Addressing Drainage Issues at Trees for Canterbury: A microscale hydrological survey

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Contents

Executive Summary

- Trees for Canterbury (TFC) is a community-based plant nursery located in Ferrymead, Christchurch, adjacent to the Charlesworth Reserve and the Avon-Heathcote Estuary.
- The staff work regularly outdoors throughout the year across the approximately 1.6ha site, performing manual labor tasks associated with the nursery operation.
- The site is subject to regular flooding, which leads to less-than-ideal working conditions and disruptions to the operation in general.
- This study investigates the question: **Using a hydrological survey, what are the drainage issues at the Trees for Canterbury site, and what native plant species can help improve this?**
- To answer this question, a quantitative study of the drains and swales that constitute the flood water mitigation scheme on the site was employed, in conjunction with an assessment of ecological aspects.
- Key findings are that the drainage system is compromised in several ways, primarily buildup of organic matter, poor interconnectedness, and minimal slope contributing to limited ability to drain the site.
- Future research could build upon this study, broadening the scope to include the effects of sea level rise or perhaps refining the model to reduce the uncertainty in the results obtained here.

Introduction

Trees for Canterbury (TFC) is a community-based plant nursery located in Ferrymead, Christchurch, adjacent to the Charlesworth Reserve and the Avon-Heathcote Estuary. Established in 1990, TFC operates as a not-for-profit organization focused on ecological restoration, education, and inclusive employment. The nursery produces over 40,000 native plants annually for use in revegetation projects across Canterbury and provides vocational training for individuals with disabilities and other barriers to employment. Their mission "Employ, Educate, Regenerate" positions it as a key contributor to biodiversity and community resilience.

The TFC site occupies approximately 1.6 hectares of low-lying land historically characterized as coastal wetland. The area retains many of its natural hydrological features, including shallow groundwater, clay-rich soils, and proximity to tidal influences. During redevelopment in 2002, a system of swales and drains were dug to manage surface runoff and direct excess water toward the nearby Charlesworth Reserve and estuarine network. However, these features have become increasingly inefficient over time due to sedimentation, vegetation growth, and a lack of a gradient that limits outflow to the estuary. As a result, water frequently ponds within the nursery grounds, particularly following heavy rainfall or seasonal groundwater rise.

Figure 1: Study area

Despite past drainage interventions, the site continues to experience persistent flooding, particularly in the swale and drain network. These issues have intensified during recent years due to organic clogging, reduced infiltration capacity, and restricted surface runoff, which disrupts nursery operations, and threatens plant viability.

This research was developed in collaboration with TFC to investigate the hydrological dynamics contributing to site flooding and to identify ecologically appropriate mitigation strategies. The study combines a micro-scale hydrological survey of the site with (see Figure 1), with a review of native wetland vegetation to assess both physical and biological interventions. These findings aim to support TFC's long-term site management by providing low-cost, implementable solutions that align with the nursery's restoration goals and community-led operational models.

2.0 Literature Review

Four key literature topics were reviewed to guide this research project. These themes were chosen based on the group members' skill sets and a discussion with our community partner, in which we outlined the research question and rationale for the project.

2.1 Role of Native Plants in Wetland Hydrology and Restoration

Clarkson et al. (2004) states native wetland vegetation plays a critical role in regulating hydrological processes and supporting ecosystem restoration. In the case of Sorrell et al. (2000), species such as *Carex secta*, *Typha orientalis*, and *Eleocharis sphacelata*, are well-adapted to saturated soils and contribute to flood mitigation, sediment stabilization, and water filtration through their root structures. These plants enhance infiltration and reduce surface runoff, which according to Schipper et al. (1994), helps maintain water balance across wetland environments. Tanner et al. (2013) states restoration-focused studies emphasize that reintroducing native vegetation is essential for re-establishing natural hydrological cycles and improving water quality. According to Schipper et al. (1994), native species absorb nutrients and contaminants, supporting denitrification and reducing nitrogen loads in wetland systems. Additionally, Clarkson & Clarkson (1994) found that native plants are more resilient to local climate conditions and require less maintenance than exotic alternatives, making them suitable for long-term restoration projects. The literature also highlights the cultural significance of native species in New Zealand, which according to Harmsworth & Awatere (2013) align with mātauranga Māori principles and enhancing community engagement in restoration efforts.

2.2 Modelling Stormwater Management Facilities

Yin et al. (2020) states that the Low Impact Development (LID) facilities are effective at reducing runoff volumes during small and medium rainfall events but have minimal impact during extreme storm conditions. This finding is backed up by Davis et al. (2012) which finds that during large storms, swales act primarily as conveyance channels due to limited infiltration capacity. The study also noted that grass swales are effective at reducing runoff volume during moderate rainfall events, especially when vegetated check dams are included. Another study by Allendre-Prieto et al. (2018) noted that for accurate stormwater modelling in urban catchments, aerial LiDAR provides sufficient resolution for terrain analysis. The study also found that adjacent rural sub-catchments, despite their permeability, can significantly influence urban flooding and should be included in drainage design. In the case of Jato-Espino et al. (2016), Sustainable Urban Drainage Systems (SUDS) such as green roads, and porous pavements, can mitigate flooding and reduce sewage surcharges, but their effectiveness depends on strategic placement within the drainage network.

2.3 Sea level Rise and Salinity

Rising sea levels are expected to drive saltwater further inland, increasing salinity in groundwater and surface soils according (Tonkin & Taylor 2013). This threatens freshwater availability and plant health in coastal nurseries. Jie et al. (2022) noted that saltwater infiltration is more severe in areas with deeper groundwater tables, where saline water can move more freely through saturated soils. Elevating planting areas can mitigate these impacts by enhancing drainage. Hu et al. (2022) found that higher raised fields reduced soil salinity levels by the end of the growing season, indicating that elevation-based strategies may benefit coastal restoration sites. Wetlands also face pollution from irrigation and sewage inputs, introducing toxic metals according to Ostad-Ali-Askari (2022), compounding salinity effects in poorly drained areas. Land movement near shorelines can increase exposure to salinization and flooding. Young et al. (2009) found that regions immediately seaward of the shoreline are highly susceptible to liquefaction and groundwater encroachment. These findings informed our understanding of how sea level rise and salinity may interact with landform instability at TFC site.

Figure 2: A map highlighting the effects of a 10m sea level rise scenario in Christchurch, New Zealand. (Musther, J, n.d.).

2.4 Wetland Hydrology and Urban Drainage Systems

Wetland restoration improves hydrological function and ecosystem services, including reduced nutrient runoff, increased carbon sequestration, and enhanced flood mitigation. Tomscha et al (2021) found that restored wetlands decreased peak flood flows by approximately 25%, supporting their role in urban drainage systems. Chen et al. (2023) also states that bio-swales reduce peak stormwater discharge by 30-35%, by removing suspended pollutants through filtration and plant uptake. Clarkson & Peters (2010) notes revegetation using native wetland species improves soil moisture regulation and plant survival in fluctuating water tables, highlighting that sites with active management showed a 30% higher success rate in native plant establishment. Additionally, native vegetation within bio-swales enhances pollutant removal efficiency and supports macroinvertebrate and bird diversity. Waihora Ellesmere Trust (2014) noted unmanaged drains accumulate sediment at rates of 3-5cm per year, reducing flow capacity by up to 40% and increasing flood risk, but revegetation with native species and regular sediment removal can improve flow capacity by 35%.

3.0 Methods

To assess the performance of the drainage system, a quantitative approach using a 2D hydrodynamic flow model was used. The basic model inputs are DEM and rainfall data for the study area. Additional inputs were evaporation data, estimated inflow, an appropriate Manning's N-value, and a clay-type soil profile. Other parameters were left as default values. To create the DEM, multiple data collection methods were employed due to the nature of the study area. The swales and drains are heavily planted therefore occluded from above. The consequence of this is that aerial data collection methods such as LiDAR and drone imaging are not sufficient to capture the elevation of the occluded areas, which are essential inputs into the model. To model these areas, manual survey methods were employed and the data from these surveys was integrated with aerial data to create a complete DEM for the study area. Additional data was collected from curated, online sources such as historical rainfall data and groundwater level.

Raw data collected from the field surveys and curated online sources was processed using proprietary and open-source software. The workflow from raw data collection to the final flood model output is shown in Figure 5. A detailed methodology is included in Appendix A.

3.1 Structure for Motion Drone Survey

A drone survey was conducted, capturing 179 images (image size: 5280 x 3956 pixels) of the site using a DJI Mavic 3 Enterprise drone with an RTK module. The drone was flown on an automated flight path to cover the whole of the TFC site, avoiding private dwellings where possible. These images were processed in "Agisoft Metashape", the final output being a DEM of the study area able to be captured by this method.

3.2 Manual survey methods

Measurement of drainage channel profiles was first carried out using a Sokkia Total Station. A location was chosen so that a large proportion of the channels and swales were visible without moving the instrument. The chosen point 'CP' is shown in Figure 3 the channels to be measured, A, B, C and D. Setting up the instrument consisted of centering and levelling the tripod over a survey peg inserted in the ground at point 'CP'. An arbitrary coordinate system assigned with origin at X, Y, Z 100, 100, 100 was entered. A 'backsight' measurement was taken using a point on the top of the Fire Station training tower, adjacent to the site to the South.

Figure 3: TotalStation base and drainage locations

To capture a channel / swale profile, 4 points at each transept of the channel were recorded at approximately 5m intervals, see Figure 4. The first point was at the edge of the channel, the second at the lower end of the slope bank, the third at the lower end of the opposite bank, and the final point at the upper edge of the bank. Using this technique, the profiles of drainage channels and the swale were recorded.

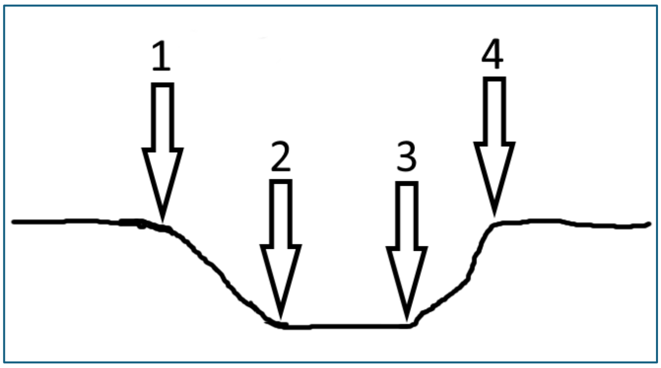

Figure 4: Measurement points on channel transept.

Additional profiles were collected using a Lecia GNSS Rover covering drainage channels 'D' and 'E', by the same method shown in Figure 4 and described above. The first point recorded

(GS001) was the survey peg at point ‘CP’. The purpose of recording this point is to geo-reference the Total Station arbitrary coordinate system, a process detailed in Appendix A.

3.3 Online data Collection

Historical rainfall data was downloaded from www.hirds.niwa.co.nz to provide realistic data as an input to the flood model. Data from a local monitoring site named Tunnel Road Heathcote, ID 325619, was selected with an Average Return Interval of 2 years.

An overview of the methodology is shown in Figure 5 and a full breakdown in Appendix A.

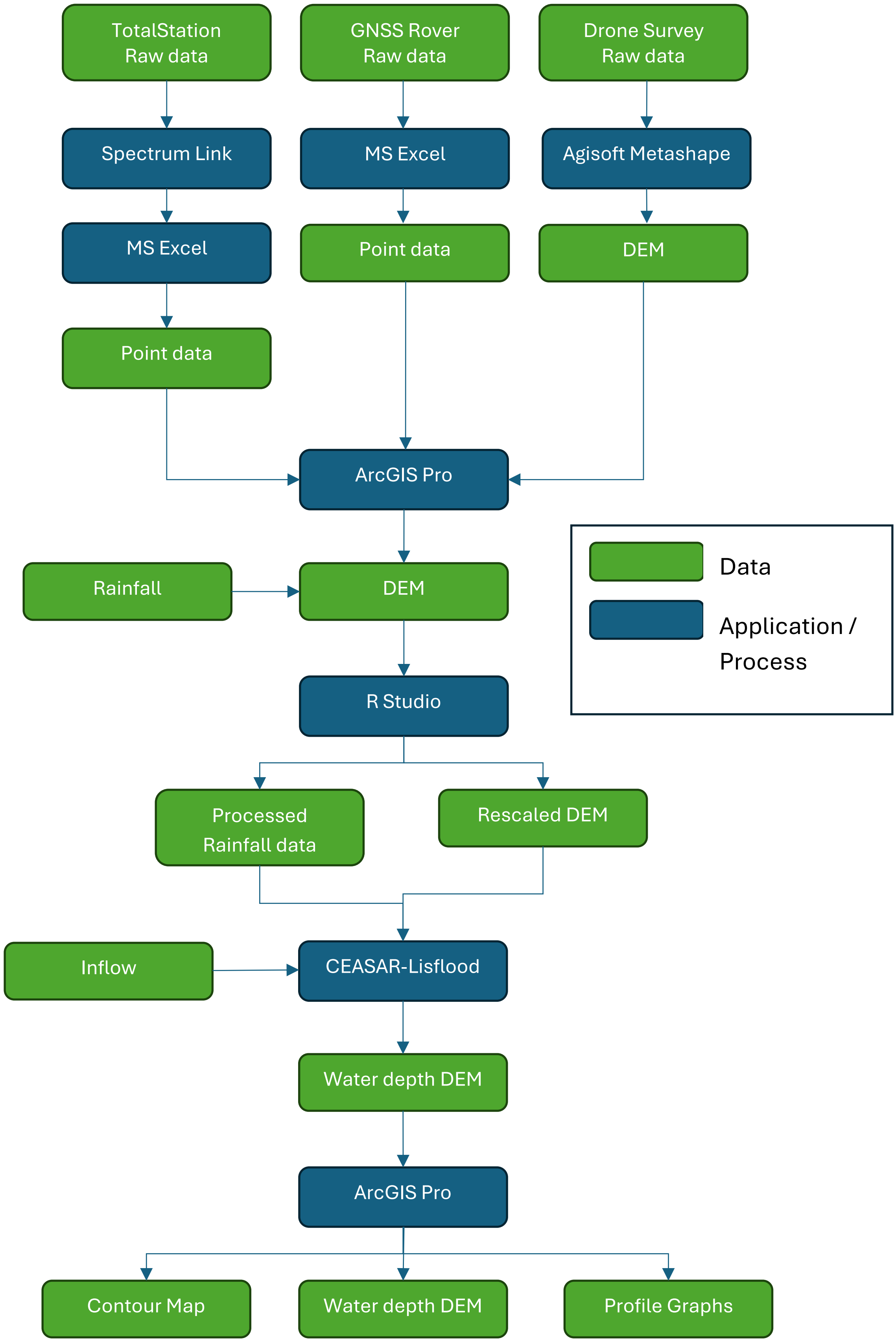

Figure 5: Methodology overview

4.0 Results

4.1 Contour map

The study area contour map in Figure 6 indicates where depressions in the working areas (up to 100mm) are present. These depressions are generally located on the periphery of the working areas as indicated. The other working areas have a flat, slightly elevated profile between 1.8m and 1.9m AMSL. Also apparent is the elevation decline towards the reserve to the NE, however not shown is the waterway that connects to the swale outlet to the waterway network in the reserve as this fell outside the study area.

