Planning for Flooding at Trees For Canterbury

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University of Canterbury - 18/10/2024

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Trees For Canterbury
Te Waonui o Tane Ki Waitaha
The Green Effect Trust Te Roopu Kakariki

Cite as: 'Bogale E, Pease A, Roberts M, Smith R, Westgarth B, 2024, Planning for Flooding at Trees For Canterbury. A report produced for Trees For Canterbury as part of the GEOG309 Research for Resilient Environments and Communities course, University of Canterbury, 2024.'

Contents

Executive Summary

- This research examines the flooding in the Outback areas of Trees For Canterbury. To identify effective mitigation options, it is important to understand the key causes of the flooding.
- The research question addressed within the study is finding the main contributing factors to the flooding in the Outback area of Trees For Canterbury and identifying potential strategies to manage the flooding.
- The methods carried out include a combination of qualitative and quantitative data collection. Specifically, fieldwork for collecting high-resolution imagery of this location, and interviewing Steve Bush, the community partner to obtain background information about the site.
- Open-source data was retrieved for Sea level data from NZ Sea Rise, groundwater measurements from ECAN, and precipitation data from StatsNZ and NIWA.
- The study identified three primary causes of flooding in the Outback area: an impermeable clay layer that blocks drainage, uneven topography that leads to water accumulation, and continuous irrigation and rainfall.
- A major limitation was the limited time available to examine all relevant variables.
- Long-term efforts should include more local research analysing the key factors contributing to flooding in the coastal areas of Christchurch.

1.0 Introduction

Across New Zealand, native forest cover has faced significant reduction since settlement, contributing to biodiversity loss, habitat fragmentation, and ecosystem degradation (Ewers et al., 2009). This trend is particularly evident in the Canterbury region, where native vegetation cover has fallen to just 2% of its original cover, driven by land use changes, deforestation, and agricultural development (Department of Conservation, n.d.). The loss of vegetation not only affects local biodiversity, but also affects the resilience of natural ecosystems to climate change, leading to increasing flooding, erosion, and the decline of water quality (Osterkamp et al., 2011).

In response to these issues, there has been an increasing presence of non-profit organisations which now play a key role in restoration efforts, often by engaging local communities, educating the public, and providing employment and training opportunities for marginalised groups. One such organisation is Trees for Canterbury (TFC) which was founded in 1990 with the goal of addressing the low levels of native vegetation in the Canterbury region.

TFC Nursery is located next to the Avon Heathcote Estuary in Christchurch, producing approximately 47,000 native plants annually (Trees for Canterbury, n.d.) (figure 1). This low-lying coastal location has numerous hydrological influences including shallow groundwater, the nearby Heathcote River, and impacts of sea level rise, leaving it vulnerable to flooding (Bosserelle et al., 2022). In 2022, the Christchurch City Council (CCC) granted TFC access to an additional 1,900m² of land adjacent to the nursery, an area known as the 'Outback' to expand their plant production.

While the initial development of the Outback in October 2022 involved creating a bund and raising the elevation using AP40 gravel aggregate, the area began experiencing persistent flooding in the winter of 2023. The area has now become a year-round pond, which causes problems with plant cultivation by water-logging soils and disrupting growth conditions (Ren et al., 2013), while also raising concerns about staff safety due to slippery surfaces and potential water contamination (Jones et al., 2016).

Climate change projections for the Canterbury region indicate increased rainfall intensity and frequency (Griffiths & Pearson, 1993), which will make it increasingly difficult to manage flood risks (Jakob & Church, 2011). While this project may not prevent the inevitable flooding of this location, it can serve as a case study, informing the wider community of likely long-term impacts.

This research aims to provide a comprehensive analysis of why the Outback area of the Trees For Canterbury Nursery floods, investigate factors contributing to the issue, how they influence each other, and suggest potential methods that could be used to mitigate the issue. This report will provide support for TFC's decision-making process moving forward to address the flooding issue and continue the success of their native plant restoration efforts.

