shows the measured WWTP outlet flow (in red) against the adjusted wastewater flow which will be used to estimate the RDII relationship over the long-term model time series (shown in green and blue). The quadratic relationship was applied to the longer WWTP flow series to estimate the flow at the pump station recorder for the earlier period where only WWTP data was available. The measured pump station data is used where available.

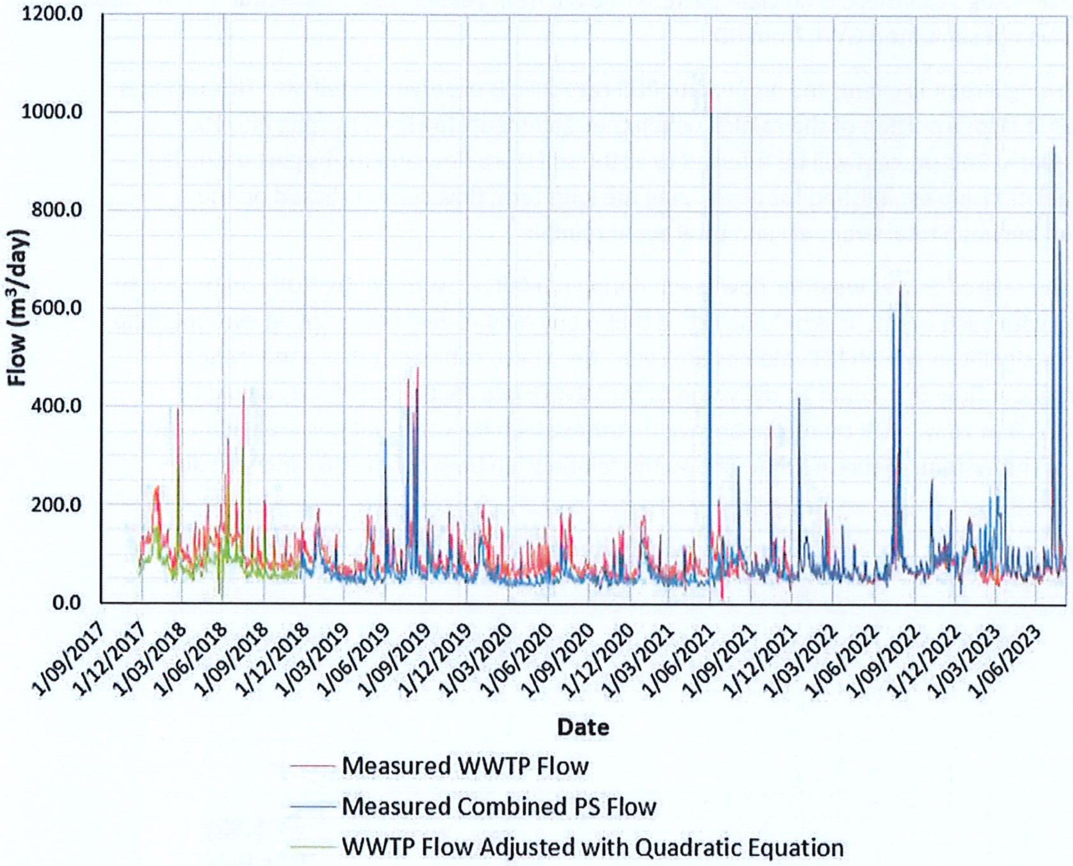

Figure 3: "Adjusted" Flow (WWTP Flow Adjusted with Quadratic Relationship + Measured PS Flow, Used to Estimate I&I) vs Measured WWTP Flows.

4.0 Long Term Flow Series

4.1 Dry Weather Flow Values

Previous modelling work has used a dry weather flow of 54 m^3/day (rising to 119 m^3/day during holiday periods). This was based on a visual inspection of the WWTP flow series. With the additional period of data, further inspection indicated a reduction in flows during periods of COVID-19 lockdowns (2020 – 2021) with increases seen in recent high rainfall years. It was deemed overall that the approximation of 54 m^3/day and 119 m^3/day during holiday periods is still considered appropriate for the WWTP outlet flow series.

4.2 Inflow and Infiltration Relationship

Previous work determined an inflow and Infiltration (I&I) flow with two components; rainfall inflow and infiltration (RDII), and groundwater inflow and infiltration (GWII). A GWII was only applied in one of the three years analysed (2018, 45 m³/day between the months of May to July inclusive) with the other two years (2019, 2020) assumed to be significantly dry such that no GWII was observed. Using the longer data set spanning 2018 – Aug 2023 there is no clear pattern to GWII from year-to-year. Consequently, for this modelling we have not separated GWII from RDII.

In the days following a rainfall event, the immediate RDII response is observed to tail off. This tailing is estimated to result from a portion of the rainfall within the catchment slowly infiltrating into the wastewater network. This process will be referred to as the soil store flow and forms part of the I&I response. The relationship established for developing the long-term flow series is based on the relationship seen between total event I&I and total event rainfall.

Rainfall events are related to wet weather flows seen during rainfall to estimate the RDII component of flows associated with each event. It should be noted that many rainfall events continued over multiple days, hence some significantly high I&I volumes are seen. Beca have estimated that a theoretical maximum wastewater flow that could be delivered to the WWTP (via PS608 and PS609) would be approximately 1,200 m³/day. PDP therefore believe that these high I&I contributions are within the practical limits of the system. Figure 4 below shows the relationship between the I&I and rainfall.