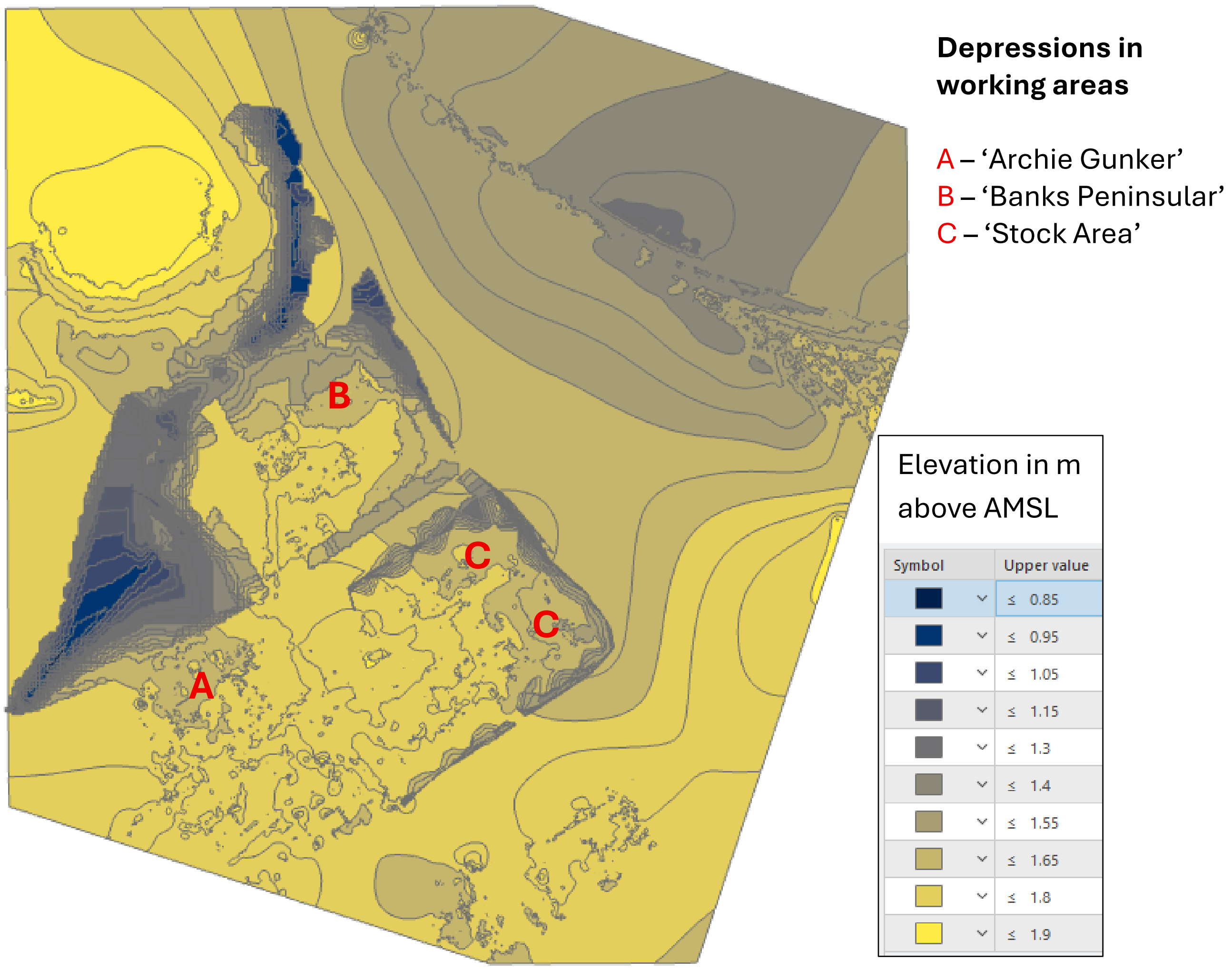

Figure 6: Study area contour map indicating depression in working areas.

4.2 Drainage channel slope profiles

The average fall in elevation of Drain A is less than 1% over the ~27m length from SW to NE, see Figures 7 and 8. The slope is relatively linear with undulations superimposed on it. The elevation of the bottom of the drain is approximately 300 to 400mm lower than the working area it is designed to drain from.

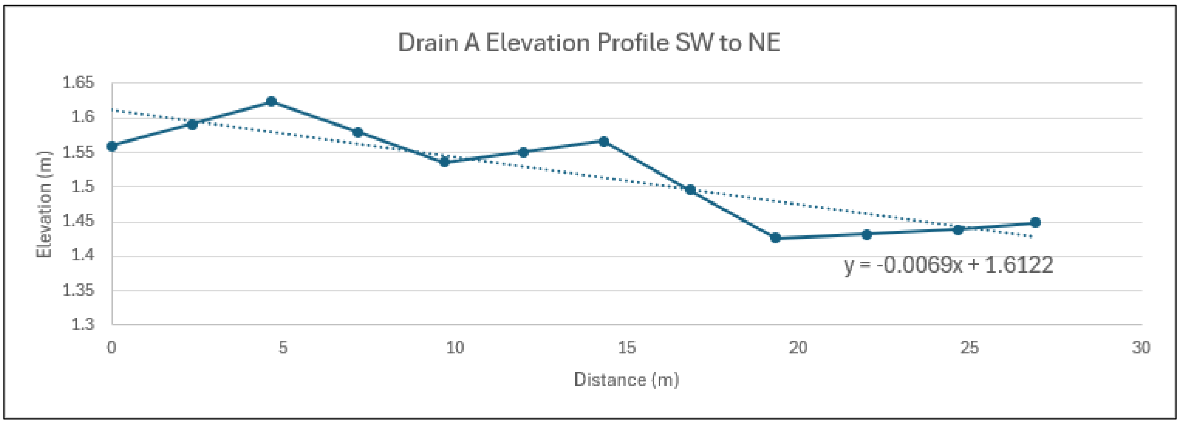

Figure 7: Drain A slope profile SW to NE

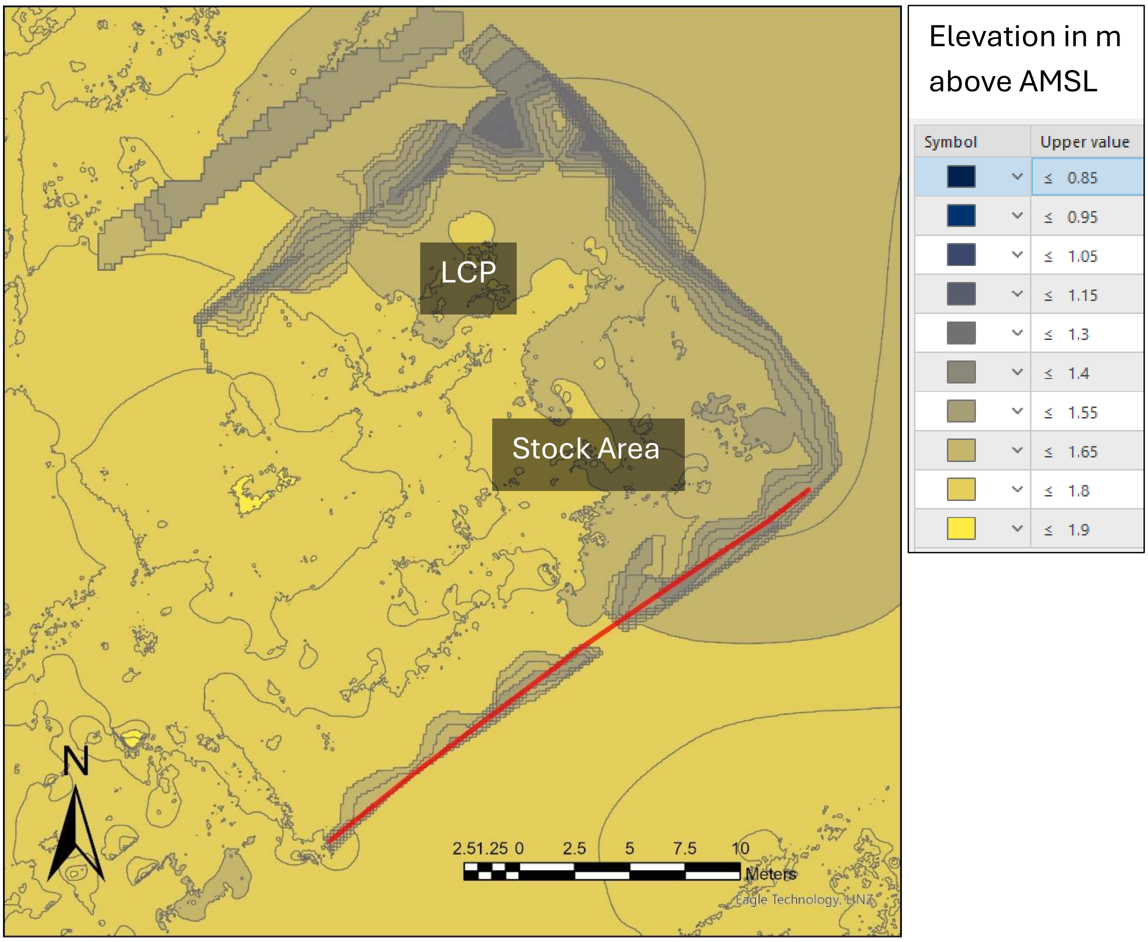

Figure 8: Drain A location overlaid on site contours

The average fall in elevation of Drain B is just over 1% over the ~19m length from SE to NW as shown in Figures 9 and 10. The slope is linear. The elevation of the bottom of the drain is approximately 200 to 450mm lower than the working area it is designed to drain from.

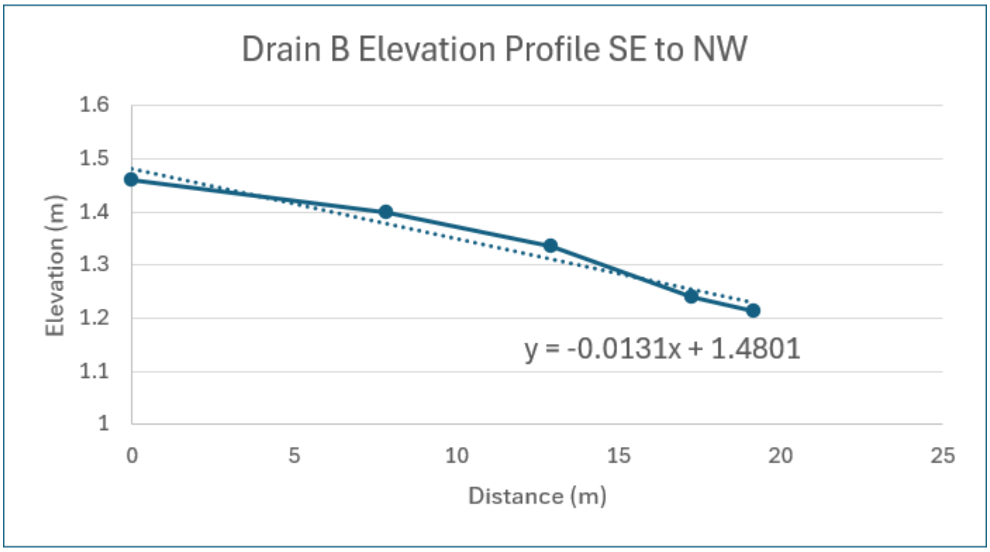

Figure 9: Drain B slope profile SE to NW

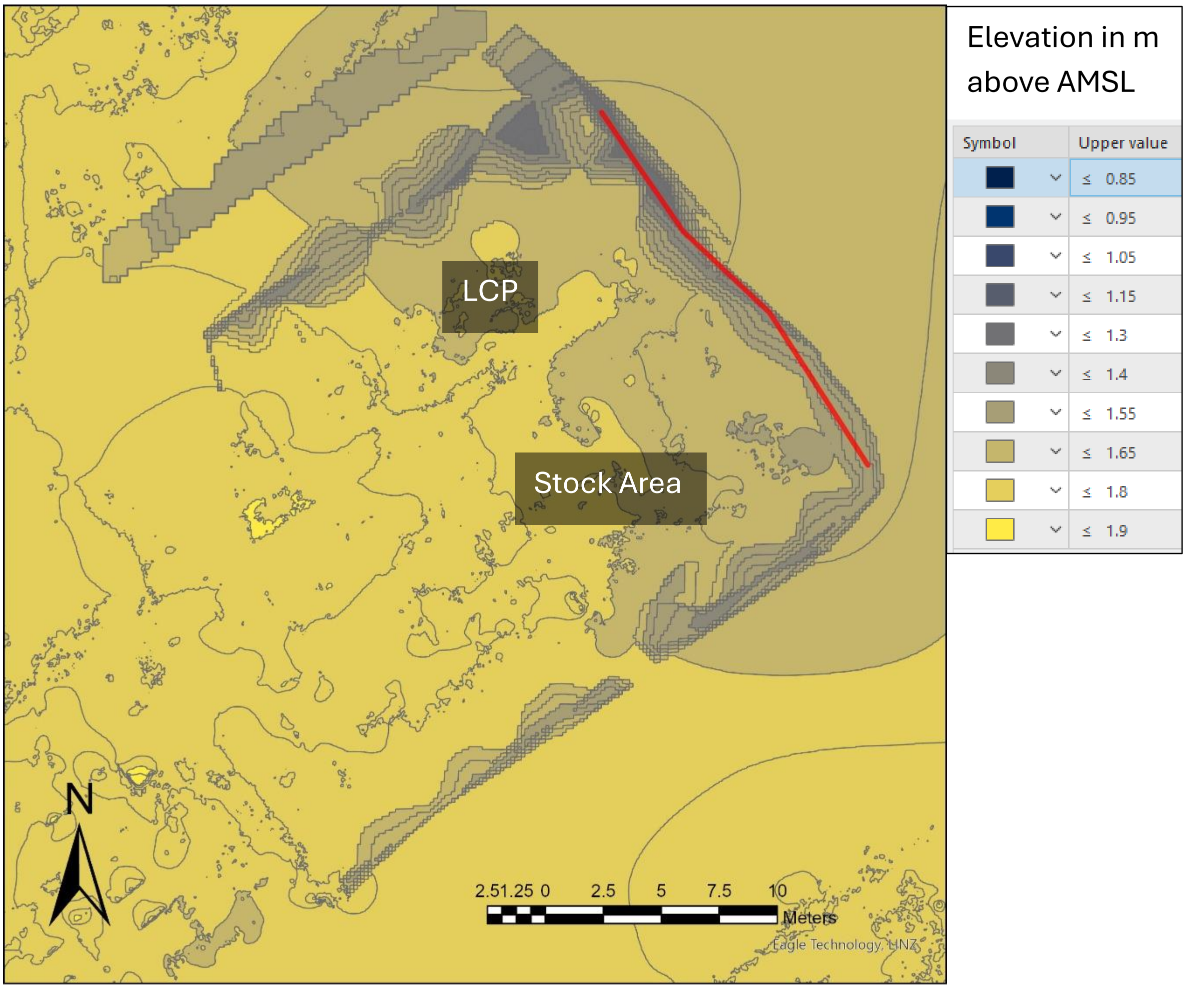

Figure 10: Drain B location overlaid on site contour map

The average fall in elevation of Drain C is 1.6% over the ~20m length from SE to NW, see Figures 11 and 12. The slope is relatively linear. The elevation of the bottom of the drain is approximately 100 to 450mm lower than the working area it is designed to drain from.