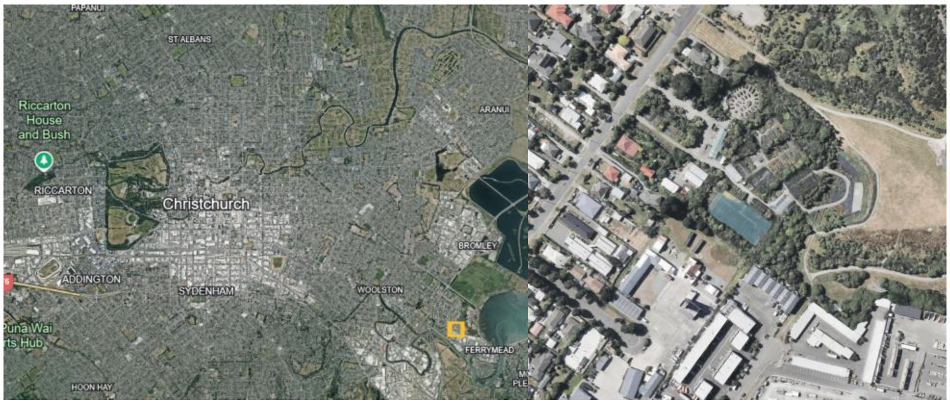

Figure 1 Map of Christchurch City with Trees For Canterbury Nursery located in Ferrymead, indicated by the yellow square (left) & Closer view of the nursery (Google Maps, 2024).

2.0 Literature Review

Five broad topics were investigated for the literature review. The topics were selected based on the initial discussion and understanding of areas that affect drainage and flooding. The chosen topics were:
2.1 Elevation, **2.2** Groundwater, **2.3** Sea level rise, **2.4** Soil Structure, **2.5** Precipitation

2.1 Elevation

Hughes (2015) and Quigley & Duffey (2020) both investigated how the Canterbury Earthquake Sequence (CES) changed the topography of Christchurch and the resulting impact on flood risk. Both studies used different methods, with Hughes (2015) using pre-existing LiDAR data from before the CES and flying their own LiDAR survey after the earthquakes, while Quigley & Duffy (2020) used pre-existing data. Hughes (2015) with the use of LiDAR, found that there were areas around the Avon Heathcote estuary that experienced increases of relative sea level rise as a result of lateral spreading, potentially increasing coastal flood risk. Quigley & Duffy (2020) also found there has been an increase in flooding hazards post-earthquake. They found that changes in topography as a result of liquefaction had the greatest impact. The maps produced by Hughes (2015) show much of the area adjacent to the Avon Heathcote estuary at greater flood risk as a result of the CES.

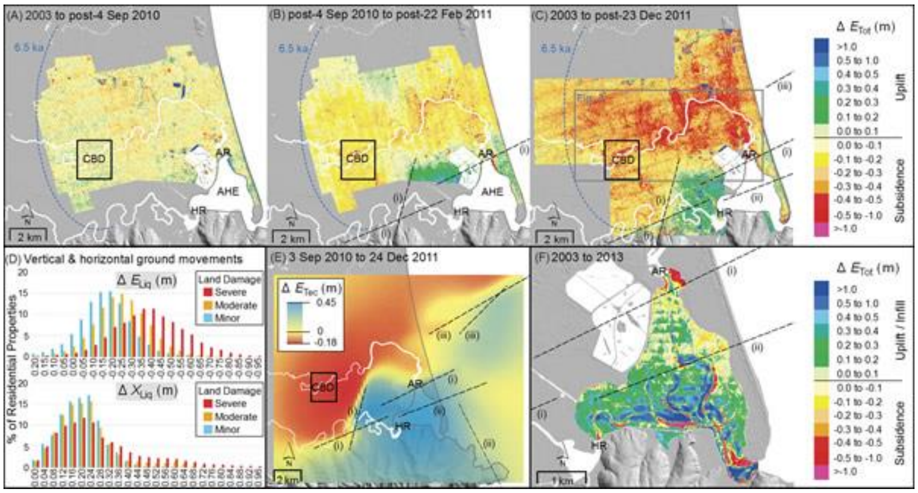

Figure 2 LiDAR models illustrating different measures of vertical land movement through the Canterbury Earthquake (CES) in 2010 (A) & 2011 (B) (Hughes, 2015).

2.2 Groundwater

Groundwater and surface water interactions influence flood risk, particularly in coastal areas (Bosserelle et al., 2024). Research shows high groundwater levels can lead to flooding even with low rainfall due to reduced soil absorption (Becker et al., 2022) (figure 3). Sea level rise enhances this by increasing groundwater inundation and reducing the hydraulic gradient between groundwater and the ocean (Chambers et al., 2023; Bosserelle et al., 2024). Soils with low permeability such as clay reduce infiltration (Hölting, 2019), and this urban expansion has increased surface runoff (Hughes et al., 2015; Chambers et al., 2023), resulting in compounded flood risks. Long-term flood mitigation may require a combination of engineering solutions, such as drainage systems and land elevation, alongside sustainable practices like wetlands and permeable paving (Becker et al., 2022; Quigley and Duffy, 2020).