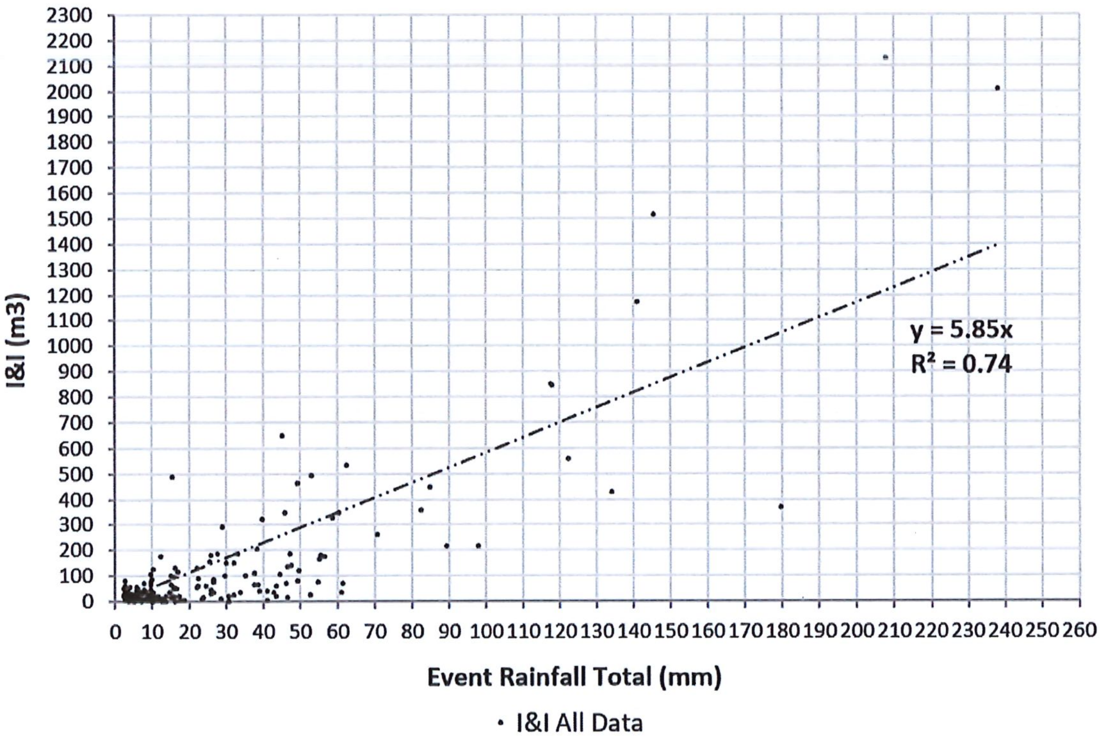

Figure 4: I&I vs Event Total Rainfall for Adjusted Flow Series Data (December 2017 to August 2023).

The rainfall used to estimate the wet weather component of the flow was a combination of the following:

- Duvauchelle CWS (Akaroa Golf Course) data, where available (18 September 2020 to 7 August 2023 (end of series))
- Akaroa EWS prior to this date (25 November 2017 (start of the series) to 17 September 2020))

Duvauchelle CWS data was used preferentially as this was deemed to be the most appropriate rainfall for the area of the network where I&I would be occurring.

Following a RDII event, a portion of the flows form the soil store flow which then decays over time. The soil store relationship is empirically estimated as shown in Equation 1, where the coefficient C is described in Table 1. The parameters in Equation 1 have been calibrated to best match measured flows from June to September (inclusive). These winter months drive the peak storage requirements in the soil moisture modelling.

$$\textit{soil store flow} = RDII \times C \times exp^{-0.12*days}$$

Equation 1: Soil Store flow equation

Table 1: Soil Store Coefficients

Rainfall[1]	C
<30 mm[2]	0
30 mm to 100 mm	0.05
> 100 mm	0.125

Notes:

1. *Rainfall event totals*
2. *No Soil store estimated for rainfall events below 30 mm*

4.3 Modelled Flow Series

The long-term synthetic flow series used for modelling the irrigation of recycled wastewater is developed by adding weather-related I&I to the dry weather flow. The I&I is estimated using the relationship with rainfall shown in Figure 4, applied to a long-term rainfall data set. The following section details how this data set was found.

4.3.1 Long-Term Rainfall and Evapotranspiration Data

The modelling process uses a long-term daily climate data set in two ways. These are as follows:

- Long-term daily rainfall data is used to estimate the component of wet weather flow in the synthetic series.
- Long-term daily climate data (rainfall and PET) is used within the SMB model to calculate the soil moisture balance. This governs the volume of treated wastewater which can be irrigated in deficit irrigation scenarios.

Historically, the nearest weather station to the site is the Onawe Duvauchelle Bay weather station (Station 327901) administered by NIWA. The station is located approximately 2 km to the south of the site. NIWA records the altitude of this station at 46 m which is slightly higher than the proposed irrigation area. Daily rainfall is available from this site between 1934 and 2012. The rainfall record for the site is virtually complete with complete records in all but two years between 1934 and 2012.

In 2020, a new rain gauge was set up at the Akaroa golf course (Duvauchelle CWS). This has recorded the daily rainfall to date.

The period of record for the Onawe and Duvauchelle stations is insufficient as the rainfall data terminates at the end of 2012 until resuming with the Duvauchelle CWS data in 2020. Furthermore, evapotranspiration data is not available for either site.

NIWA maintains Virtual Climate Network Station (VCSN) data within New Zealand which provides long-term estimated daily weather data across a 5 by 5 km grid. The nearest VCSN digital node to the site is VCSN 20116 located approximately 2.5 km to the north of the site.

The altitude of this node is approximately 400 m which is significantly higher than the proposed irrigation area. Daily rainfall for the VCSN 20116 node is available from 1960 to present.

It is likely that due to its higher elevation, the VCSN20116 node overestimates the rainfall at the site. Because of its lower elevation, the Onawe station is likely to better represent rainfall at the site. Figure 5 shows a comparison of daily rainfall from the VCSN20116 node and the Onawe station for the year 2012.

