Is there any spatial variability of soil types, plant species & terrain characteristics within Riccarton Bush, and is it linked to the inefficiencies of the current irrigation system?

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1.0 Executive Summary

- Pūtaringamotu/Riccarton Bush is a small remnant Kahikatea Forest of the ancient Canterbury plains, that holds significant ecological and historical values.

- Irrigation of the bush has occurred for the past 30 years to replicate and maintain the swampy damp ecosystem climate, but not efficiently, the Trust has asked us to investigate problems with standing surface water from irrigation.

- This project investigates any potential spatial variation of soil types, vegetation, and topography within Riccarton Bush, to help explain inefficiencies linked to irrigation.

- The research question we aim to answer was developed into, "Is there any spatial variability of soil types, plant species & terrain characteristics within Riccarton Bush, and is it linked to inefficiencies of the current irrigation system?"

- A review of related literature was conducted, to focus in on and identify some key potential influencing factors, which may cause pooled surface water within a woodland.

- Soil core samples were collected using an AMS corer and hand auger method, identification of nearby plant species also conducted. Open Topography software used for basic terrain data.

- All 10 soil samples sites were divided into 15cm increments, allowing for 6 sub-samples per sample site for particle size analysis using an MSLV.

- Soil sample analysis indicates uniform compositions, particle size distributions and sorting profiles.

- Minimal and limited distribution of understory plant species, canopy species exhibit distribution.

- Topographic analysis and results were inconclusive.

- Soil and vegetation distribution appear to be insignificant with regard to surface water distribution, terrain distribution could not be determined so may still be significant.

- Surface water distribution is more feasibly linked to characteristics of observed soil type and vegetative water needs and niches.

- It is anticipated that the results, data, and GIS Map tool will be utilised in the future design of any new irrigation infrastructure and in research of a similar nature.

- Consideration of a new type of sprinkler head for the irrigation system or finding a way to automate the process could be of potential.

- Investigating the groundwater situation beneath the bush could provide further information regarding what may predominantly influence the observed surface water.

2.0 Introduction

Riccarton Bush is a site of profound historical, cultural, and ecological significance, which has undergone substantial transformations in recent years. These transformations include the reduction of its forested expanse and the diversion of natural springs, resulting from more than a century of drainage and urban development. Consequently, the ecosystem has become significantly drier than its original, moisture-rich condition. Over the last three decades, the Riccarton Bush Trust has proactively employed irrigation to restore and recreate the moisture-rich conditions that once characterised the environment. Nevertheless, the existing irrigation system faces substantial challenges and exhibits signs of deterioration, resulting in inefficiencies in water resource management. A significant limitation of the current system lies in the fact that it causes pooled surface water throughout the bush, meaning the ranger must delegate a significant amount of his time to monitoring the standing surface water levels in the bush.

This research is dedicated to identifying whether there is any spatial variation in soil types, vegetation species and terrain features within the bush, which may be associated with irrigation inefficiencies. The approach is rigorous and systematic, incorporating core and auger sampling techniques, followed by particle size distribution analysis facilitated by a Particle Size Analyser. The primary objective is to unravel the intricate correlations between variations in soil properties and their corresponding particle size and their ensuing hydrological impacts on the surrounding vegetation. This report aims to provide a comprehensive understanding of the context and objectives of our research, encompassing a literature review, methodologies, results, and a discussion to contribute valuable insights to enhance the irrigation practices within the unique ecosystem of Riccarton Bush.

Figure 1. Aerial capture of Riccarton Bush and surrounding area (Harvie, 2022).

3.0 Background Literature

The comprehensive literature review encompassed several key sub-themes, including historical context, groundwater dynamics, vegetation variations, terrain influences, and the role of soil, which collectively provided a thorough foundational understanding to support this research's effort. Within the context of groundwater dynamics, it was observed that minimal pumping had limited impact, moderate pumping reduced groundwater discharge, and intensive pumping disrupted the balance, with the potential to alter streamflow patterns (De Graaf et al., 2019). Our research primarily centres on soil variation and efficient irrigation practices rather than groundwater dynamics. Nonetheless, it is important to acknowledge that some studies have explored interactions between groundwater and surface water, offering potential insights for future recommendations (Kalbus et al., 2006).