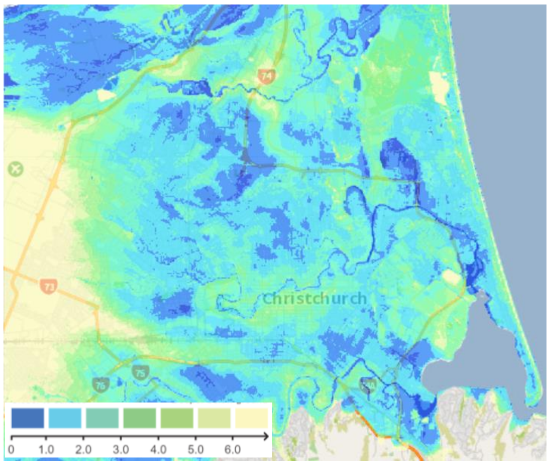

Figure 3 Average (median) depth to groundwater across Christchurch in metres below ground level. Dark blue indicates water close to the surface, yellow indicates water deeper in the ground (Christchurch City Council, n.d.).

2.3 Sea level rise

Sea level rise on the Christchurch coastal interface is unique compared to other case studies around the world, this has been discussed by Stephens and Paulik (2023), who state that coastal flooding occurs due to a combination of natural factors increasing the height of the ocean relative to the land, figure 4 shows natural processes cause SLR such as tidal changes from the moon and sun, storm surges from strong winds, waves pushing water onto land, and climate change.

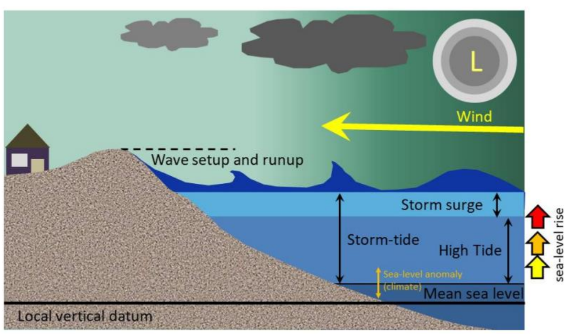

Figure 4 Display of how natural ocean processes impact sea level rise in coastal areas (Stephens & Paulik, 2023)

However, climate change plays a significant role in sea level dynamics, this is achieved through positive feedback processes (NIWA, n.d.). These processes occur when temperatures rise, ice sheets and glaciers melt, and ocean waters expand, as illustrated by historical tide station records in figure 5.

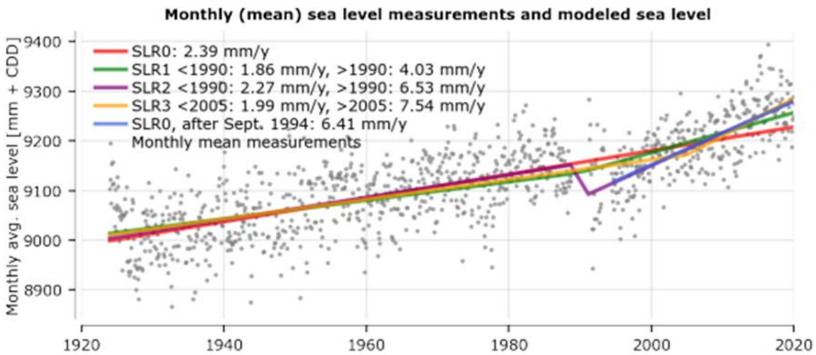

Figure 5 This graph shows a positive linear line of sea level rise from 1920 to 2020 illustrating the constant increase of sea level in New Zealand (Christchurch City Council, 2021).

2.4 Soil structure

A previous TFC Study by Macdonald et al. (2016) details the soil structure, composition, and permeability that leads to the flooding on the site. The study consisted of the analysis of five soil core samples across the TFC site, the methods used involved a variety of soil tests.

This study was conducted before the Outback expansion however the data collected and analysed was taken near the border of the site and the expansion therefore the findings are most likely closely representative of the Outback.