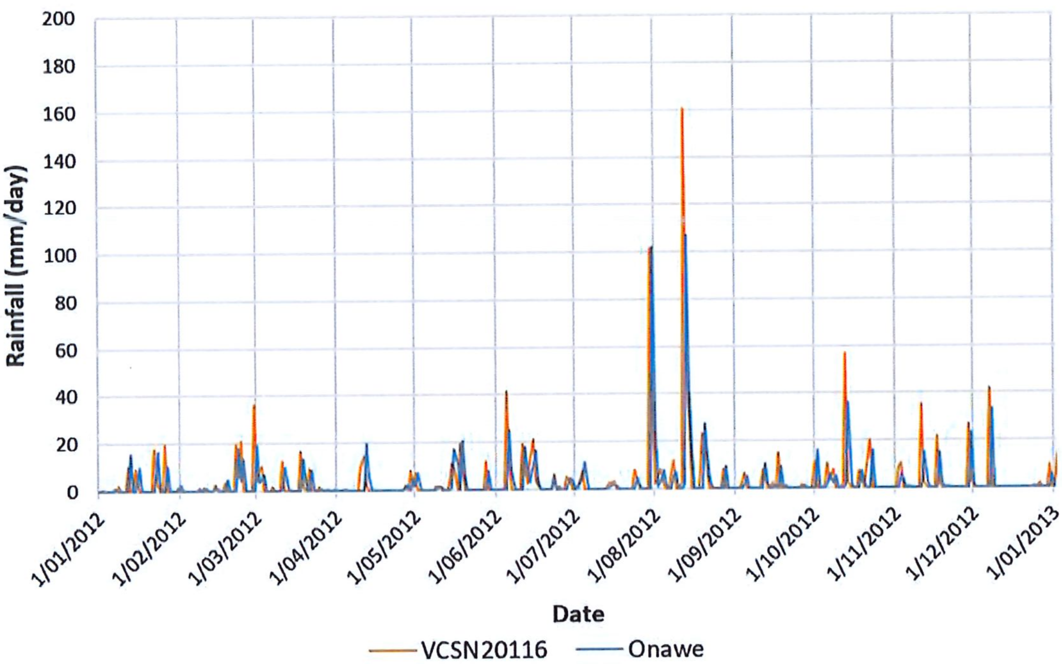

Figure 5: Daily VCSN 20116 vs Onawe Rainfall Data for the Year 2012.

Figure 5 shows that the VCSN 20116 node typically overestimates daily rainfall compared to the Onawe station. Rainfall appears to be overestimated for all magnitudes of rainfall events. The same applies when comparing VCSN 20116 daily rainfall to data from the Duvauchelle CWS (Akaroa Golf) station. This can be seen in Figure 6 below.

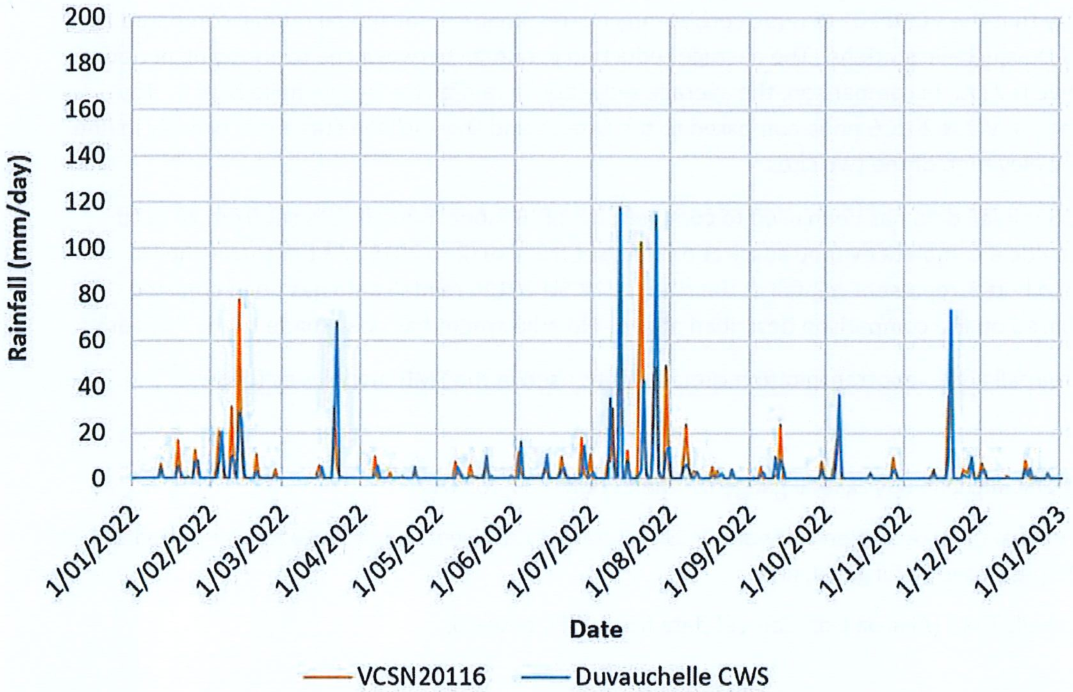

Figure 6: Daily VCSN 20116 vs Duvauchelle CWS Rainfall Data for the Year 2022.

Figure 7 shows the total annual rainfall for the VCSN 20116 node, Onawe and Duvauchelle CWS stations for the overlapping records (1960 to 2023).

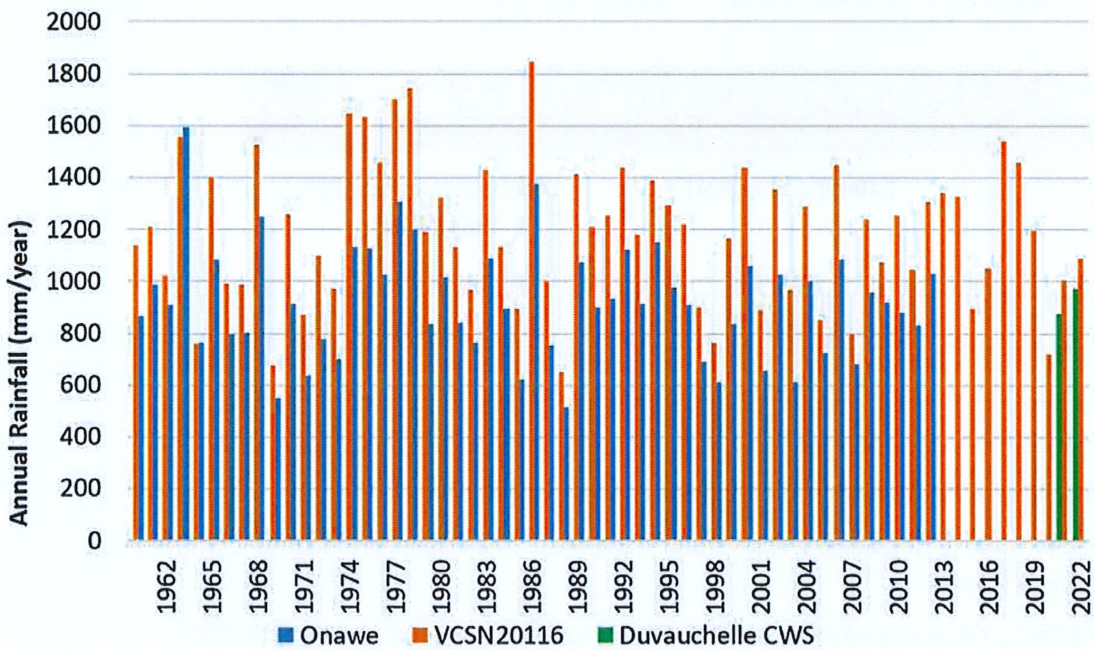

Figure 7: Annual VCSN 20116, Onawe and Duvauchelle CWS Rainfall Totals.