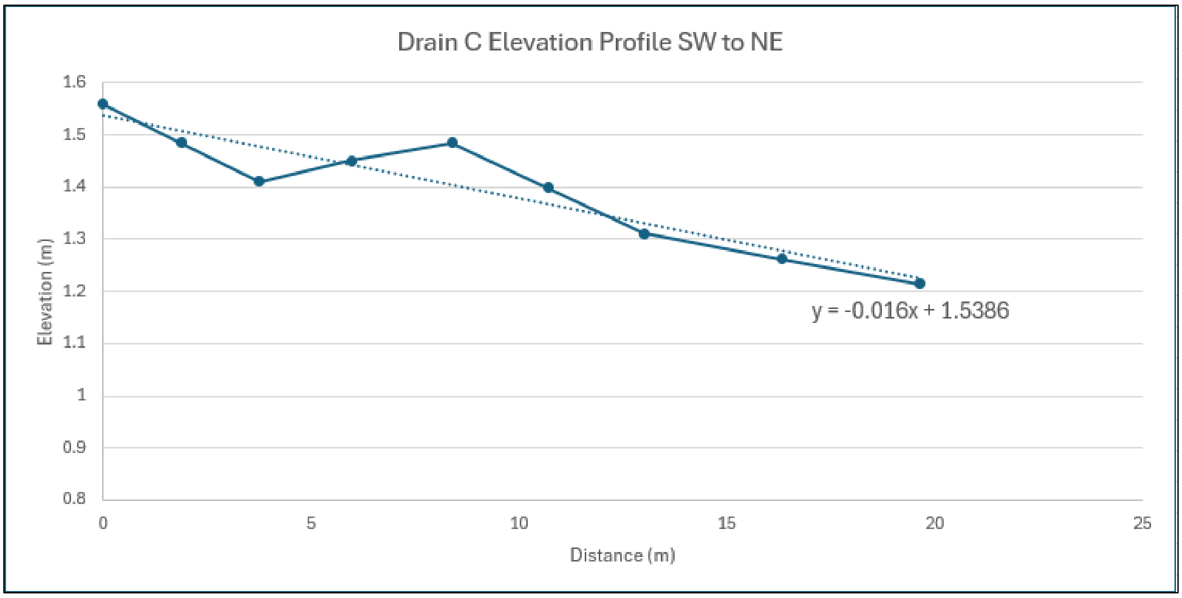

Figure 11: Drain C slope profile SW to NE

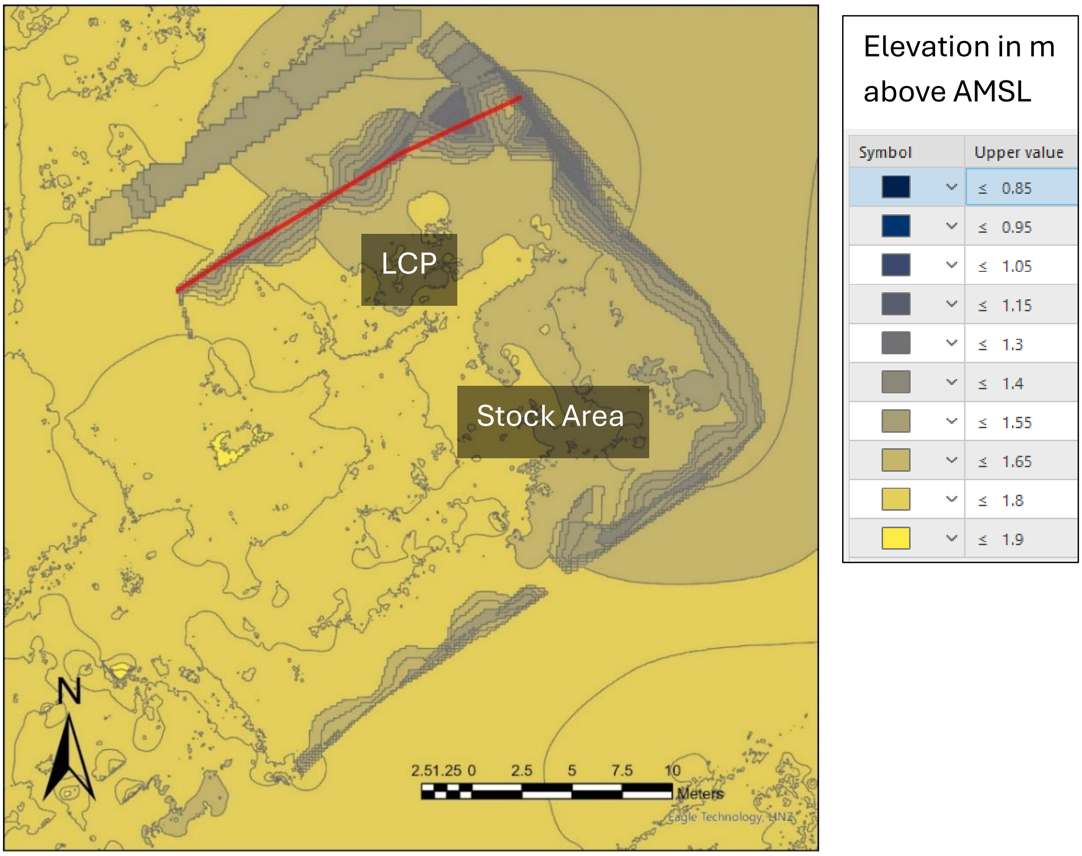

Figure 12: Drain C location on site profile

The average fall in elevation of Swale D is less than 1% over the ~85m length from SW to NE, see Figures 13 and 14. The slope has noticeable peaks and troughs throughout the length. The elevation of the bottom of the drain is approximately 100 to 500mm lower than the working areas it is designed to drain from.

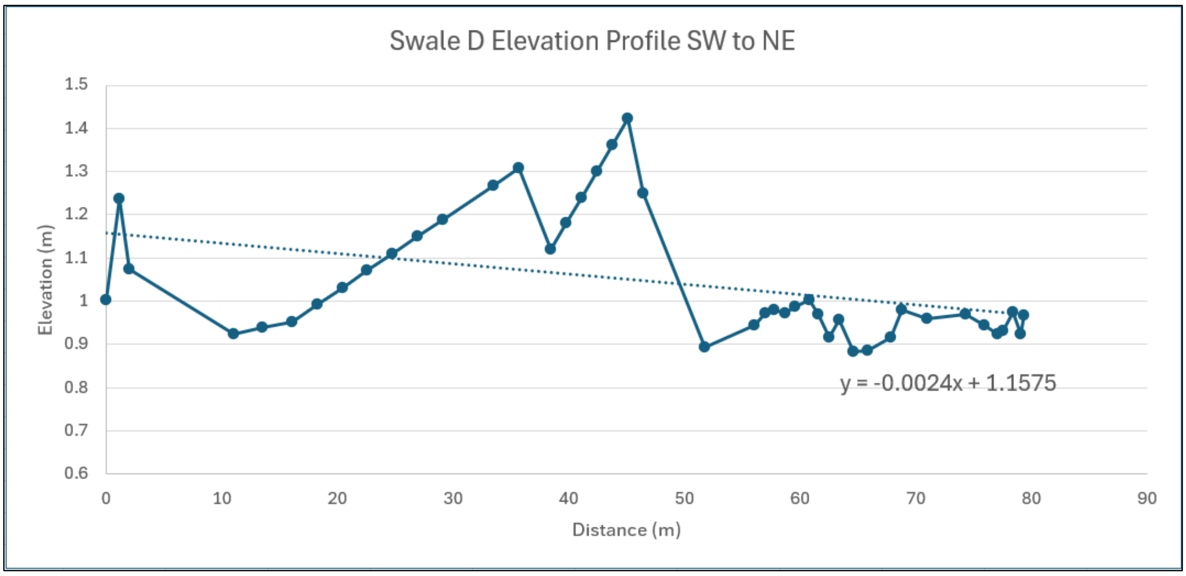

Figure 13: Swale D slope profile SW to NE

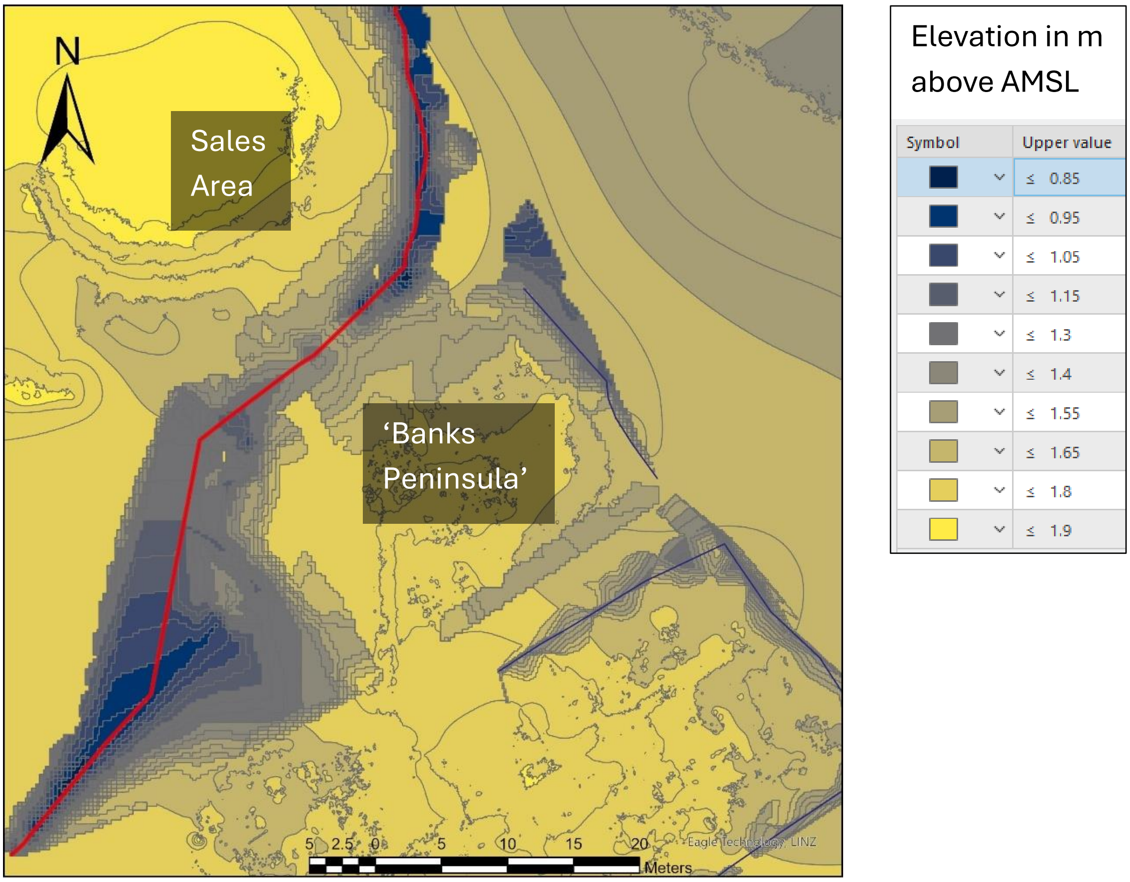

Figure 14: Swale D location on site profile

Note: the slope profile for Drain E is not included as the GNSS and interpolated points do not accurately represent the drain elevation.

4.3 Hydrodynamic 2D Flood Model

The output from the flood model is shown overlaid on the TFC site in Figure 15. The extensive flooded area to the NE is in the adjacent reserve which is outside the study area. Swale D has breached the SE and NW onto the 'Archie Gunker' and 'Sales' areas respectively. Drains A and B have breached at their intersection onto the 'Stock' area and adjacent stands of trees.

Swale D shows pools of water collected at the upper reaches, to the NE of the footbridge connecting the sales area to the 'Banks peninsular' area. This aligns with the swale profile in Figure 13 beyond the 50m mark where the elevation dips substantially then undulate for about 20m. Also, to note, although outside our study area, the flooding on the 'McShady', 'Libertias, Flaxes and Astelias', 'McBasil' and 'Outback' areas have also been identified.

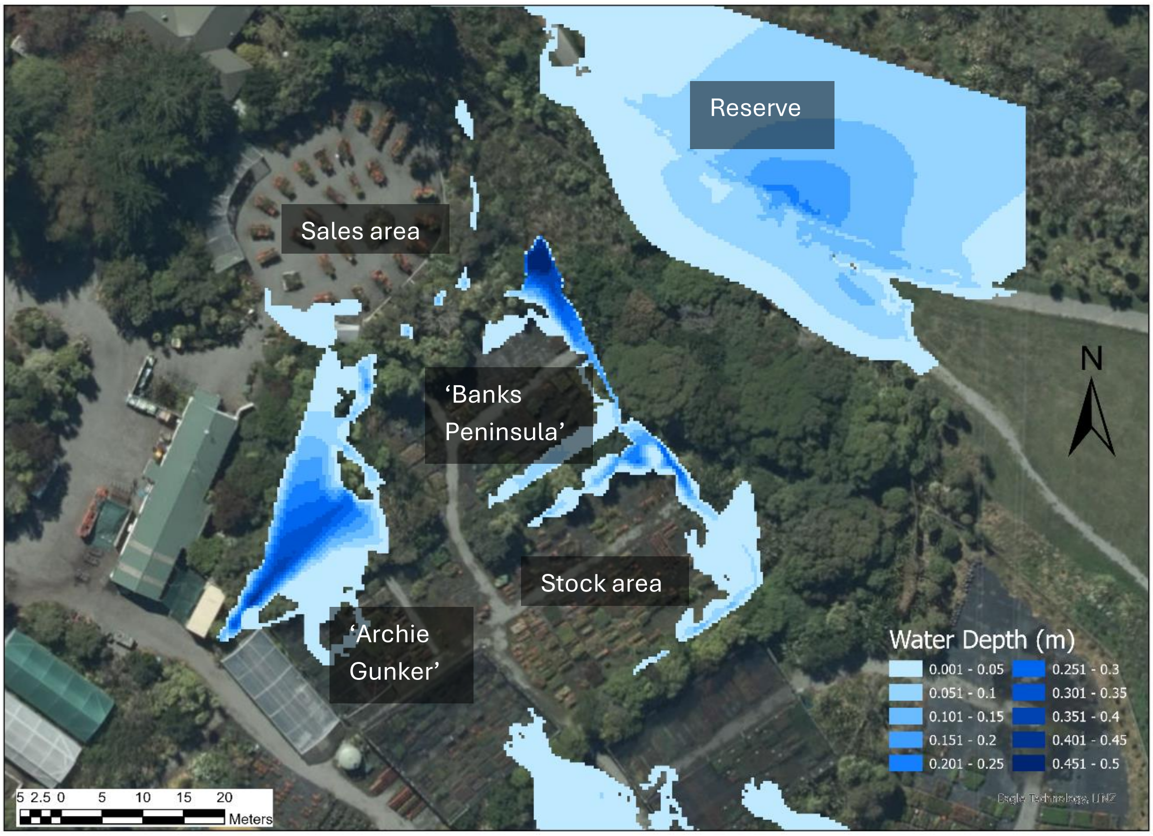

Figure 15: Flood model result after 60hr rainfall event, ARI 2 years, clay soil.

4.4 Key Findings

The flooding observed at the Trees for Canterbury site results from a complex interaction between seasonal groundwater rise, low surface elevation, and compromised drainage infrastructure. The survey data indicates that the swales and drains are situated within a shallow basin, where limited slope and poor connectivity cause restricted flow and flooding onto adjacent areas. This problem is exacerbated by a high groundwater level, confirmed by data from a nearby monitored well (Appendix B), which limits the site's infiltration capacity and leaves minimal storage capacity for rainfall. As a result, even small precipitation events during peak months can cause immediate surface flooding, as the soil remains near saturation (Bosserelle et al 2022). In this research, on-site verification of groundwater depth, could not be undertaken due to equipment limitations.