Macdonald et al. (2016) study found that the top ~1m of soil consisted of four distinct units of varying thickness (figure 6). The top three layers were found to be permeable, the top organic layer being the least so perhaps due to organic content absorbing water. The next unit was AP40 gravel aggregate which was highly permeable, the larger sand layer beneath was also found to be highly permeable. The clay layer at the base of the site was found to be highly impermeable and only 4.5mm of water was drained through a 50g sample (in a cylinder that was 76mm diameter x 150mm height) over 24 hours, highlighting its impermeability. This clay layer was also found to be 1.5m at sample site 1 and was therefore at least 76cm across TFC's site.

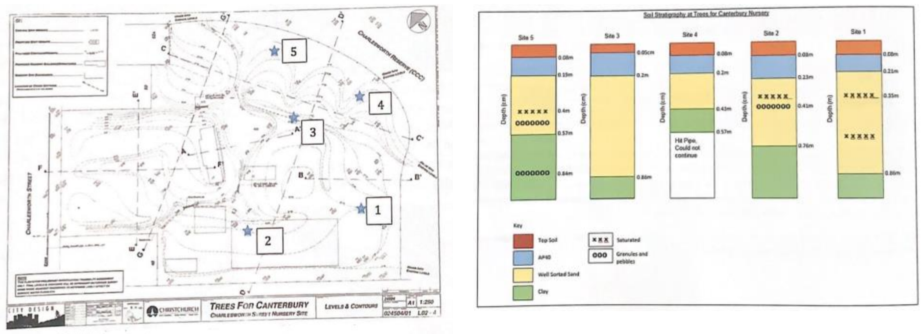

Figure 6 Map of locations of soil samples (left) and Soil stratigraphy for each sample (right). (Macdonald et al., 2016)

2.5 Precipitation

Precipitation in New Zealand is very dynamic, and the amount of rain received varies through location and seasonality. STATS NZ has released precipitation data from 1960 through to 2022, conveying how seasonality and location affect volume and frequency (figure 7). The CCC dataset shows that rainfall is likely in winter and spring. The CCC also proposes that there will be 10% more rainfall in winter with a 15% reduction during the summer seasons (Christchurch City Council, n.d.). These findings are also consistent with academic literature; a paper from Griffiths and Pearson (1993) also proposes that there will be far more frequent precipitation in the cooler seasons. Another factor of climate dynamics is El Niño and La Niña. El Niño influences 25% of New Zealand's year-to-year rainfall (NIWA, n.d.). The El Niño stint of 2015-2016 saw severe drought in the East of New Zealand along with significant South West winds. However, as January and February approached, more precipitation was recorded. This pattern has been consistent throughout the research from 1972 up until 2016.

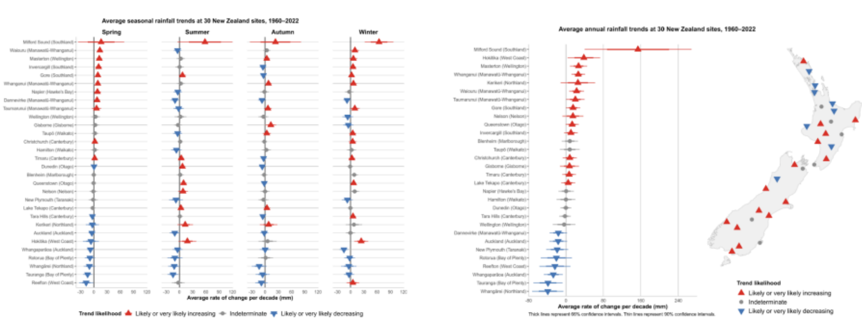

Figure 7 Seasonal rainfall across Aotearoa(STATS NZ, 2023) Rainfall | Stats NZ

3.0 Methods

3.1 Field Work

The first visit to the Trees For Canterbury site involved exploring the area and inspecting the current drainage and irrigation systems. During this overview, a pre-existing groundwater monitoring well belonging to Environment Canterbury was discovered. Through the exploration of the site, it was decided that it would be valuable to investigate the topography of the Outback. Research began by looking for existing elevation data, however, the best available data was a 1m resolution Lidar dataset from 2020/2021 which was created before the establishment of the Outback area. This meant it would be essential to create a new higher resolution map of the area. Using a DJI Mavic 3 enterprise with an RTK GPS, a high-resolution photogrammetry dataset of the area was taken. Due to the presence of overhead power lines & council UAV regulations, the project was restricted to a smaller drone, with a larger drone, such as the DJI Matrice, the dataset would have been a higher resolution and provided increased accuracy.