Figures 5-7 show that the VCSN 20116 node consistently overestimates total annual rainfall compared to the Onawe and Duvauchelle stations. The average reduction in rainfall between the overlapping period of record for Onawe is 23%. In comparison, the average reduction in rainfall for Duvauchelle is 14%. The higher rainfall at the VCSN 20116 node compared to the Onawe and Duvauchelle stations is broadly in line with the relative elevation of the two sites.

The VCSN 20116 rainfall data has been used to complete the SMB model rainfall data set from 2013 to 2019 and to provide a complete evapotranspiration data set from 1972 to 2019. As the Duvauchelle station is likely to better represent rainfall at the site, the VCSN 20116 rainfall data has been adjusted down by 14% based on the comparison described above. No adjustment has been made to the PET series.

The final daily rainfall and evapotranspiration climate series used in the SMB model is as follows:

Rainfall:

- Onawe Duvauchelle Bay rainfall gauge for the period 1972 to 2012,
- NIWA Virtual Climate Station Network (VCSN) station 20116 (reduced by 14%) for the period 2012 to 2020 (also used to fill gaps), and
- Duvauchelle CWS (Akaroa Golf Course) data from 2020 onwards.

PET:

- NIWA VCSN 20116 evapotranspiration (PET) from 1972 to 2023.

Note that the period of record for the VCSN 20116 PET starts in 1972 so limits the model period from 1972 to 2023.

Table 2 provides the key climate statistics for the final climate series used.

Table 2: Combined Daily Climate Statistics: Onawe (1972 to 2012) + VCSN20116 (2013 to 2020) + Duvauchelle CWS (2020 to 2023)

	Rainfall (mm/year)	Evapotranspiration PET (mm/year)
Average	936	828
Median	916	838
Max	1376	996
Min	516	388

4.3.2 Applying the Rainfall Series to Estimate Wet-Weather Flows

The 51-year rainfall data set (found above) was used in two ways when creating a long-term synthetic flow series. These are as follows:

- The rainfall series was used along with the I&I relationship to develop a wet weather flow component over the 51 years of data. This was added to the estimated dry weather flow to produce a synthetic long-term flow series equivalent to "present" conditions. This was done to assess the model fit to the recorded WWTP data. The purpose of the flows is to size peak recycled water storage. Therefore, emphasis was placed on calibrating to the winter flows which drive peak storage.

- The same rainfall series was provided to Beca who adjusted each rainfall event for projected climate change impacts. This adjusted series was then used along with the I&I relationship to develop a wet weather flow component over the 51 years of data (as above). This was then added to the estimated dry weather flows with the scaling factors shown in Table 3 applied, to produce a second synthetic long-term flow series equivalent to "future" conditions. This is the flow series that is taken into the SMB model for sizing storage.

Note that within Table 3, factors used in previous modelling work are shown. This was done to provide clarity on the differences between current and previous modelling. Changes include no reduction in I&I (due to planned network improvements having already been completed) and the removal of the "water treatment plant backwash" (due to planned design changes). No change has been made to future holiday and non-holiday flows.

Table 3: Future Flow Series Factors

Parameter	Previous Factor Used	Updated Factor
I&I	20% RDII reduction 20% GWI reduction	0% I&I Reduction
Water Treatment Plant backwash	10 m^3/day inclusion	0 m^3/day inclusion
Holiday Flow	33% increase	33% increase
Non-Holiday Flow	0% increase	0% increase

Figure 8 and Figure 9 below show the two long-term flow series compared to measured flows (i.e., the "adjusted" series created above) over the period of available data. Measured flows are as per the green/blue series shown above in Figure 3.

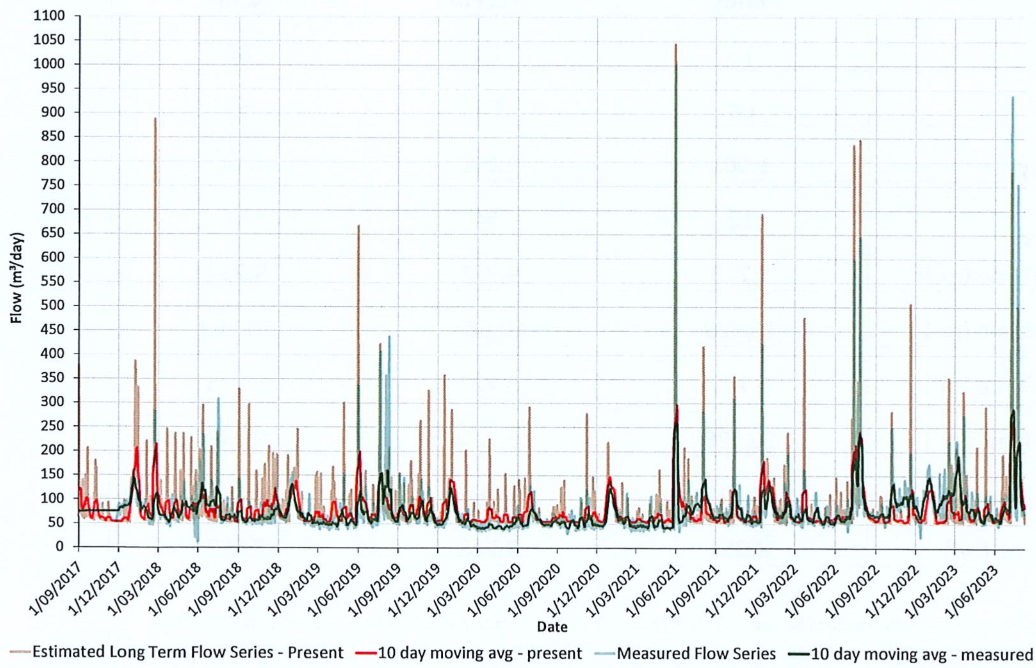

Figure 8: Measured Flow vs Synthetic Series (Present).