Field observations revealed that much of the drainage system is clogged with organic material and dense stands of *Typha orientalis* (bulrush), substantially reducing flow volume and velocity in the low-lying areas (Figure 16). Additionally, a significant portion of the 'Banks Peninsula' and 'Stock Area' zones experience recurrent flooding, largely due to surface depressions identified in Figure 6, that act as localized water traps. While *T.orientalis* contributes to wetland ecology, its dense biomass and root mats make it unsuitable for engineered swale systems, where unmanaged biomass can drastically reduce hydraulic efficiency (Chen et al., 2023).

Figure 16: The organic clog observed on site, that prohibits water movement.

5.0 Recommendations

Trees for Canterbury want to know what actions they can take to improve the flow of drainage on site, and what native plants can be implemented to help. It was also made clear they needed low-cost solutions that could utilize their team of volunteers. We have outlined four key recommendations for the site which could provide a mixture of short and long-term solutions to improve the persistent flooding. These recommendations include a native vegetation maintenance and planting plan, improving connectivity between swales, and creating a short-term structural fix on site.

5.1 Ecological Solutions

Our results indicate that one contributing factor to the drainage issues is the presence of dense or unmanaged vegetation. To address this, the most effective approach would involve implementing targeted maintenance measures, followed by a zoned planting strategy.

Firstly, we recommend targeted removal of *T. orientalis* (Bulrush) from key flow paths, particularly where it obstructs swale outlets and low-elevation catchments. This should be done manually to minimize soil disturbance, with follow-up monitoring to prevent regrowth. Secondly, it is important to understand that as the site already contains a strong foundation of native wetland species, new vegetation planting should be minimal. Our research found *Phormium tenax (*Harakeke Flax*)* currently residing along the banks of the swale system. As this species is known a well-structured species for it's tolerance to saturated soils and structural role in erosion control (Sorrell et al., 2000), rather than introducing new plants, we recommend focusing on maintaining and managing this to optimize hydrological function.

Tanner et al, (1995) and Mitsch & Gosselink (2015) suggests suggest species such as *Carex secta* (Māorepo) and *Juncus edgarie* (Wīwī) (Figure 17) are well-adapted to saturated soils and offer low-litter profiles that resist matting. *C. secta* is especially valuable for its elevated tussock form, which raise the effective ground level and tolerate brackish water, making it a proactive choice for future salinity risks, and perfect for TFC's site (Clarkson & Peters, 2010; Waihora Ellesmere Trust, 2014). Provided *T. orientalis* (Bulrush) is manually removed and regrowth is monitored, *C. secta* and *J. edgarie* can successfully recolonize former bulrush zones without competition, restoring hydraulic connectivity and soil stability.

Figure 1716: Potential species that can be implemented on the TFC site.

To enhance moisture drawdown, we recommend reinforcing swale banks with *Cordyline australis* (Tī kōuka), a species known for its high transpiration rates and deep rooting structure, which can reduce soil moisture over time (Rodrigo, 2021). This tree layer should be supported by fast-growing pioneer shrubs such as *Coprosma robusta* (Karamū) and *Pittosporum tenuifolium* (Kohūhū), which provide immediate bank stability, shade, and biodiversity benefits (Figure 18). These species are already present on site and can be selectively encouraged through thinning, transplanting, and targeted planting. The recommended planting strategy for TFC is detailed in Table 1.

Table 1: Zoned Planting Strategy

Zoned Planting Strategy
1. **Swales and base margins:** Maintain and expand *Carex secta* and *Juncus edgariae* species in areas with persistent saturation (highlighted from our results).
2. **Swale banks and elevated edges**: Plant *Cordyline australis* at 2-3m intervals, supported by clusters of *Karamū* and *Kohūhū*.
3. **Flow paths and outlets**: Remove *Typha orientalis* and replace with low-litter species to maintain hydraulic connectivity.

These recommendations align with the best practices Tomscha et al. (2021) suggests in wetland restoration, which emphasize the importance of species zonation, adaptive planting, and the use of vegetation to stabilize soils and regulate water movement. By focusing on maintenance and strategic enhancement of existing native plants, Trees for Canterbury can restore swale function, reduce flooding, and build long-term resilience to climate-driven changes in hydrology.

5.2 Structural Management Solutions

In addition to ecological interventions, our research supports low-cost structural actions. Manual clearing of organic debris from swales is the most immediate and effective step to restore flow capacity, but this should be followed by improving connectivity between the swales and drains through digging or re-linking channels. Our drone survey revealed a fragmented system, and enhancing hydraulic continuity will allow water to move more efficiently across the site. The specific locations for organic matter removal are indicated in Figure 18Figure 18.

A. Next to the footbridge on the North-East side.
B. Next to the footbridge on the South-West side.
C. The junction of drains B and C.

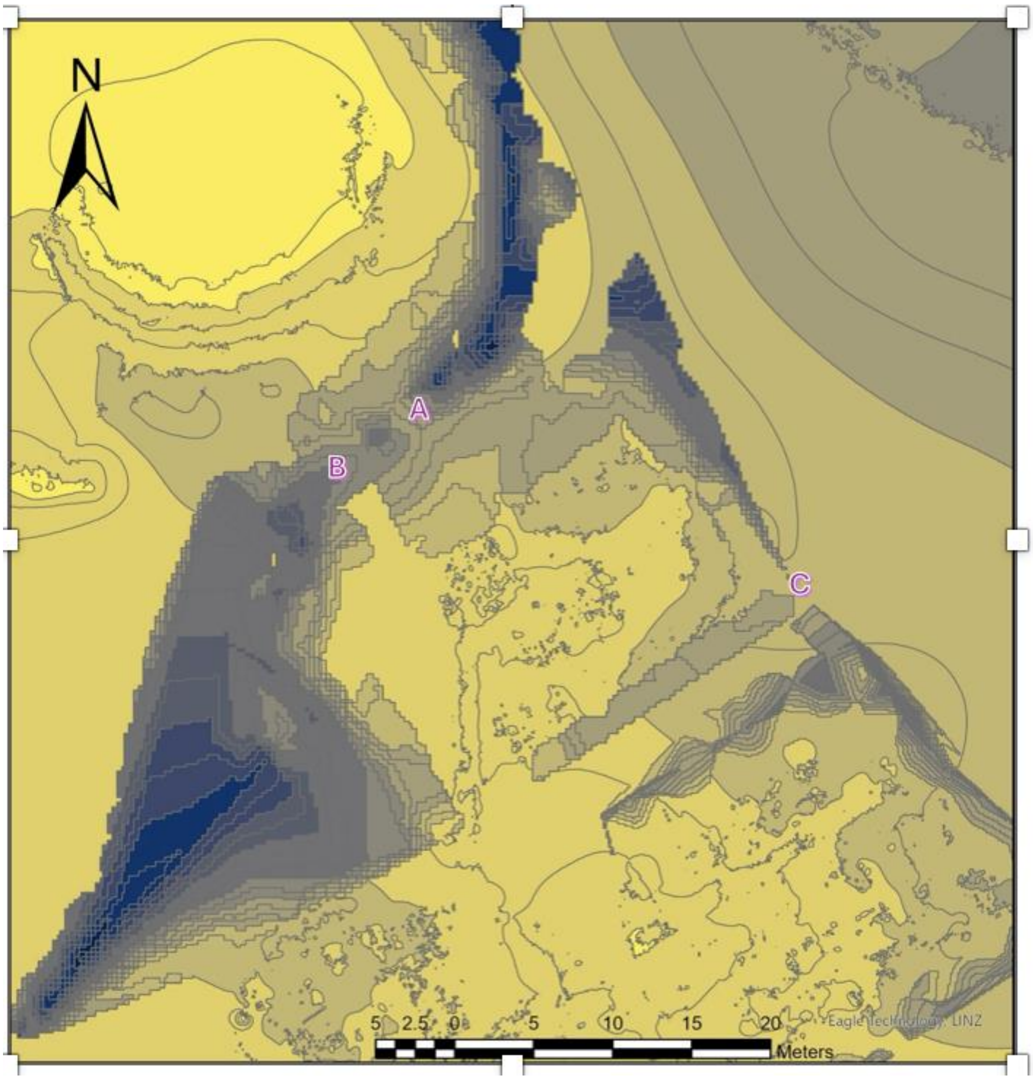

Figure 1817: Locations recommended for organic matter removal.

While studies highlight that bio-swales reduce peak stormwater discharge by 30-35% (Chen et al., 2023), our research highlights that in a case of swales in low-lying elevation and with a small elevation gradient across the system, as such of those on the Trees for Canterbury site, do not allow for efficient movement of water off site. To address access and stock protection in persistently flooded zones, we recommend installing duckboards to raise the working platform elevation. Duckboards offer a practical, low-cost solution for improving access across commonly saturated areas of the trees for Canterbury site. Constructed from treated timber or recycled decking, they can be installed with minimal excavation using basic tools and volunteer labor. Placement should focus on low-lying zones identified in the hydraulic survey, particularly along swale margins and work platforms. This approach is supported by restoration literature, which recommends raised walkways to maintain access without disturbing wetland hydrology (Clarkson & Peters, 2010; Bay of Plenty Wetlands Forum, 2009). International guidelines also highlight their role in protecting sensitive soils and vegetation while continuing site use (U.S Forest Service, 2023). For Trees for Canterbury, duckboards provide an immediate fix that supports staff safety and nursery operations during wet seasons, while longer-term drainage and ecological improvements are developed.

5.3 Limitations of our Study

Several limitations affected the scope and precision of this research. The aerial drone survey was conducted using nadir-angle imagery, which restricted the ability to reconstruct detailed 3D structures beneath the tree canopy. The manual field survey produced a sparse dataset due to time constraints, requiring interpolation to generate additional data points. Groundwater levels could not be verified on-site because of equipment limitations, and inflow data used in the hydrodynamic model were estimated rather than measured. The hydrodynamic model itself required a minimum 48-hour rainfall input, making it less suitable for simulating short-duration flooding events, within a small study area. Furthermore, limited familiarity with the flood modelling software, combined with a lack of documentation, restricted the team’s ability to fully utilize its capabilities. Future studies could improve data accuracy by employing sideways looking airborne LiDAR, which can partially penetrate vegetation to capture subsurface drainage profile more effectively (James et al., 2007). However, this would necessitate the use of a larger drone and prior flight approval from Christchurch City Council due to nearby power infrastructure.

6.0 Discussion

The flooding issues at Trees for Canterbury reflect a combination of hydrological, ecological, and topographical factors acting within a low-lying coastal landscape. The site's limited elevation gradient restricts natural drainage, while persistent groundwater saturation reduces infiltration capacity. Over time, the swale and drain systems designed in 2002 have lost hydraulic efficiency due to sedimentation, organic clogging, and dense growth of *Typha orientalis*. (Becker et al., 2022) suggests such conditions are typical of reclaimed wetland environments, where shallow groundwater and clay-rich soils prevent effective runoff. The factors we identified on the Trees for Canterbury site reduce flow velocity and exacerbate ponding after rainfall, consistent with studies done by Chen et al. (2023), that found unmanaged drains can reduce flow by up to 40%.

6.1 Future Scenarios and Climate Resilience

Looking ahead, Trees for Canterbury's adaption to climate change may, in the future, require transitioning from the current drainage system towards a managed wetland state that better accommodates natural hydrological processes. Rising sea levels of 0.61m by 2100 are expected to permanently elevate the groundwater table and increase the risk of saline intrusion soils (Musther, n.d; CCC, 2025). Therefore, TFC should adopt a resilient, vegetation-based approach to ensure a sustainable long-term pathway for their work. Literature emphasizes that native wetland species are essential for restoring hydrological balance and improving drainage efficiency. This research suggests TFC should consider species such as *C. secta* and *J. edgariae* to tolerate prolonged saturation, stabilize sediments, and reduce how long floodwaters linger. Planning to transition into a managed wetland state, like that of the site historically, would align with TFC's ecological and social mission through integrating community-led restoration with adaptive management principles. In the long term, such an approach could transform future flooding challenges into opportunities to demonstrate wetland restoration as both an ecological and educational model for wider urban restoration efforts.

7.0 Conclusion

The current drainage system is compromised due to the original design, lack of maintenance and underlaying topography. This research indicates that the current drainage system is not flowing out into the nearby estuary as intended, and instead significant amounts of water pool in low-lying elevation areas year-round. Key findings of this research indicate *T.Orientalis* (Bulrush) as a significant organic clog to the swale system, and our recommendations for the flooding issue suggest this plant needs to be removed and maintained. This research also suggests introducing native species such as *C. secta,* and *J. edgariae* in areas where *T.Orientalis* is removed. Locations where the study recommends removal of organic material may not be reliable due to the raw data collection limitations and interpolation of additional data points. Results from the flood model may be an unreliable indication as to the depth and location of flooding with reference to model unfamiliarity and suitability for this geographic scale. In future, this study could further investigate the groundwater table on the Trees for Canterbury site to understand the key areas contributing to significant flooding and how a high groundwater table year-round influence this.

8.0 Acknowledgements

We would like to thank the team at Trees for Canterbury, specifically Steve Bush and Laura for their guidance through our initial site visits and throughout the project. We also thank Matthew Wilson for his supervision and support through our flood modelling, as well as Giles Ostemeijer for his work flying the drone, Gorden Jiang for our GIS skills, and Paul Bealing and Justin Harrison for their assistance with the equipment. Finally, we want to thank Simon Kingham and Sophie Horton for their assistance with our group, and the 2025 TFC GEOG309 undergraduates for their commitment and work towards this report and data collection.

Appendix A

A.1 Detailed Methodology

The detailed methodology is a complete workflow, starting with data collection with the final output being the result from the flood model. The filenames noted align with actual datasets which are held in electronic format with TFC. The aim of the detailed methodology is to allow future students to ability to replicate and build upon the study, adjust the methodology and ultimately improve the analysis.