3.2 Data collection

The main data collected for the precipitation portion of the study was precipitation was temperature data for Christchurch. This data has been selected with location in mind to supply the most accurate data suitable to the TFC site. Irrigation data has been obtained through TFC irrigation partner, Waterforce who supply all their water and irrigation.
Sea level rise projection data was obtained from SeaRise (n.d.). This is important for predicting accurate projections by understanding uplift, subsidence, and isostatic rebound (Nicholls & Cazenave, 2010).
Groundwater data was obtained from Environment Canterbury's groundwater monitoring well 170m northeast of the nursery (NZTM coordinates: 5177700 E, 1575500 N). During the period from 6 Nov 2004 to 31 Dec 2023 groundwater levels were recorded daily at this site and the resulting data was downloaded from Environment Canterbury's well monitoring website (Christchurch City Council, n.d.).
In addition to collecting quantitative data, an interview was conducted with Steve Bush, the Manager of TFC. This provided essential background information about the site, including details on the history of the site, land use changes, drainage systems, and previous mitigation efforts.

3.3 Data Analysis

When beginning the analysis of the LiDAR data, several issues became clear. While the data had been collected, it was not referenced to a datum correctly. This was fixed by performing a global shift using Cloud Compare. Another issue that was addressed was a patchy point cloud with inconsistent distribution. This was due to the parts of the site being covered in vegetation which the photogrammetry was unable to penetrate to accurately map the ground surface. This required the data to be manually removed from the vegetation from the dataset using Agisoft Metashape.

While these areas were not strictly necessary for understanding the flooding, it did result in a rougher dataset.

Once the data cleaning had been completed, the dataset was brought into ArcGIS Pro where it was converted from a .LAS file into a raster, producing a Digital Elevation Model (DEM). A bathtub model of the Outback area was created to model inundation based on flood depths. The DEM was reclassified for 2cm-300cm flood depths by two classes, *flooded* & *non-flooded*. Each class was assigned values e.g. *flooded* was assigned the value of less than 2 = 1, meaning that anything less than 2 centimetres in elevation will be inundated under this model. *non-flooded* is given the value of greater than 2 = 0 meaning that anything higher than 2cm won't be inundated under this model. The results were visualised by draping each of the flood zones over the elevation surface with an offset so that each zone was visible. In addition to flood modelling, the DEM was also used to create elevation cross-sections of different parts of the area. This was done using the Profile Graph tool to draw a line across each of the desired areas. This produced a dataset that was used to make a graph in Microsoft Excel.

Evaporation was analysed using the Hargraves evaporation formula. This formula has been used to compare the precipitation data to find an excess or surplus of precipitation. When calculating the data, an issue with using annual data was encountered. New Zealand has very dynamic seasons which did not work well when most data relied on averages, for this reason, the data was broken down by season to give a better idea of the evaporation-to-precipitation ratio. To account for rainy days the data points were subtracted from the irrigation based on the average number of rainy days that season receives per year using data provided by NIWA.

The Environment Canterbury groundwater level data was converted from Lyttleton 1937 local vertical datum to New Zealand Vertical Datum 2016 (NZVD2016) by minusing -0.343 off all data points. All data points from February 22 2011 onwards were also adjusted to account for uplift post-earthquake after a survey undertaken by Anderson and Associates updated the measuring point from 2.116 m asl to 2.48 m asl (+0.364 added). Finally, the data was adjusted to relate to the ground elevation at the TFC site from the drone LiDAR data.

4.0 Results

4.1 Precipitation

Figure 8 shows the water cycle for the TFC area with estimated amounts of precipitation, irrigation, and evaporation.

The evaporation results can be seen below (figure 9). It was found that all seasons see a significant surplus of precipitation, but balance to approximately the same, with irrigation accounting for the dry periods in the warmer seasons. Despite being the warmest and driest season, summer experiences the most precipitation. Winter is the wettest season, according to this research, but it sees the least amount of precipitation.