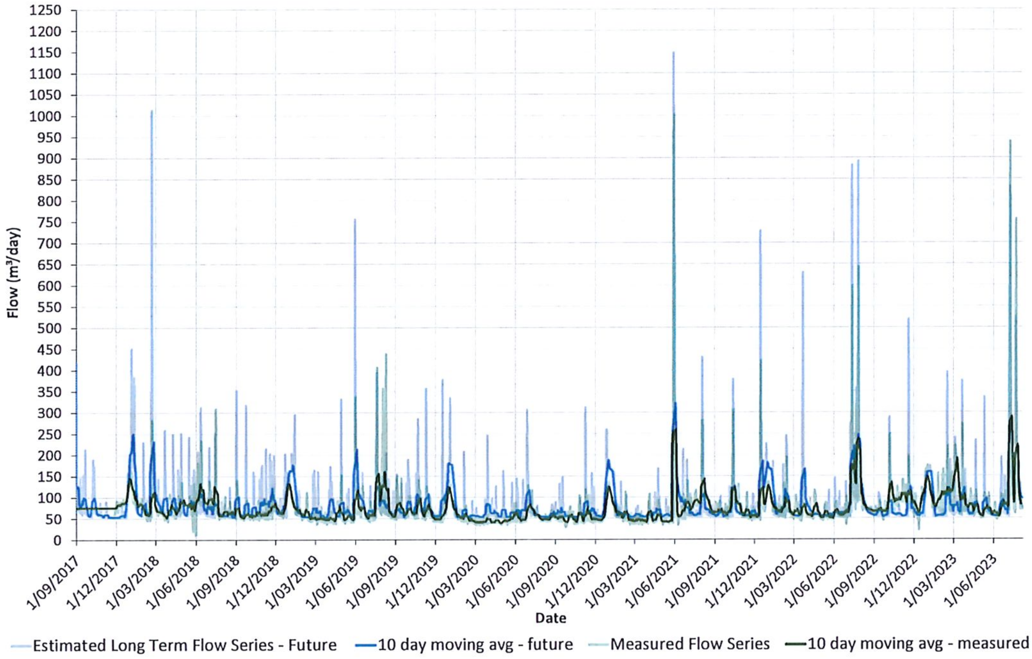

Figure 9: Measured Flow vs synthetic series (Future).

Table 4 below compares the WWTP flow measurements against the flow series presented in Figure 8 and Figure 9.

Table 4: Flow Statistics between December 2017 and August 2023

	Measured Flow Series[1]	Modelled Flow - Present	Modelled Flow - Future
Average (m^3/day)	76	80	82
Median (m^3/day)	64	57	57
Max Event[2] (m^3/day)	1,001	1,040	1,147
Min (m^3/day)	12	54	54
2018 Jun - Sept Volume (m^3)	9,723	9,221	9,234
2019 Jun - Sept Volume (m^3)	10,529	10,664	10,193
2020 Jun - Sept Volume (m^3)	6,709	8,223	8,086
2021 Jun - Sept Volume (m^3)	10,188	9,225	9,342
2022 Jun - Sept Volume (m^3)	11,312	11,417	11,450
2023 Jun - Jul Volume (m^3)	8,014	7,918	7,892

Notes:

1. *WWTP Flow adjusted with quadratic equation between 25/11/2017 and 21/11/2018. Measured PS data from 22/11/2018 to 07/08/2023.*
2. *The event classification for this measure is the sum of flows that occur during rainfall days for a given event. The event classification is the same as in the soil moisture model, where rainfall after one no-rainfall day will be a new event.*
3. *The measured data during 2020 and 2021 are expected to have additional variance due to the influence of COVID lockdowns.*

5.0 Conclusion and Recommended Flow

The long-term synthetic "future" flow series will be used as the WWTP outflow to be irrigated onto land in the soil moisture balance model. This series has been developed using an estimated I&I and dry weather flow based on measured Duvauchelle wastewater pump stations and wastewater treatment plant data.

The WWTP flow is known to have historically included a recirculation flow. As per the directions of CCC, the pump station flow has been used as a better representation of wastewater volumes. Due to the WWTP flow data being present over a longer period, a relationship between WWTP and pump station flows was established so that a more "complete" pump station flow series could be found to better estimate I&I to the network. Knowing that the flow meter on the WWTP flow was eventually moved, PDP have created this relationship on data up until the change to avoid skewing the relationship. This date was determined to be the 27 June 2021.

The I&I was estimated as RDII and Soil Store. This was due to the extended wastewater flow series showing a tailing of flows following a wet weather event. A relationship between event total I&I and event total rainfall was estimated by comparing pump station flows to the rainfall from the Akaroa EWS and Duvauchelle CWS rainfall stations.

A 51-year rainfall dataset was then created. This is a combination of three rain gauges (Onawe EWS, NIWA VCSN 20116 and Duvauchelle CWS). The NIWA VCSN 20116 station was reduced by 14% as a part of this process due to rainfall being considerably higher than both the Onawe EWS and Duvauchelle CWS historical data.

This 51-year rainfall data was then used to estimate wet weather flow over this period. This was added to the dry weather flow to create a long-term flow series from 1972 to 2023. This includes a 33% increase in flows during holiday periods accounts for the future population growth expected at Duvauchelle. It is recommended that the long-term flow series accounting for future population growth be used to estimate peak storage requirements.

6.0 References

Pattle Delamore Partners Ltd. (December 2020). *Irrigation Model Results For Land Disposal Of Recycled Water At Duvauchelle - Hyrbid Design.* Christchurch: Pattle Delamore Partners.

7.0 Limitations

This report has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Beca. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the report. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

This report has been prepared by PDP on the specific instructions of Beca for the limited purposes described in the report. PDP accepts no liability if the report is used for a different purpose or if it is used or relied on by any other person. Any such use or reliance will be solely at their own risk.

Yours faithfully

PATTLE DELAMORE PARTNERS LIMITED

Prepared by

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Environmental Engineer

Neeraj Pratap

Environmental Engineer

Reviewed and Approved by

Murray Kerr

Technical Director – Water Infrastructure

C

Appendix C – Irrigation Model Results for Land Disposal of Recycled Water at Duvauchelle – Comparison of Areas (2023)

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15 December 2023

Innes Duncan
Senior Civil Engineer
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Dear Innes,

IRRIGATION MODEL RESULTS FOR LAND DISPOSAL OF RECYCLED WATER AT DUVAUCHELLE – COMPARISON OF AREAS

1.0 Introduction

Beca Ltd (Beca) is investigating options for the disposal of recycled water from the Duvauchelle wastewater treatment plant (WWTP) for Christchurch City Council (CCC). As part of this project, Pattle Delamore Partners Ltd (PDP) have been engaged by Beca to develop a soil moisture balance (SMB) model for the irrigation of recycled water to land at the Akaroa Golf Club (Golf Club) located in Duvauchelle.