Regarding terrain dynamics, the interaction of clayey subsurface layers with water flow, especially relevant to Riccarton Bush, highlighted the necessity for effective outflow to maintain balanced soil moisture (Turunen et al., 2015). However, the hindrances faced by drainage in Riccarton Bush, attributed to flat topography and specific vegetation patterns, have had adverse implications. Creating drainage routes and diversifying natural springs may impact the forest's self-sustainability (Maloletko et al., 2018), necessitating regular artificial irrigation. These challenges underscore the need to address drainage issues within the broader context of optimizing irrigation practices. Furthermore, the research revealed that clay-based soils, prevalent in Riccarton Bush, exhibit notably low drainage coefficients, highlighting the importance of addressing these specific soil dynamics (Jalilvand et al., 2018).

Additionally, research uncovered that forests with complex root systems and expansive pore spaces have high hydraulic conductivity, effectively mitigating runoff and preventing surface water pooling (Hayashi et al., 2006). This discovery challenged the initial assumption that Riccarton Bush, characterized by robust root systems, would be immune to pooling issues and inadequate infiltration. These findings collectively emphasize the substantial impact of these subthemes on the forest's infiltration capacity. The literature also unveiled an intriguing aspect of soil characteristics: soil water repellence. Hydrophobic coatings on soil particles influence hydrological properties, plant growth, and irrigation efficiency, reducing soil wettability, increasing runoff, creating preferential flow pathways, limiting plant water access, reducing irrigation efficiency, and elevating pollution risks (Moore et al., 2010). These findings may explain the observed pooling issues within Riccarton Bush.

Furthermore, the research considered the ecological pressures urban forest areas face, such as fragmentation, non-native species, the urban heat island effect, and higher pollution levels (Wallace & Clarkson, 2019). These challenges could increase temperatures within Riccarton Bush, requiring increased irrigation, especially for vulnerable Kahikatea trees, including juveniles. Lastly, the exploration of inter- and intra-competition among Kahikatea and Rimu trees revealed minimal interspecific competition but significant intraspecific competition among juvenile Kahikatea trees due to their need for direct sunlight access (Denyer & Deng, 2019).

This research will bridge these findings, providing valuable background knowledge to address the forest's irrigation challenges while respecting its unique historical and ecological context. Furthermore, it acknowledges the profound cultural and historical significance of Riccarton Bush as the last remnant of Canterbury's podocarp forest, deeply rooted in Kahikatea trees (Molloy, 1995).

4.0 Methods

4.1 Field Methods

4.1.1 Site Division and Random Sampling

A map of the site from Molloy (1995) served as the basis for a systematic partitioning into eight equal sectors, thereby mitigating potential sources of bias (Figure 2). Within each sector, a random sampling method was applied to designate two specific sites for investigation to collect a comprehensive dataset of 16 cores, adequately representing the entire study area