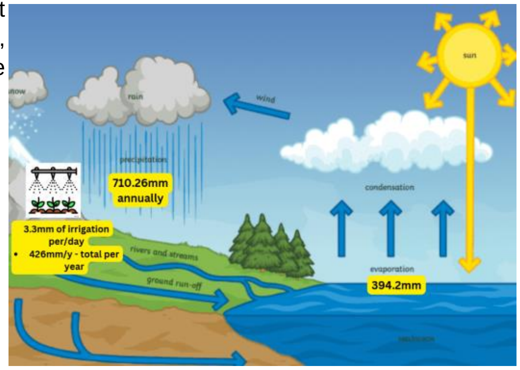

Figure 8 What comes in and what goes out of the water cycle in Christchurch

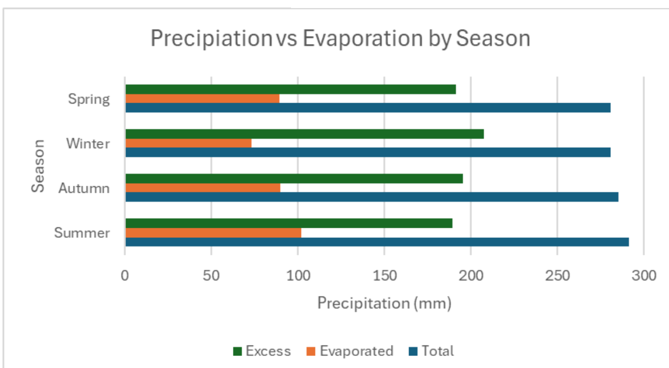

Figure 9 Excess evaporation table and graph using Hargraves formula with data supplied from NIWA

4.2 Groundwater

Analysis of groundwater levels near the TFC site shows consistent seasonal patterns as groundwater depth increases over summer and decreases over winter, except for a period in 2015 where low groundwater recharge levels caused a large drop. During the Canterbury earthquake in 2011, the groundwater level was temporarily recorded at +0.351 metres above the surface level, indicated by the sharp peak in the graph *(figure 10).* Post-earthquake, groundwater levels dropped due to minor tectonic uplift in this area of the estuary, causing groundwater to shift further below the surface.

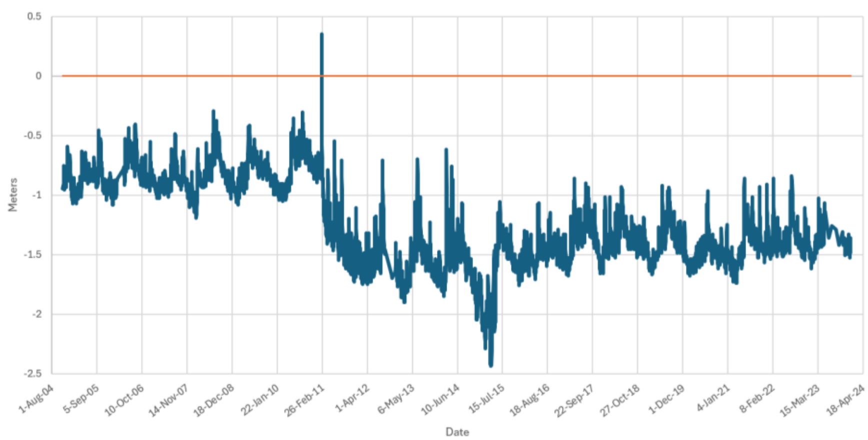

Figure 10 9 Depth to groundwater at Environment Canterbury's monitoring well 170 metres north of the site, red line indicates the surface level.

4.3 Sea level rise

Within 400 metres of TFC, sea level rise is expected to accelerate for the next century, as shown in Figure 11. These projections include data on vertical land movement and recorded high tide levels at the location to create a confidence interval. Projections were made under Shared Socio-economic Pathways. SSP2-4.5 assumes the current rate of greenhouse gas emissions continues to rise at the rate it is progressing, which is the moderate rate. In this scenario, global warming will reach +2.7°C. The results for the 50% confidence (the most likely outcome), sea levels are expected to rise by 0.2 metres by 2050 (shown in Figure 12), 0.33 metres by 2070, and 0.61 metres by 2110 (Takiwā, n.d.).