This letter describes the modelling completed for the irrigation of recycled water to land under four different scenarios. These are as follows:

- Scenario 1: Irrigation of recycled water from the Duvauchelle WWTP to trees (8.20 ha) with additional spray irrigation to the golf course fairways, greens, and tee areas during summer months;
- Scenario 2: Irrigation of recycled water from the Duvauchelle WWTP to trees (8.20 ha) only;
- Scenario 3: Irrigation of recycled water from the Duvauchelle WWTP to trees (6.40 ha) with additional spray irrigation to the golf course fairways, greens, and tee areas during summer months; and
- Scenario 4: Irrigation of recycled water from the Duvauchelle WWTP to trees (6.40 ha) only.

The model uses a synthetic long-term flow series developed from modelling the wastewater network's response of flow to rainfall and applying this historical climate data. PDP developed a relationship between measured WWTP flows and rainfall data to estimate the network Inflow and Infiltration (I&I). The I&I relationship was then applied to a synthetic long-term wastewater series using a long-term (51 years) historical climate series (adjusted for future climate change by Beca). The output is a long-term wastewater flow series accounting for estimated wastewater baseflows and I&I. It is assumed that the wastewater flow is treated through the WWTP and irrigated/stored on the same day. A detailed summary of how the long-term flow series was developed is provided in the PDP letter "Duvauchelle WWTP Land Disposal Modelling – Updated WWTP Flow Series" Dated 15 December 2023.

The SMB model has been developed to understand the number of storage overflow events that may occur for a range of potential storage volumes and irrigable areas with the developed long-term flow series described above. The purpose of this work is to demonstrate the feasibility of disposing the recycled water at Duvauchelle. An indication of the volume of storage and any corresponding storage overflows is provided.

2.0 Irrigation

2.1 Irrigation Concept

For the purpose of this modelling, it was assumed that all daily flows entering the Duvauchelle WWTP are immediately treated and are required to either be irrigated or stored. The modelled storage is assumed to be covered so that no rainfall gain or evaporation losses from storage occur. When the storage is full, recycled water flows in excess of the storage volume discharge to overflow and are lost from the modelled system.

2.1.1 Tree Areas

Drip irrigation of recycled water to trees has been modelled all year round. The maximum application rates vary seasonally. Seasonal rates were chosen based on soils having "moderate drainage" as per previous work[1], and are displayed below in Table 1. Where the daily recycled water volume exceeds the daily volume allowed to be irrigated based on these rates, all excess volume is stored. Where daily recycled water volumes are below the daily irrigation limit, the difference is taken from the storage volume (if available) and irrigated. A schematic of the soil moisture balance concept is shown in Figure 1 below.

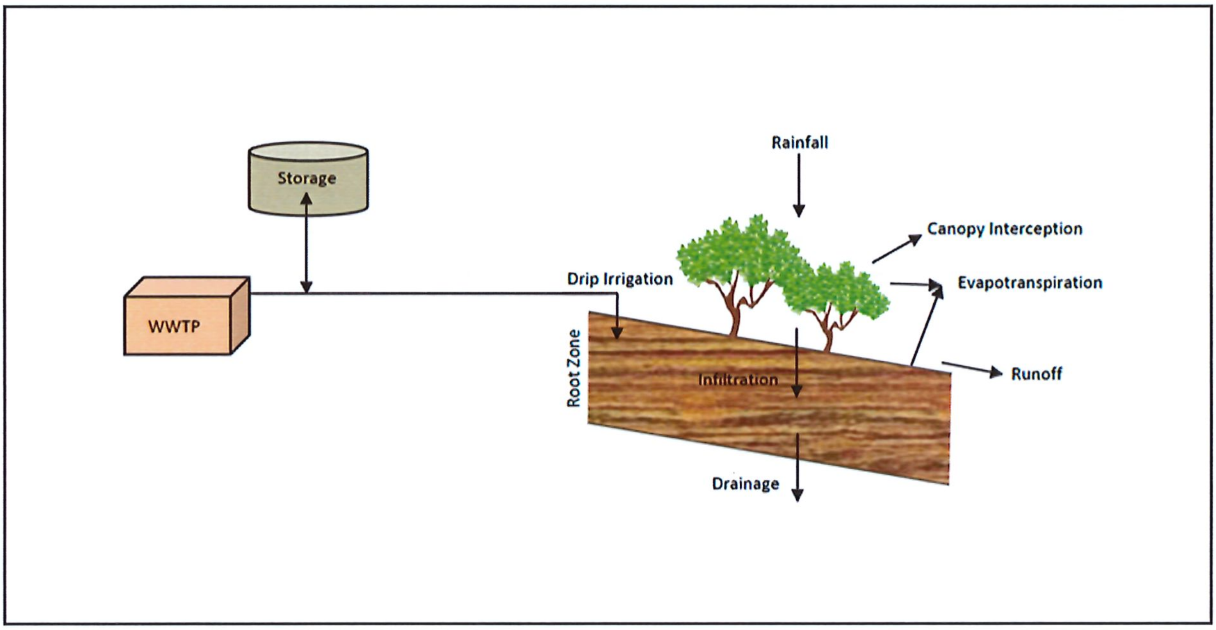

Figure 1: Soil Moisture Balance Irrigation Concept.

It should be noted that recycled water is irrigated regardless of profile available water (PAW) estimates. Irrigation is assumed to cease only when a rainfall event exceeds 30 mm in a day. When irrigation ceases, it will resume once the following subsequent days of rainfall (after the cut-off day) have ceased.

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[1] Letter to Beca Ltd dated 15 December 2020, "Irrigation Model Results for Land Disposal of Recycled Water at Duvauchelle – Hybrid Design", Pattle Delamore Partners Ltd

2.1.2 Golf Course Area

The benefit of reducing peak storage by irrigating the golf course areas during summer periods was assessed. It is assumed that 6.36 ha of fairways, greens and tee areas are available for spray irrigation. The purpose of irrigation to this area is to reduce the irrigation water demand of the golf play areas during the summer. The poor drainage and associated need for deficit irrigation (irrigation ceasing before the soil moisture level reaches field capacity) in these areas make irrigation unsuitable during other seasons. Table 1 below shows the specific parameters used within the SMB.