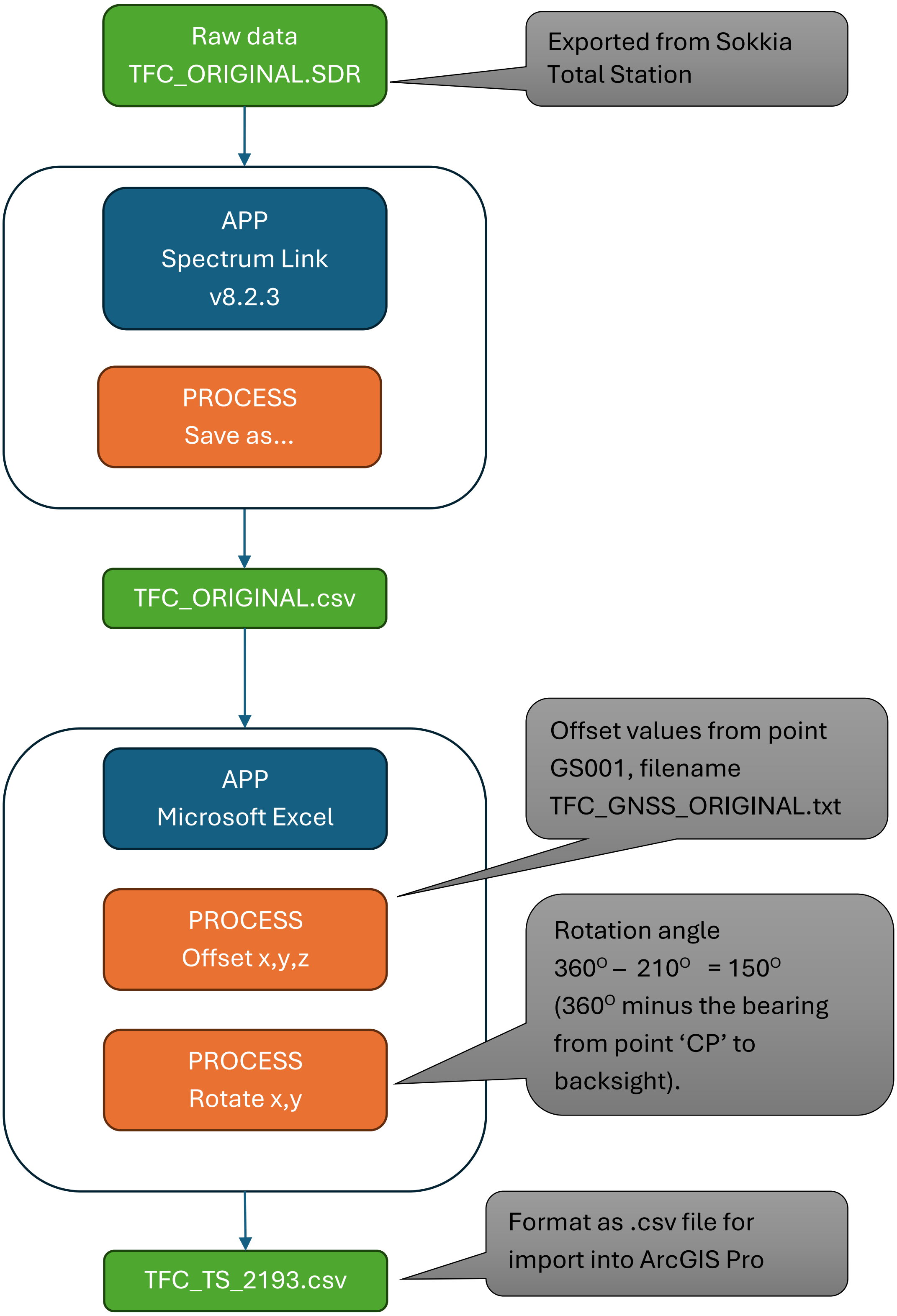

Figure A. 1 TotalStation Raw Data Processing

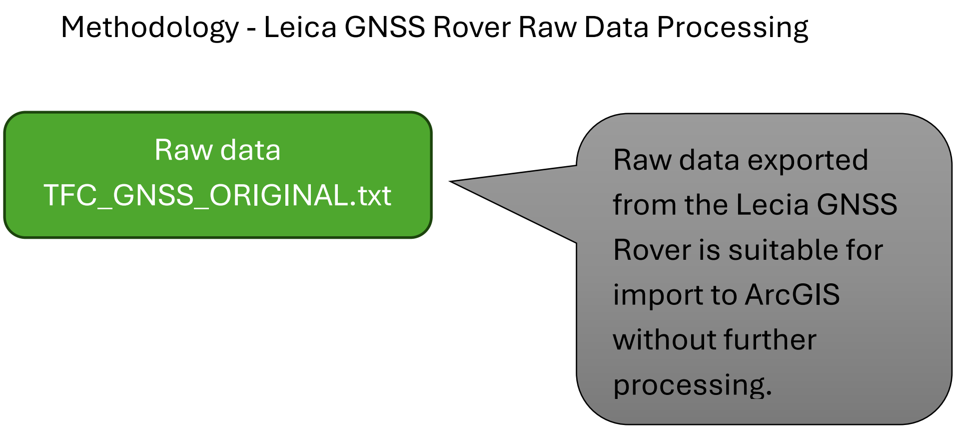

Figure A. 2 Leica GNSS Rover Raw Data Processing

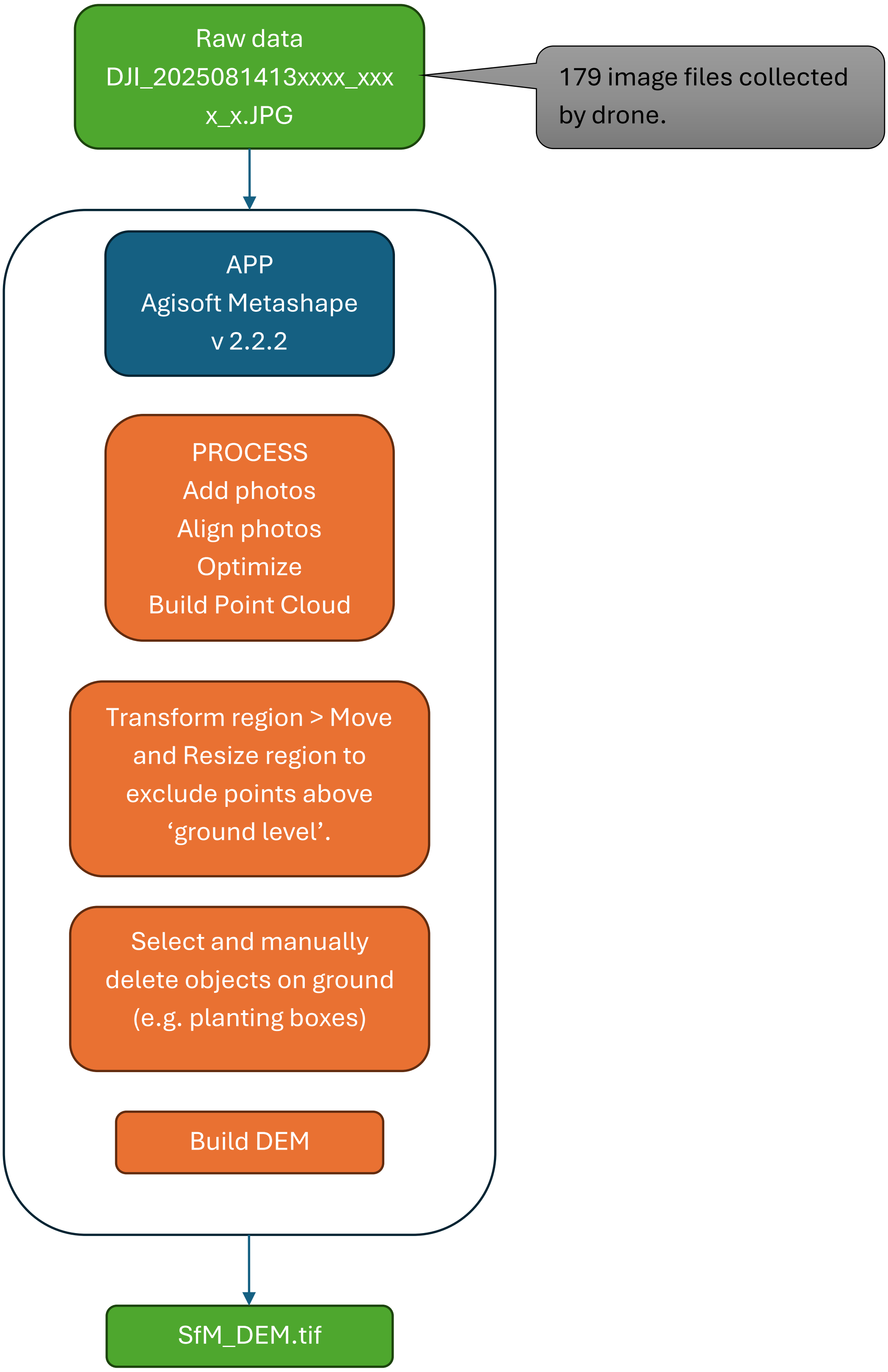

Figure A. 3 Agisoft Metashape Data Processing Steps

Methodology - ArcGIS Pro - TotalStation Raw Data Processing Steps

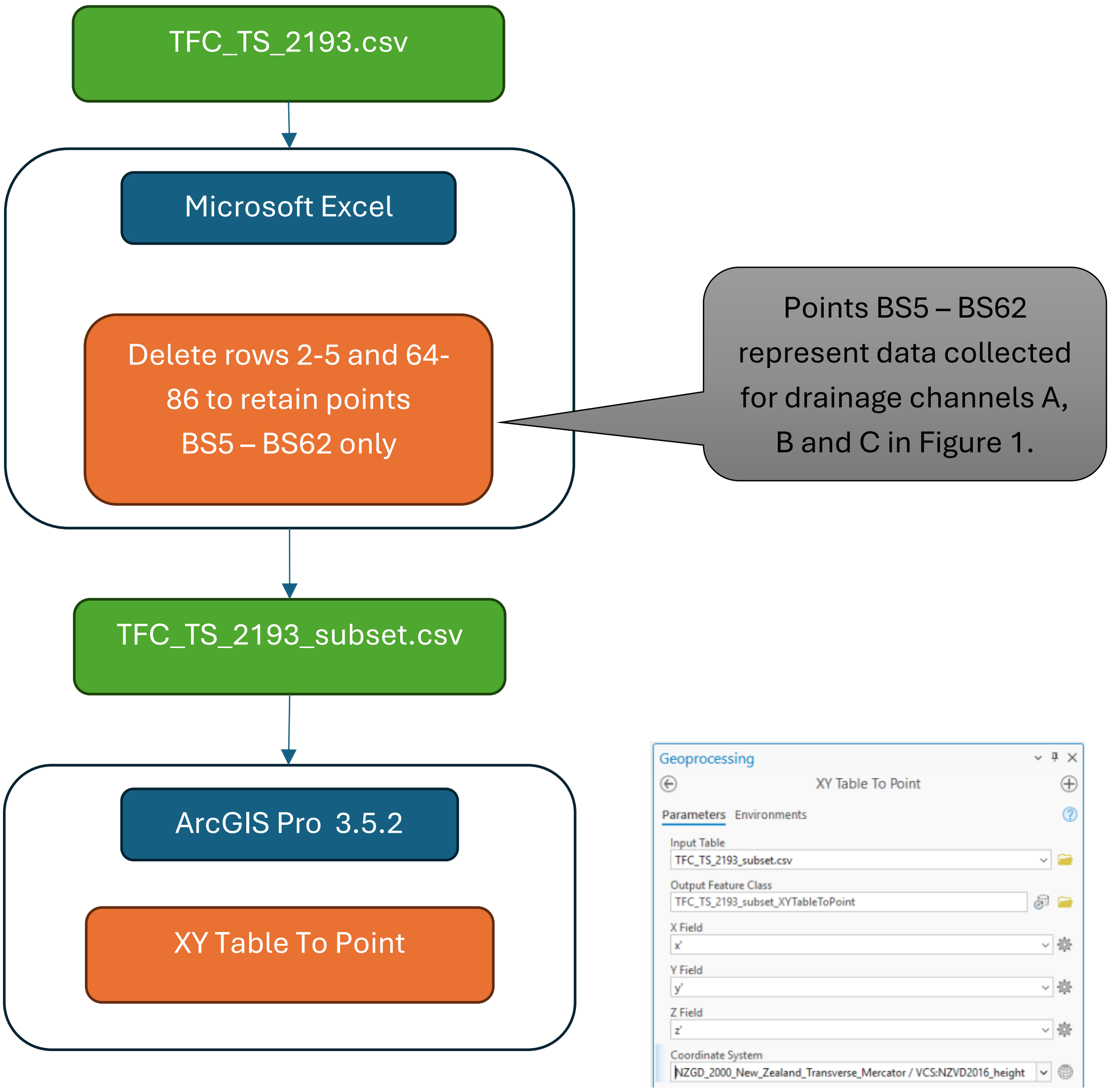

Figure A. 4 ArcGIS Pro - TotalStation Raw Data Processing Steps

Methodology - ArcGIS Pro – GNSS Rover Raw Data Processing Steps

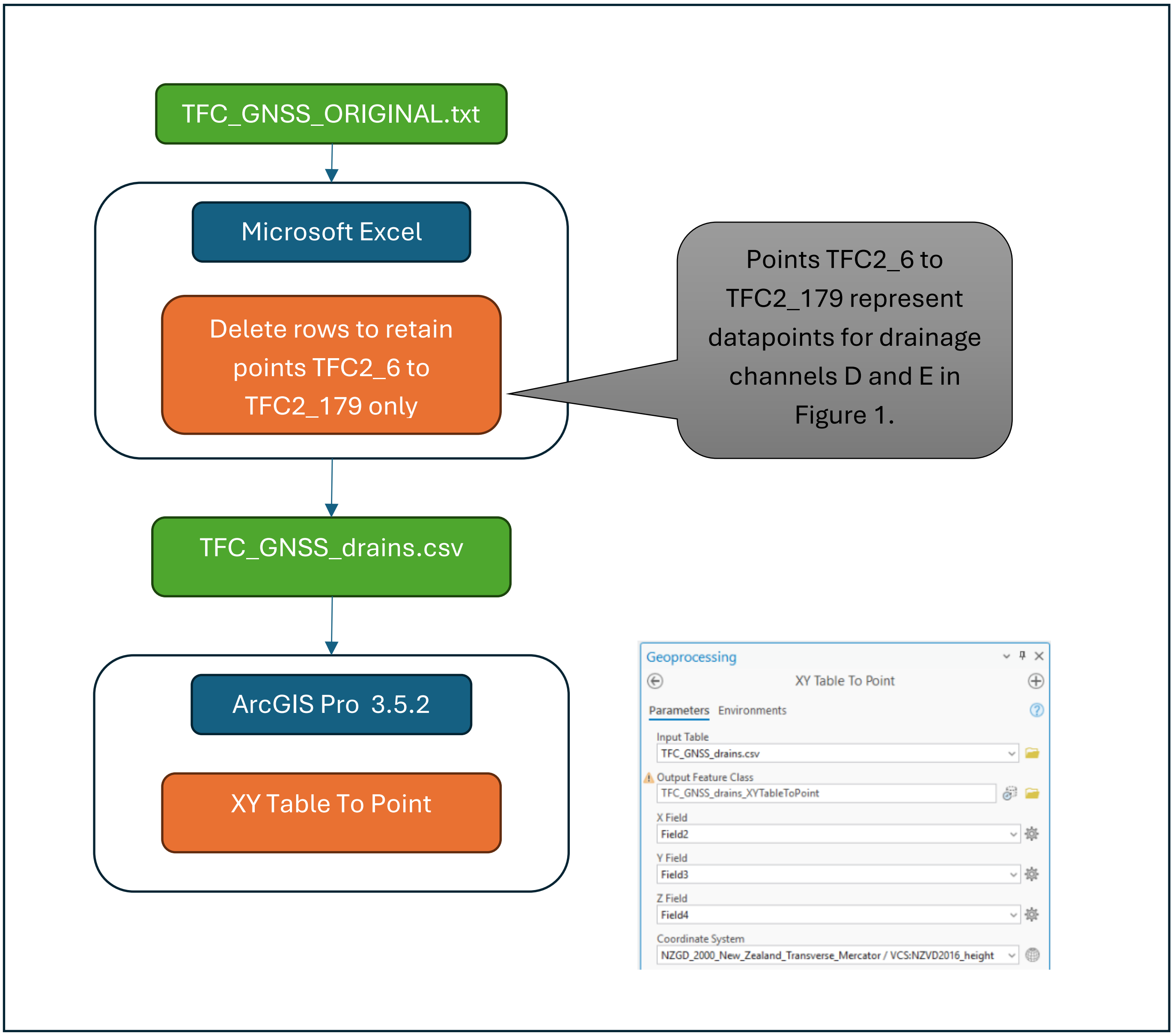

Figure A. 5 ArcGIS Pro – GNSS Rover Raw Data Processing Steps

Figure A. 6 TotalStation and GNSS Rover point data displayed in ArcGIS Pro

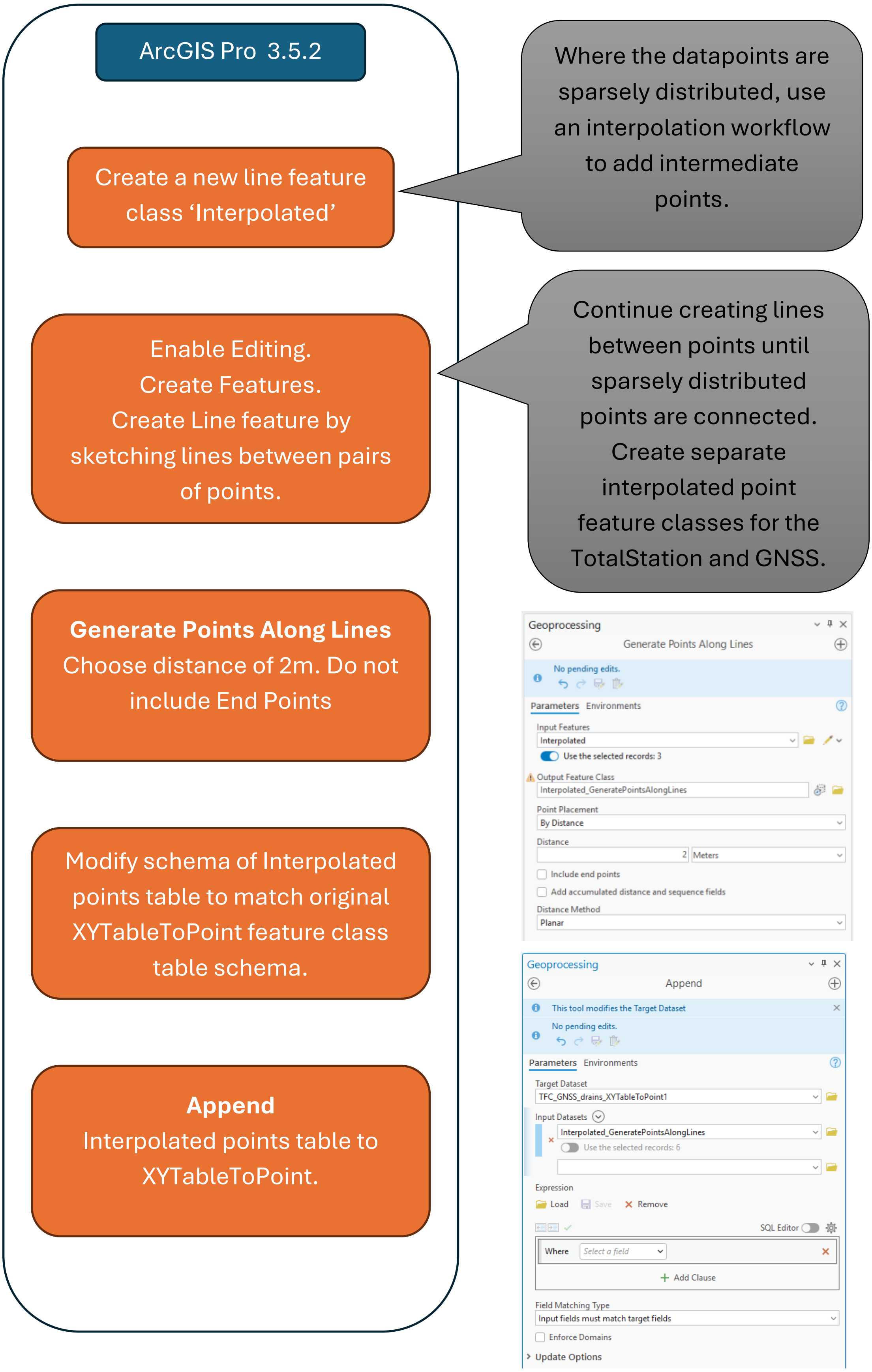

Figure A. 7 ArcGIS Pro – Interpolation of Points