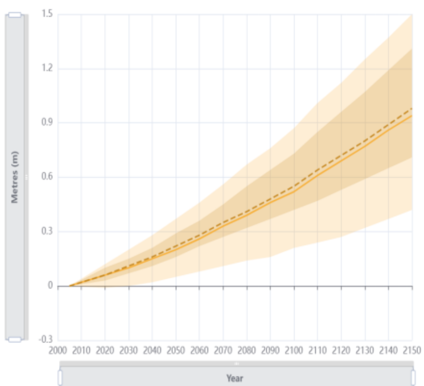

Figure 10 11 Sea level rise projection for site 4318,

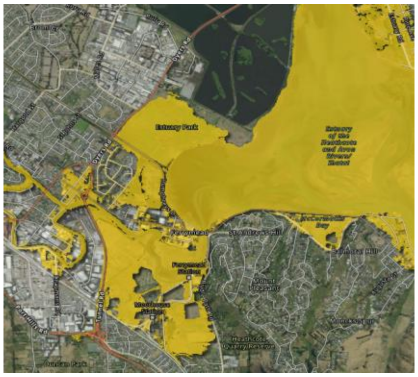

Figure 11 12 Visual projection of sea level rise expected for the year 2050, with a 0.2-meter increase under the SSP2-4.5 scenario (National Institute of Water and Atmospheric Research, n.d.).

4.4 Elevation

Elevation profiles taken across different parts of the Outback (figure 13), all intersect with the most commonly flooded area. There is significant variation in elevation and a clear difference in height between the Northern and Southern ends of the Outback. In the main catchment, the lowest point is approximately 1.5m above sea level. Sharp spikes on either side of the plot indicate the location of the bund surrounding the perimeter.

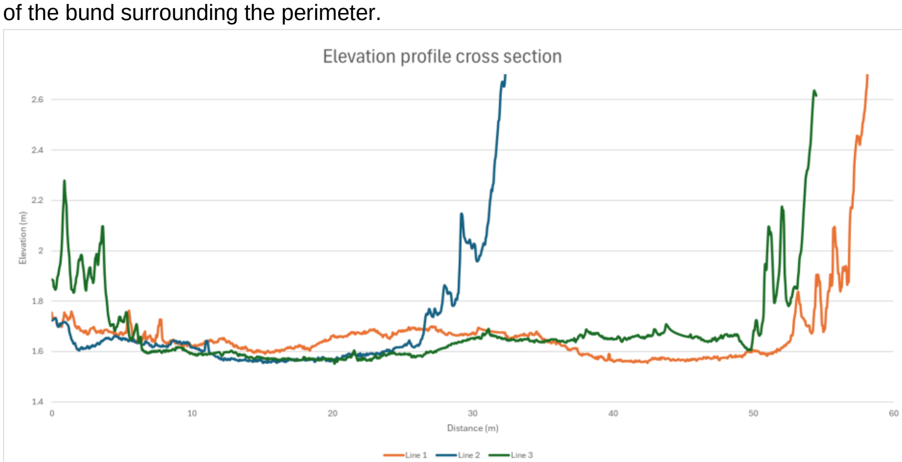

Figure 13 12 Elevation profiles of the Outback area of the Trees for Canterbury Nursery. Line 1 (Orange) & Line 3 (Green) were taken North to South across the area, while Line 2 (Blue) was taken from West to East.

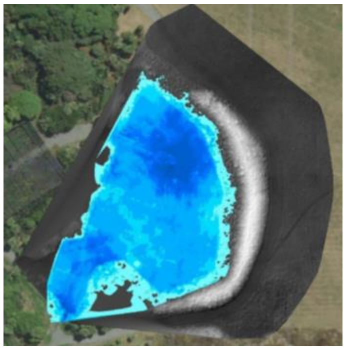

Figure 14 13 Flood model of the "Outback" area at Trees For Canterbury Nursery. The model was produced from photogrammetry data collected as part of the project. The darkest blue indicates the lowest area (<2cm) and the lightest blue indicates the highest (>300cm).

The flood model of the Outback area (figure 14) highlights the catchment area based on depth. The lowest part of the Outback (2 cm depth) is the darkest shade of blue and the highest is the lightest (300cm depth). There is a second, small catchment in the southern end of the Outback, but doesn't tend to flood in such a significant manner.