It should be noted that previous versions of this concept had a complex irrigation system including under-drainage and recirculation of irrigated flows. This has not been included in this modelling.

2.2 Soil Moisture Balance Assumptions

Table 1 shows the SMB model assumptions for the relevant irrigation areas and types.

Table 1: SMB Model Assumptions

Parameter	Drip Irrigation	Spray Irrigation
	Moderate Drainage	Fairways, Greens, and Tee Areas
Recycled Water flow	Long-term flow estimate including expected future populations[1].	
Rainfall[2]	1972 to 2012: Onawe Duvauchelle Bay rain gauge 2012 to 2020: NIWA VCSN 20116, scaled to account for local variation in rainfall[3] 2020 to 2023: Duvauchelle CWS (Akaroa Golf)	
Rainfall cut-off	No irrigation if rainfall >= 30 mm/day	
Potential Evapotranspiration (PET)	NIWA VCSN20116	
Irrigation Season	All year round	Irrigation during summer months only[4]
Irrigation area	8.20 ha or 6.40 ha	6.36 ha
Maximum Irrigation application rate[5] (mm/day)	Summer – 2.8 Autumn – 1.5 Winter – 1.0 Spring – 1.5	5
Soil profile available water	Irrigation regardless of PAW	48

Notes:

1. *Detailed in letter "Duvauchelle WWTP Land Disposal Modelling – Updated WWTP Flow Series" dated 13 December 2023*
2. *The combined rainfall series has been adjusted for climate change impacts by Beca.*
3. *Refer to section 4.3.1 of the above letter (note 1).*
4. *The summer months are December, January, and February.*
5. *Rates displayed are maximum depths that can be irrigated provided there is adequate flow/stored volume available and soil moisture deficit.*

3.0 Results

The purpose of this modelling was to compare a range of storage volumes and the associated number of overflows for each scenario over the modelled period. Overflows are defined as when incoming flows exceed the storage and irrigation capacity. These excess flows are assumed to overflow out of the system.

Tables 2 to 5 display the results from the modelling completed. There are two storage overflow values reported. The "Storage Overflow Events" column is the number of individual overflow events over the modelled period (an independent event is if there were no overflows in the previous two days). The column of 'Number of Years with Overflows' is the number of years within the modelled period where at least one overflow was modelled.

Table 2 shows the number of overflow events for a range of storage volumes for scenario 1.

Table 2: Storage vs Overflow Events (8.20 ha trees with golf course area)

Storage Volume (m^3)	Storage Overflow Events	Number of Years with Overflows
5,300	*No overflow events were seen within the modelled 51-year period.*	
4000	6	5
2000	43	25

Table 3 shows the number of overflow events for a range of storage volumes for scenario 2.

Table 3: Storage vs Overflow Events (8.20 ha trees only)

Storage Volume (m^3)	Storage Overflow Events	Number of Years with Overflows
5,300	*No overflow events were seen within the modelled 51-year period.*	
4000	6	5
2000	43	25

Table 4 shows the number of overflow events for a range of storage volumes for scenario 3.

Table 4: Storage vs Overflow Events (6.40 ha trees with golf course area)

Storage Volume (m^3)	Storage Overflow Events	Number of Years with Overflows
6,500	*No overflow events were seen within the modelled 51-year period.*	
4000	29	17
2000	96	32

Table 5 shows the number of overflow events for a range of storage volumes for scenario 4.

Table 5: Storage vs Overflow Events (6.40 ha trees only)		
Storage Volume (m^3)	**Storage Overflow Events**	**Number of Years with Overflows**
6,500	*No overflow events were seen within the modelled 51-year period.*	
4000	29	17
2000	98	33

Note that the differences between the number of storage overflow events and the number of years with overflows in the above tables is due to multiple overflow events happening in some years. The result tables above show minimal difference between models with irrigation to the golf course area to those without (scenario 1 vs. scenario 2 and scenario 3 vs. scenario 4). This is due to the disposal of recycled water during winter months being the limiting factor that drives peak storage requirements. Winter months generally see I&I flows that are higher and more frequent while the volume able to be irrigated is at its minimum. As the golf course irrigation only occurs during the summer months, this generally does not affect the number of overflows seen.

The one exception to the above is shown in the 2,000 m^3 storage volume in scenarios 3 and scenario 4. Here, one year modelled (modelled year 2018) sees a significant rain event on the 20th of February. This causes recycled water to be stored within the model. Within scenario 3, the additional golf course irrigation for the final 10 days of "summer" allow for this volume to drain down. This is shown in Figure 2 below. However, in scenario 4 there is limited area available for irrigation and no irrigation to the golf course area. Consequently, the model takes a non-zero value for storage going into autumn which eventually results in an overflow later in the year. This is shown below in Figure 3.