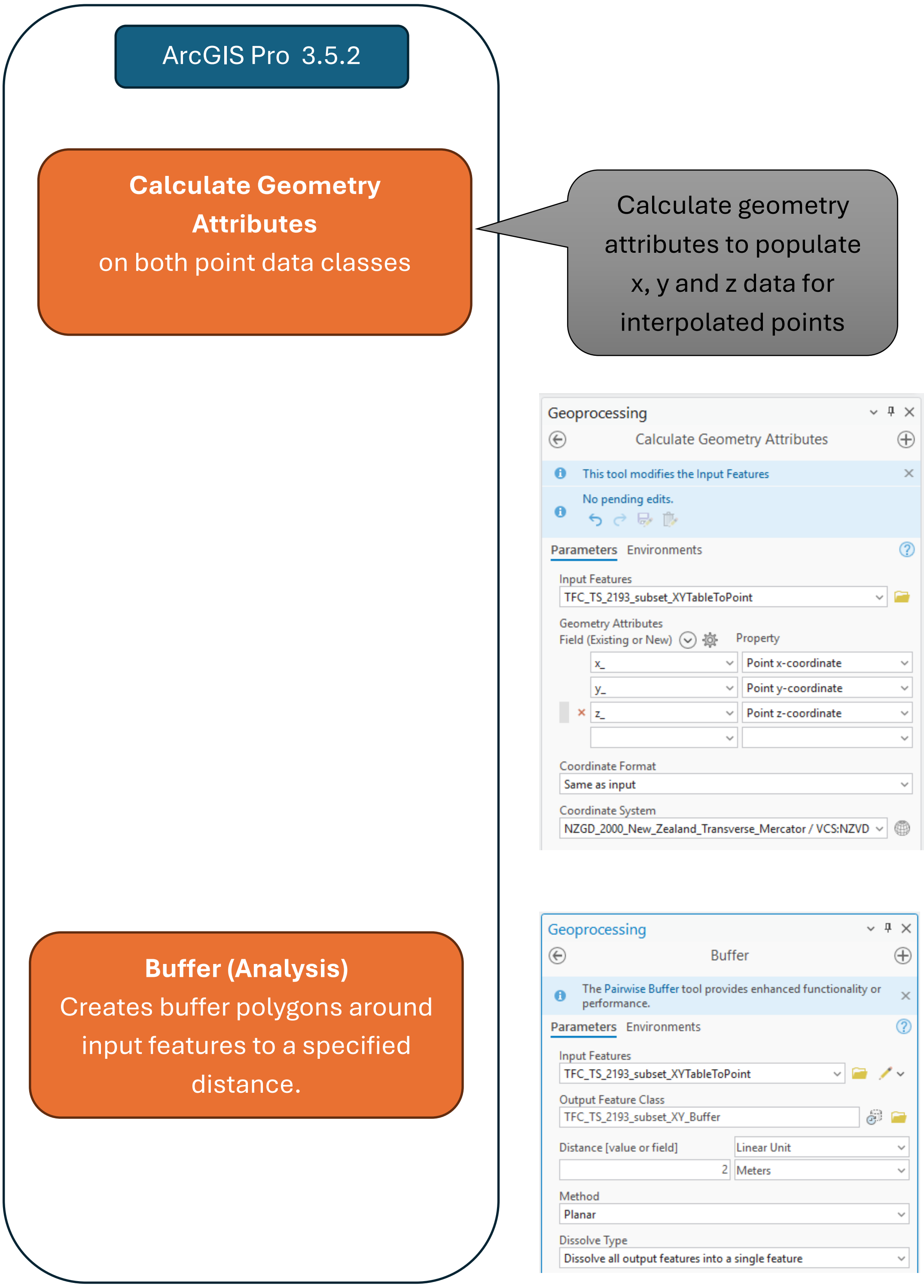

Figure A. 8 ArcGIS Pro – Interpolation of Points

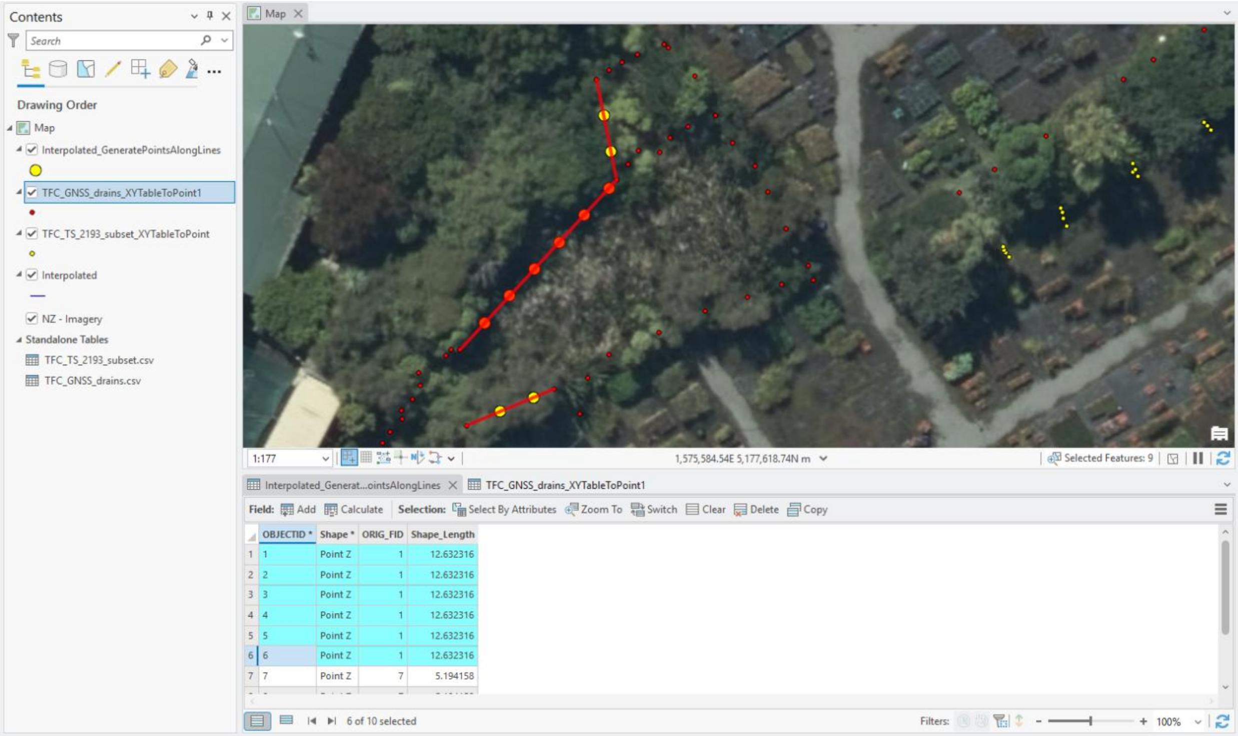

Figure A. 9 ArcGIS Pro – Interpolation of Points

Figure A. 10 Buffer applied after point interpolation

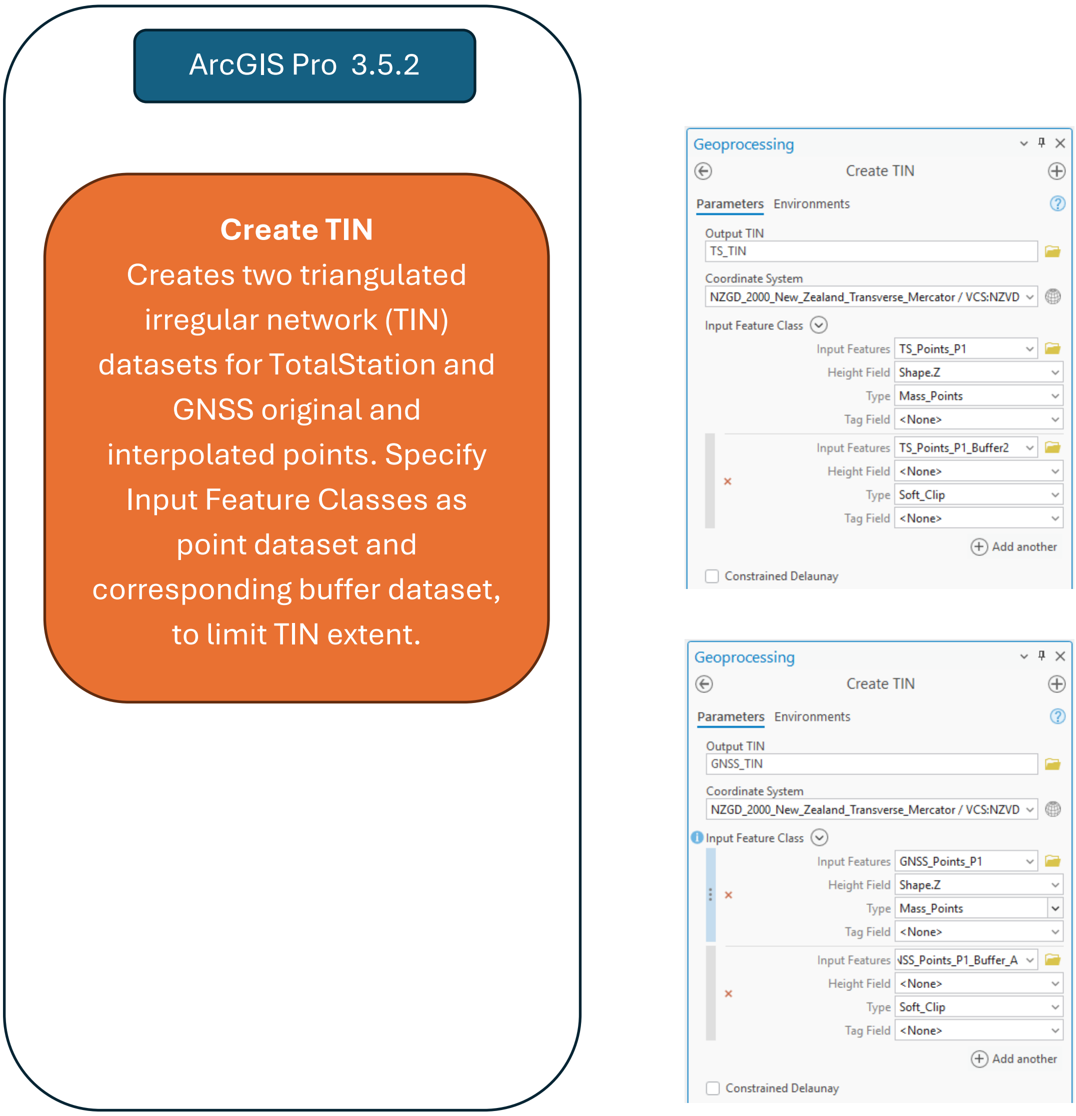

Figure A. 11 ArcGIS Pro – Create TIN

Figure A. 12 Image showing the result of TIN generation

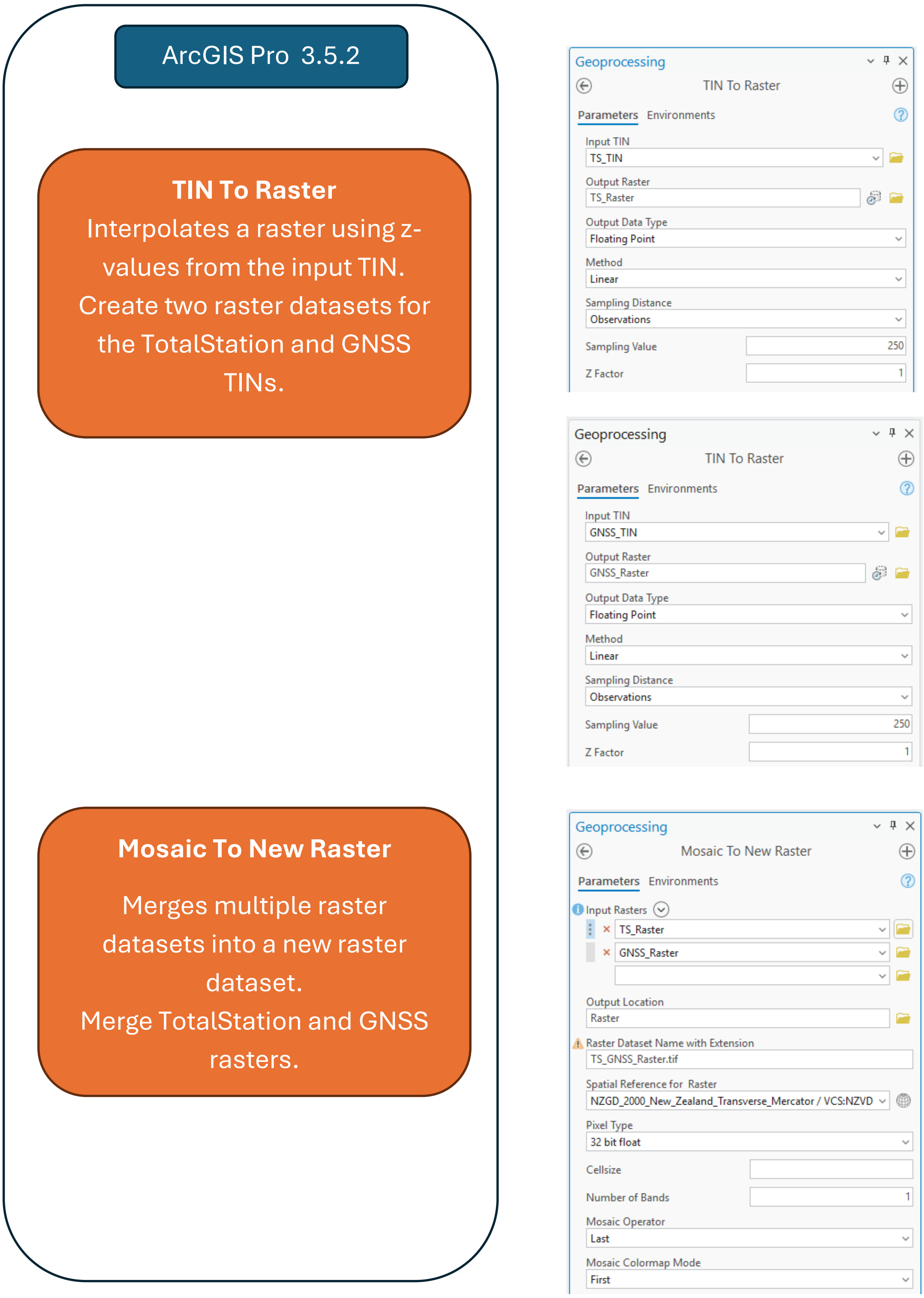

Figure A. 13 ArcGIS Pro – TIN to Raster – Mosaic to New Raster

Figure A. 14 Result of merging TotalStation and GNSS raster datasets

Figure A. 15 ArcGIS Pro – Add Structure from Motion raster dataset

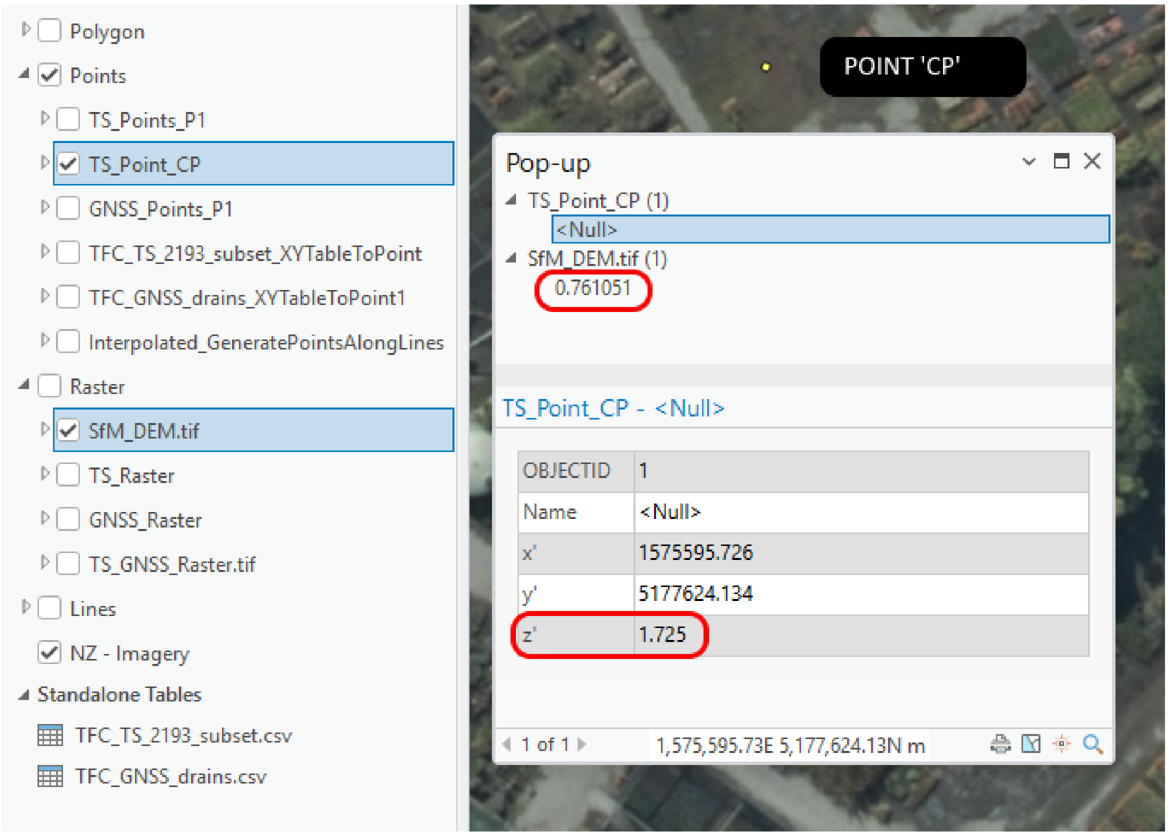

Figure A. 16 Elevation comparison between Structure from Motion and GNSS datasets at point 'CP'