5.0 Discussion

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5.1 Key findings

Throughout this research and analysis, three main factors have been identified as the primary contributors to flooding at the Trees For Canterbury site, these were soil structure, topography, and precipitation. The thick impermeable clay layer that underlies the Outback limits water from draining away from the site (Macdonald et al., 2016). The gradient of the Outback was found to be uneven, forming a small shallow basin. This has resulted in surface water flowing towards the lowest point where it pools as it is unable to drain efficiently (Harvey et al., 2009). It was also found that irrigation and precipitation also played a major role in the surface flooding issues at TFC. This is because the nursery constantly has water applied to it, either through irrigation or precipitation, which results in the already impermeable ground not experiencing sufficient time to fully drain (Macdonald et al., 2011). The consistent rate of precipitation throughout all the seasons could be due to the minimal amount of rainfall Christchurch experiences in the warmer seasons (StatsNZ, n.d.); therefore, irrigation surpasses the average rainfall volume, which explains these unexpected results. However, TFC is unable to control this as there is a specific regime they follow to successfully grow their plants. In combination, these factors create an environment where regular amounts of precipitation & irrigation accumulate in the same area of the outback, without well-draining soils to allow enough water to escape to keep up with the supply. Despite groundwater being high in the TFC area it is unlikely groundwater is directly contributing to the flooding (Bouwer, 1987). However, it could be indirectly contributing as high groundwater levels reduce infiltration capacity and the soil becomes saturated more quickly (Cox et al., 2012).

5.2 Implications

As climate change intensifies it can be assumed that flooding rates will increase, although the severity in which it will, is difficult to predict (Parliamentary Commissioner for the Environment, 2015). Accuracy is improved using RCP scenarios and 1/100-year floods of which >6 have been experienced in the last 60 years (Federal Emergency Management Agency [FEMA], 2021). Assuming current emission trends these events can be expected to increase (Riahi et al., 2011). Over the coming years, TFC can expect to experience more frequent and intense flooding across the site. The site's water may also become contaminated through saline intrusion due to rising sea levels (Webb & Howard, 2010), impacting water quality at the site. A rise in sea level and increased salinity of groundwater could also lead to the degradation of soil structure (Tang et al., 2020). The impacts of flooding may be minimised in the short term with an engineered solution. The longevity and effectiveness of any infrastructure may be reduced due to the increasing intensity and frequency of flooding. The long-term trends; sea level rise and more severe weather events may eventually overload any drainage infrastructure that is implemented leaving the majority of the current site unusable (Yan et al., 2021).

5.3 Limitations

The duration of the project was the key constraint to the extent of data collection and depth of analysis. Data collection was limited by local government regulations and permit application times which restricted the size of drone that could be flown over council land; a larger drone could have produced higher-resolution images and datasets (Chan et al., 2018). Greater processing time would have also benefited the results as more complex analysis could have been performed. The soil data collected in 2016 did not include the Outback expansion therefore new soil samples and analysis would improve the understanding of the sedimentology and drainage in the Outback area. It is important to note that the precipitation datasets are estimations. Aspects such as estimating weather for that exact location and understanding how groundwater reacts differently to evaporation, how much water is making it into the ground, and what is caught by the plants themselves—are just a few anomalies in this section of the project.

5.4 Potential solutions

A potential solution to address the flooding at the TFC site would be to construct a retention pond that uses ecological and biological strategies to manage excess surface water. This pond would capture excess water and runoff and using New Zealand native plants with high water uptake capabilities, such as Harakeke, Carex Secta, Raupō, and Mānuka, could help soak up excess water (Hawks Bay regional council, n.d.). These species are well-suited for wet environments and can also help with reducing erosion (Hannah, 2024). This solution would also improve biodiversity, provide habitat for wildlife, and create a better-looking and safer area for the TFC staff (Hassall, 2014). Any solution would require engaging engineers and may only be temporary considering the impacts of long-term climate change (Liu et al., 2020).

6.0 Conclusion

In conclusion, by examining the different processes likely to be contributing to the flooding; groundwater table, elevation, soil structure, precipitation, and sea level rise helped to understand how these interconnecting factors influence the flooding problem. The key contributors to the flooding were the impermeable clay soil structure, which prevents water from flowing through the soil, and the low elevation of the flooding area, which causes water from excessive irrigation and rainfall to accumulate in this area. In addition, the site is expected to face more frequent flooding due to climate change, which is causing an increased frequency and intensity of storms. This may be hard to mitigate due to the location of TFC, but this information can be used to plan for future flooding, or a temporary fix through the construction of a wetlands pond.

7.0 Acknowledgements

We would like to thank Trees For Canterbury especially Steve Bush and Nigel Vine for their assistance and guidance throughout the project. We also thank Matthew Wilson for his supervision and support, and Giles Ostermeijer for flying the drone and helping with data processing. Special thanks to Paul Bealing, and Gordon Jiang for their assistance in GIS modelling. We are also grateful to the 2016 TFC GEOG309 undergraduates for their report and soil core data.

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