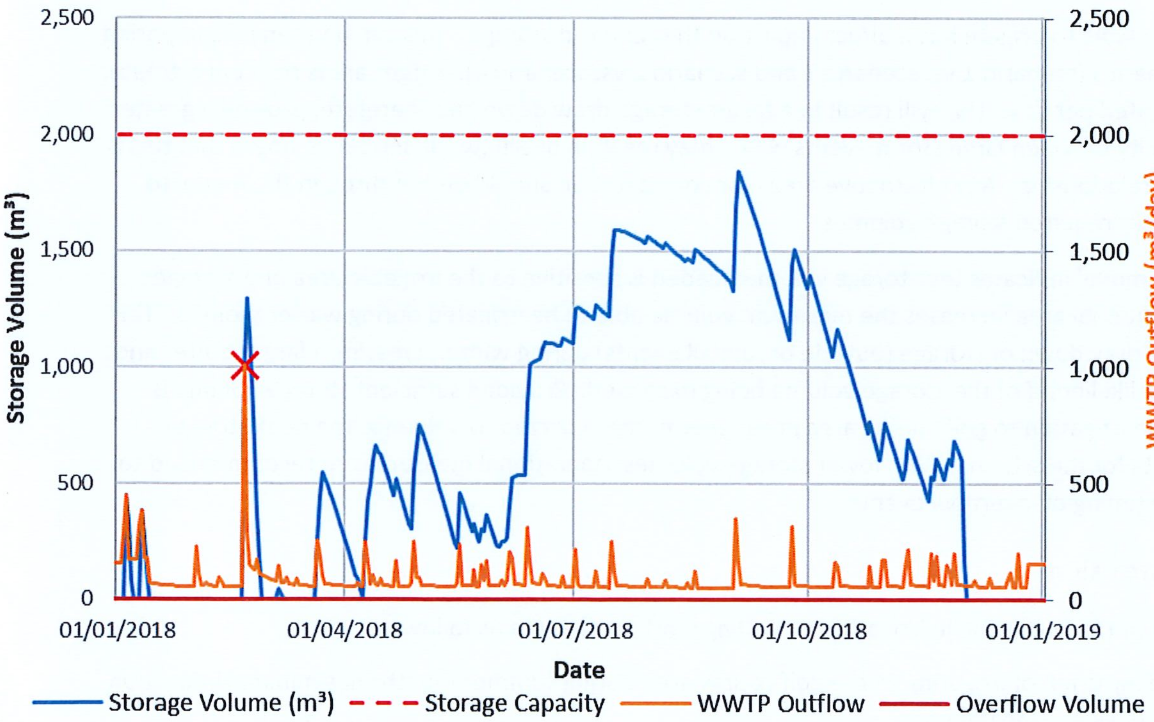

Figure 2: WWTP Outflow and Volume Stored for Scenario 3, with 6.4 ha of Irrigation to trees, 6.36 ha of Irrigation to the Golf Course Area and a Covered Storage Volume = 2,000 m^3, During the Modelled 2018 Year.

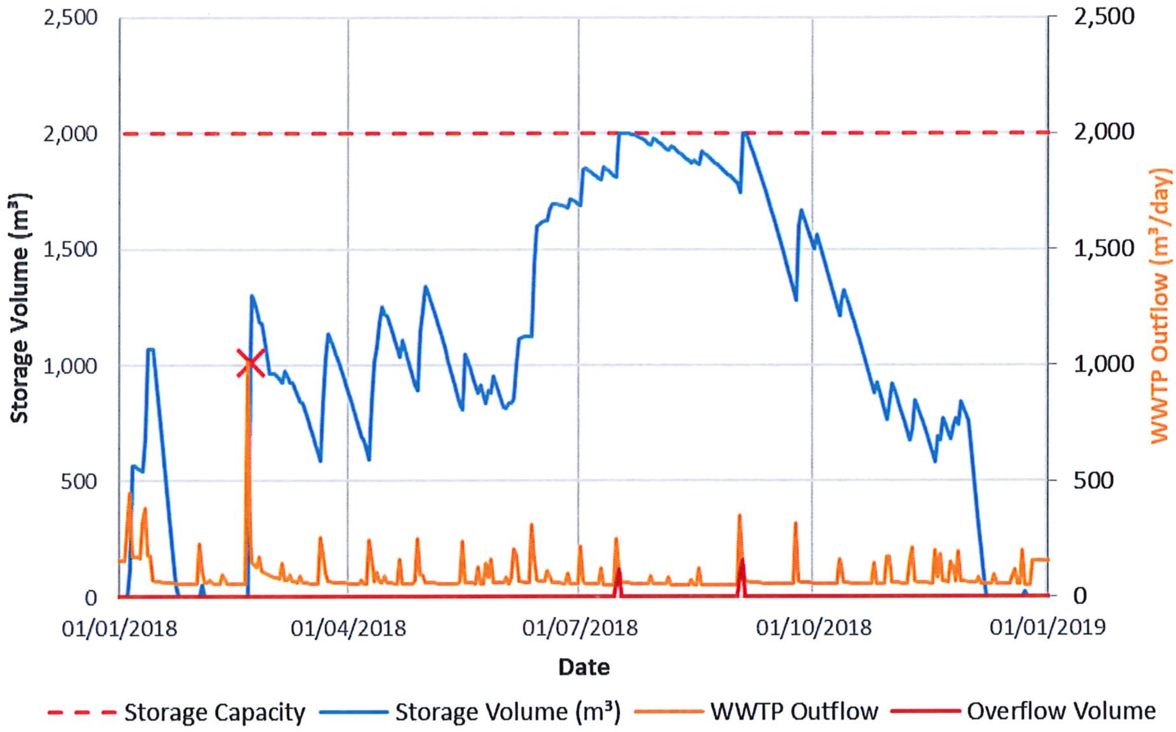

Figure 3: WWTP Outflow and Volume Stored for Scenario 4, with 6.4 ha of Irrigation to Trees Only and a Covered Storage Volume = 2,000 m^3, During the Modelled 2018 Year.

In all other scenarios, the combination of higher irrigation rates during non-winter months and generally drier climate conditions results in the storage volume emptying before winter for every year modelled. This results in no storage "connectivity" between summer and winter.

The area available to irrigate has a direct impact on the required storage. This can be seen by comparing various scenarios (scenario 1 vs. scenario 3 and scenario 2 vs. scenario 4). Larger areas result in a greater volume irrigated per day. This will result in a faster storage draw down and therefore, provide a greater buffer capacity between large storm events which may result in overflows. It should be noted that this is not a linear relationship. Any alternative areas for consideration should be run through the model to estimate other required storage volumes.

Overall, the model indicates the storage volume needed is sensitive to the irrigable area and storage volume. Additional area increases the maximum volume able to be irrigated during winter months. This allows more drawdown of storage (outside of rainfall events) during winter, creating a larger buffer and reducing the likelihood of the storage volume being exceeded. Provided sufficient storage volume is provided, the irrigation to golf course area in summer is not expected to influence the peak storage requirements for the scheme. With lower storage volumes, operational measures are recommended to manage the timing of overflow events.

4.0 Conclusion

Conclusions of the Duvauchelle irrigation modelling work to date are as follows:

- The inclusion of irrigating to the golf course area during summer months has minimal impact on the peak storage volumes.
- The storage volume required to achieve no overflows for the modelled flow series for an irrigable tree area of 8.20 ha is 5,300 m^3.

- The storage volume required to achieve no overflows for the modelled flow series for an irrigable tree area of 6.40 ha is 6,500 m^3.
- Lower storage volumes are modelled to have storage overflows. It is recommended that options to manage these overflows operationally be assessed.
- The peak storage requirements are sensitive to the irrigable area available in the winter months and the storage volume available.

5.0 Limitations

This report has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Beca Ltd and Christchurch City Council. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the report. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

This report has been prepared by PDP on the specific instructions of Beca Ltd for the limited purposes described in the report. PDP accepts no liability if the report is used for a different purpose or if it is used or relied on by any other person. Any such use or reliance will be solely at their own risk.

Yours faithfully

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