The offset for the Structure from Motion elevation is
1.725 – 0.761 = 0.964m

Methodology - ArcGIS Pro – Merge all Raster datasets

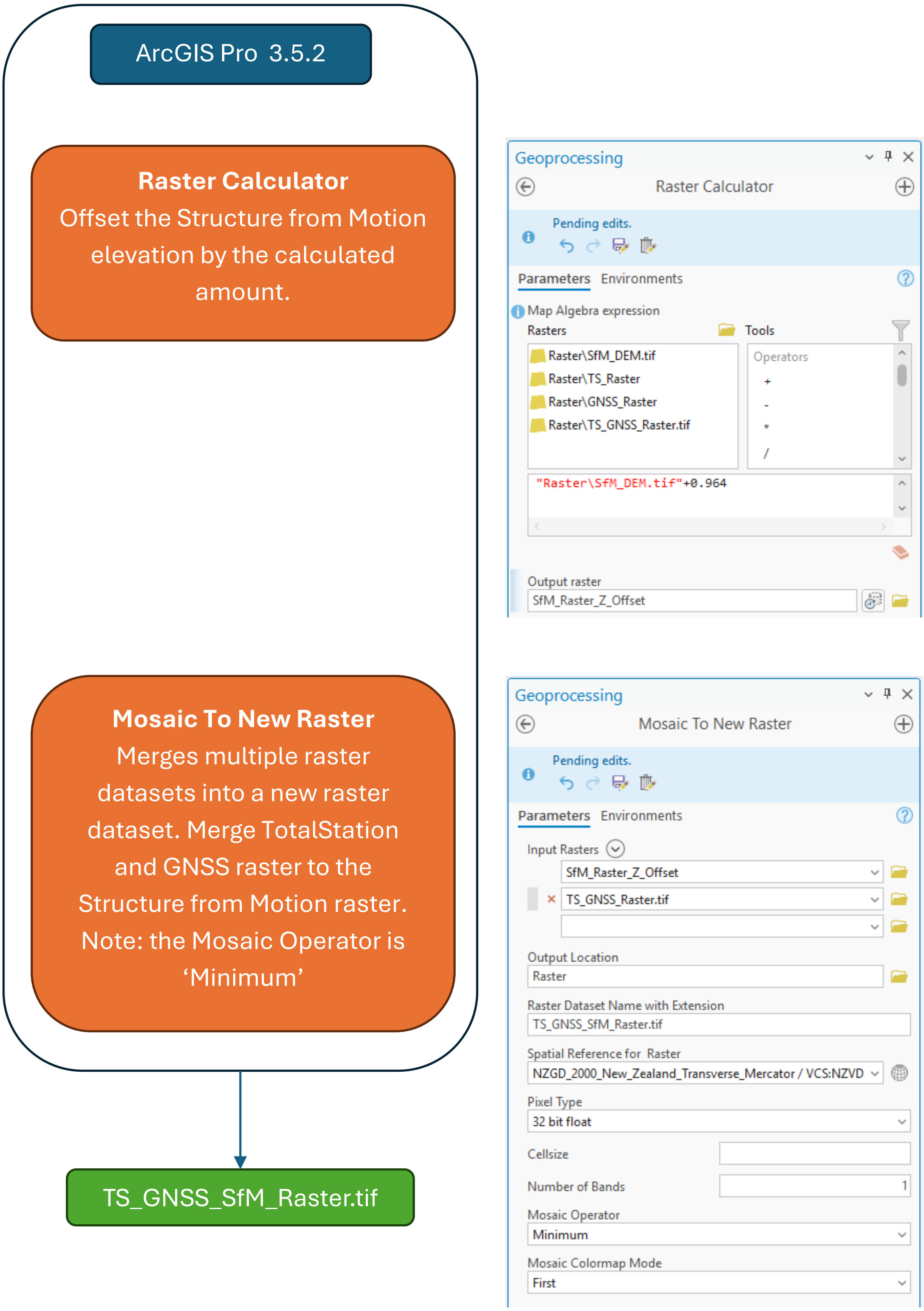

Figure A. 17 ArcGIS Pro – Merge all Raster datasets

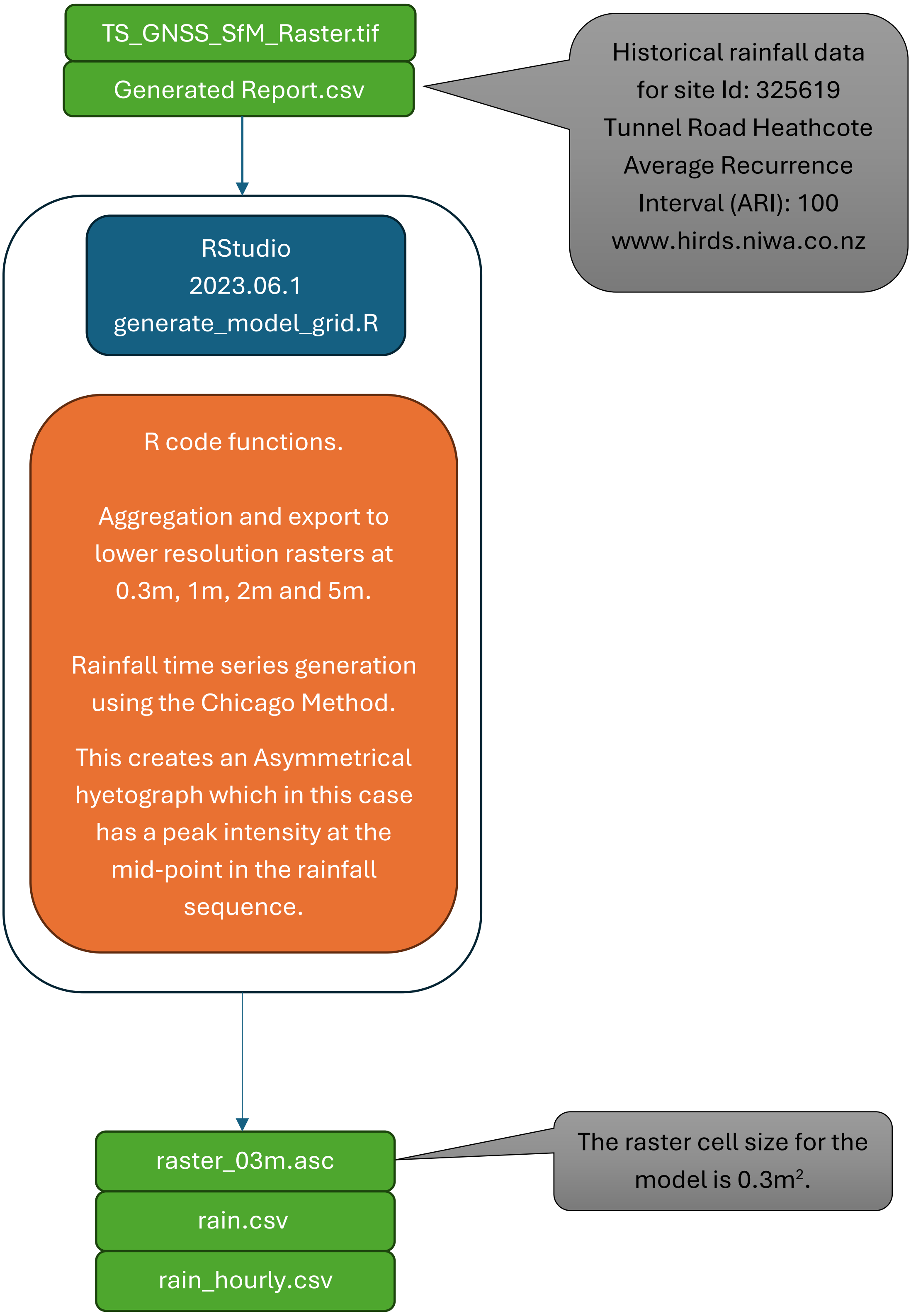

Figure A. 18 R – Elevation Data Preparation and Rainfall Time Series Generation

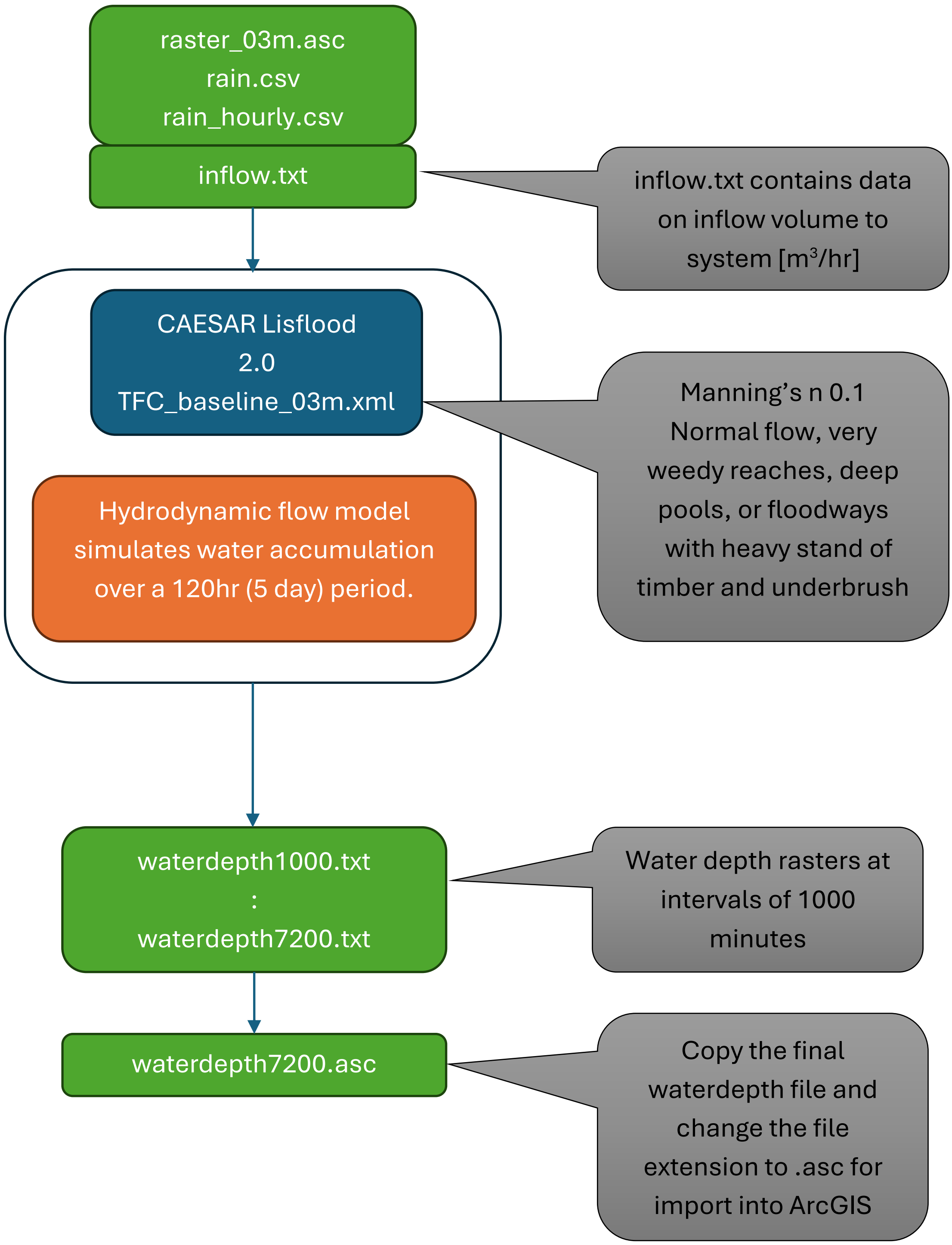

Figure A. 19 CAESAR-Lisflood 2D Hydrodynamic Flow Model

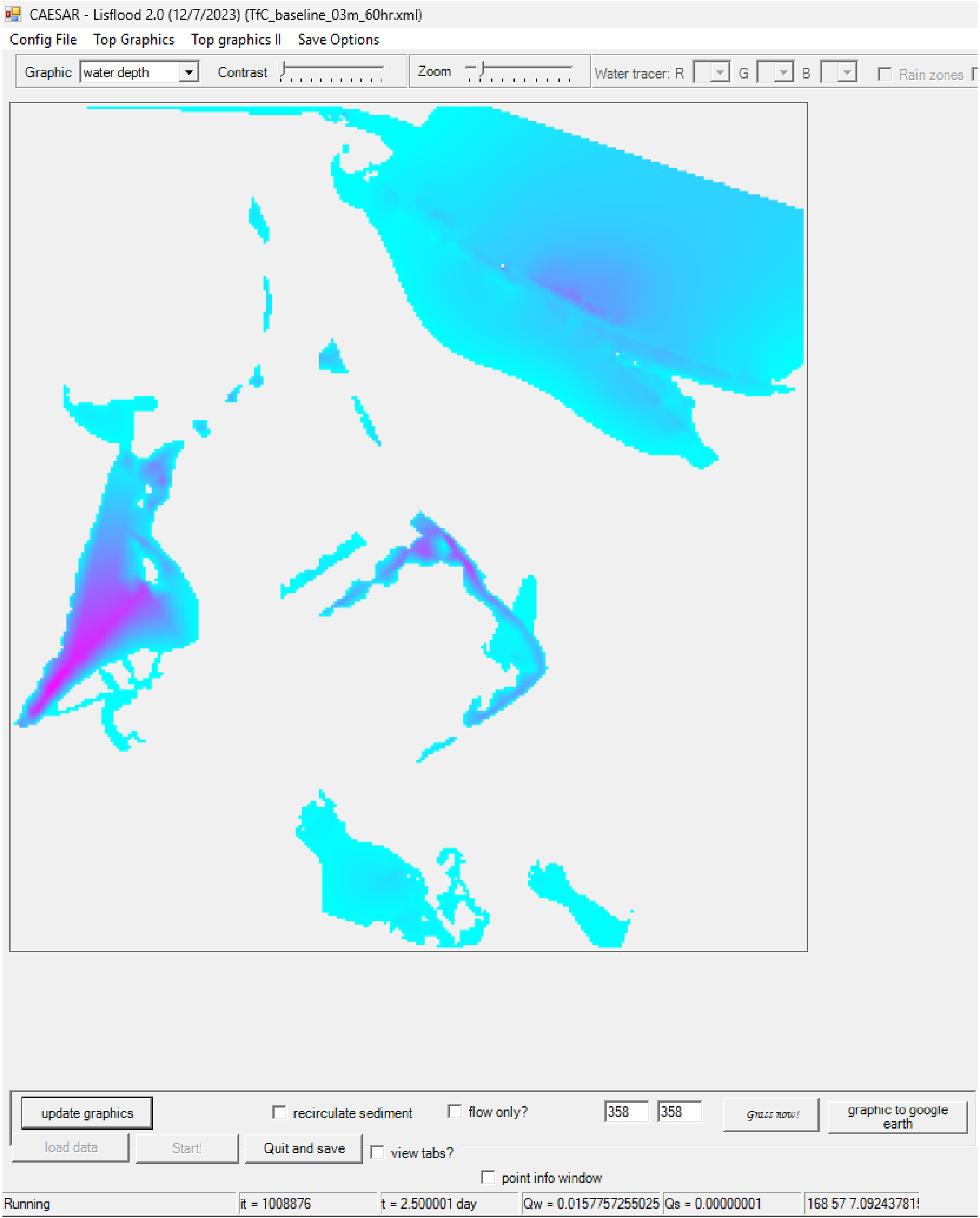

Figure A. 20 CAESAR LisFlood model output. Grid size 0.3m, run time 60hrs

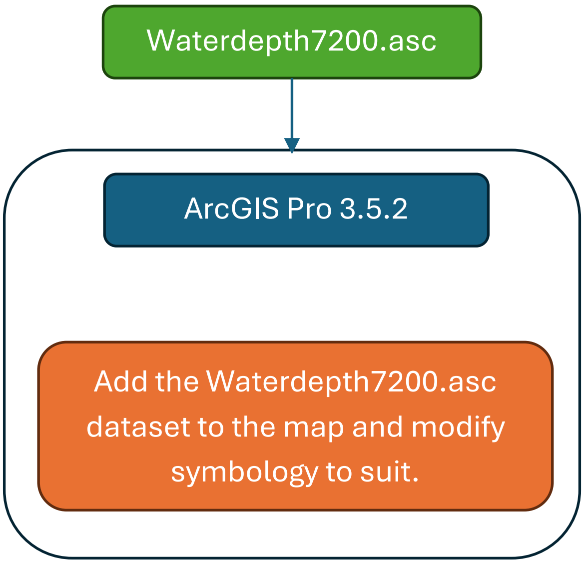

Figure A. 21 ArcGIS Pro – Add CEASAR model output

Methodology – ArcGIS Pro – Add CEASAR model output

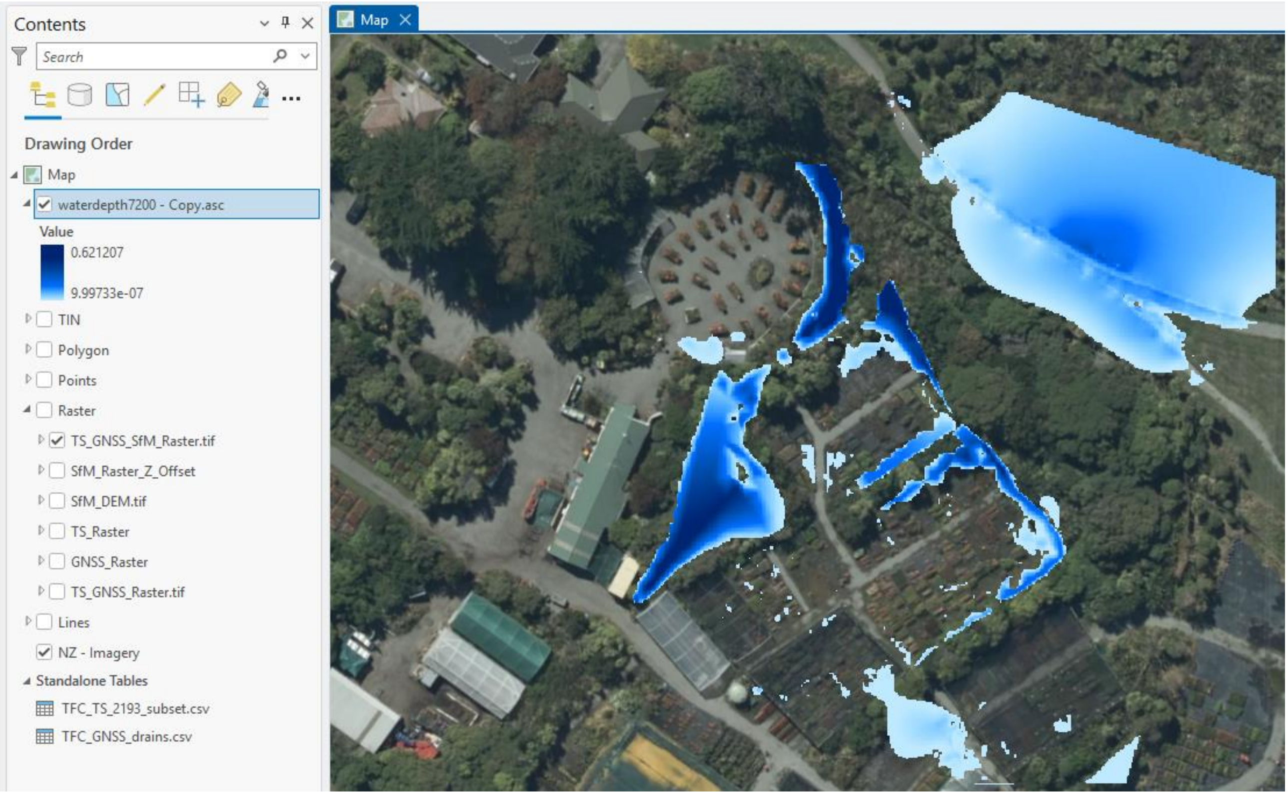

Figure A. 22 Waterdepth output from CAESAR-Lisflood mode

Appendix B

B.1 Groundwater and precipitation

The slope relationship between precipitation/sea-level rise and groundwater table was obtained by using Excel. As shown in Figure 4, the correlation coefficient (R^2) between monthly rainfall and the monthly groundwater table is approximately 0.25, indicating that rainfall accounts for 25% of the variation in groundwater levels. Moreover, the figure suggests that high precipitation can trigger a shallow groundwater level, especially during the rainy winter. Figure 5 shows that the R^2 between annual sea-level rise and the annual groundwater table is approximately 0.54, indicating that sea-level rise explains 54% of the changes in the groundwater table. Nevertheless, it differs from the precipitation effect. High sea-level rise means a deep groundwater table. Water table data was downloaded from (https://www.ecan.govt.nz/data/well-search/welldetails?WellNo=M36%2F7535)

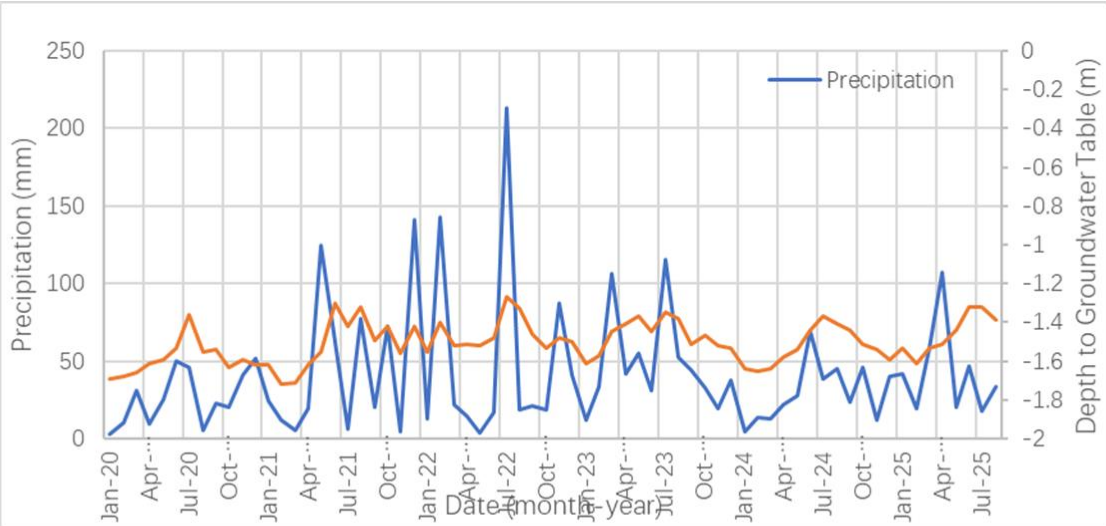

Figure C. 1 Monthly mean rainfall and groundwater table chart. (Environment Canterbury Regional Council & Earth Science New Zealand)

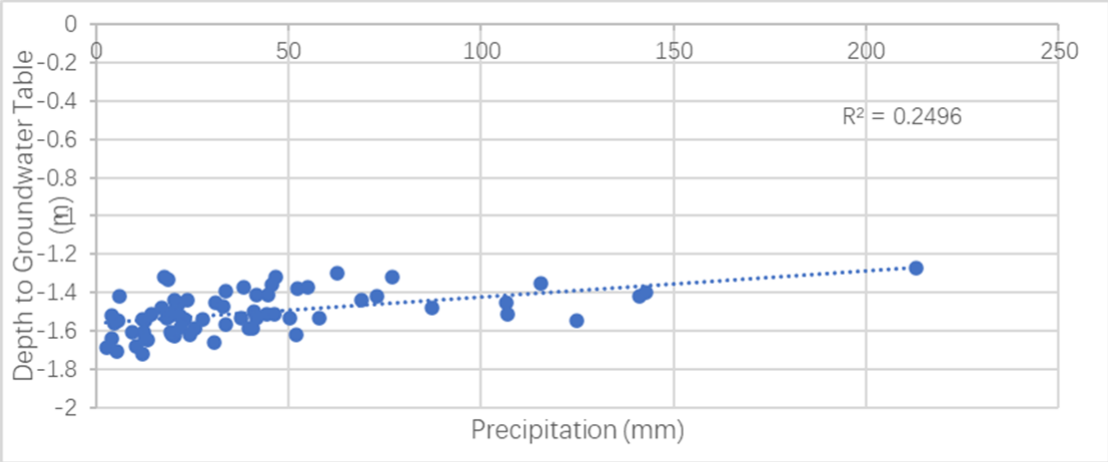

Figure C. 2 Monthly mean rainfall and groundwater scatterplot. (Environment Canterbury Regional Council & Earth Science New Zealand)

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