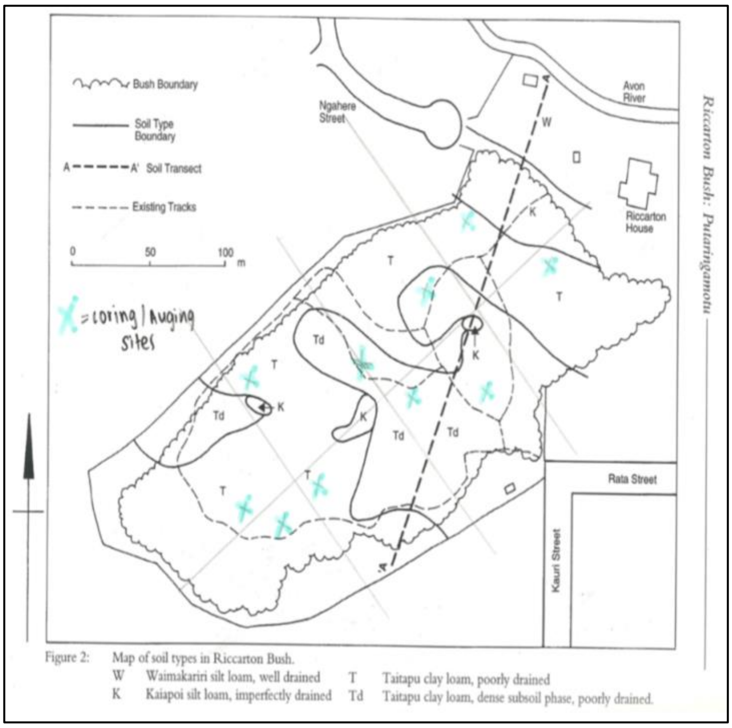

Figure 2. Sampling site plan, drawn on soil map from Molloy (1995).

4.1.2 Soil Core Collection

An AMS soil corer equipped with a hammer attachment (Figure 3) was assembled on-site after selecting random sampling sites. A 1.2-meter plastic tube was inserted into the metal core casing to encapsulate the soil core samples. The AMS corer was positioned at a 90-degree angle to the ground and was driven to the sample depth of 1 metre.

The core extraction involved a reverse hammering technique, complemented by applying a T-bar attachment with a pull-and-twist methodology, necessitating the collaborative effort of two team members. Once extracted from the ground, the soil cores were transported to the ranger’s shed for disassembly and cleaning. This process involved the team's combined strength, a vice, and a wrench. In certain instances, the university workshop technician was consulted for further assistance. To maintain the samples, plastic wrap was taped over the ends of the tubes. Cores 2, 3 and 4 saw the introduction of a wrench and lithium grease to prevent over-tightening and maintain a 90-degree alignment with the soil.

Regrettably, during the collection of core 4, the AMS corers’ hammer attachment snapped and rendered it unusable. In response to this unexpected setback and considering time constraints, the decision was made to revise the core collection target from 16 to 10 cores and transition was made to the auger method for the remaining seven randomly selected sites to ensure the study's continuity (Figure 4).

Figure 3. Photo of AMS corer with hammer attachment being driven into the ground at Riccarton Bush.

4.1.3 Auger Collection

Like the core methodology, the auger was positioned perpendicularly to the ground. A controlled rotation initiated the auger's penetration into the soil, achieving a depth of approximately 15 centimetres each time. Extracted soil was carefully removed using a specialised tool and deposited into designated plastic bags. The depth of each sample was recorded directly on the bag using a permanent marker, ensuring precise documentation. This procedure was systematically repeated until a maximum depth of 90 centimetres was reached.

Figure 4. Hand Auger used in second phase of sampling.

4.1.4 Vegetation Analysis

A concurrent vegetation analysis was conducted to augment our dataset. Vegetation analysis involved marking a 10-metre radius around each sampling site (the 10m radius was determined due to each sprinkler covering an 8m radius). A designated team member systematically captures photographs of the surrounding vegetation. These visual records served as valuable resources for subsequent analysis and interpretation.

4.1.5 GPS Data Recording

A Garmin eTrex 10 device was initially employed for precise geospatial alignment but was subsequently upgraded to a Trimble Geo7x. The Trimble Geo7x was positioned alongside the sampling site to ensure the GPS data was accurate and precise to the sample location.

Data collection continued until a minimum of 200 data points were recorded, supported by a network of at least five satellite connections to ensure data robustness. Concurrently, relevant comments were added to GPS data entries, specifically denoting site identifiers (e.g., “auger 2”) as vital reference points for subsequent analysis and geospatial assessment.

4.2 Lab Methods

4.2.1 Soil Analysis

Following the collection of the primary field data from Riccarton Bush, the samples were broken into increments of 15 cm to a depth of 90 cm to conduct analysis. This incrementation allowed for a good representation for the entire core profile. Munsell's colour chart 7.5 YR (Appendix B) was used to record the colour of all samples as it is a universal indicator for colour these were recorded in excel (Appendix C). The samples at each 15 cm increment were taken with an uncertainty of ± 5 cm (Figure 5). Samples were suspended in distilled water to prepare each sample for analysis (Figure 6).

Figure 5. Sub-Sampling at 15 increments

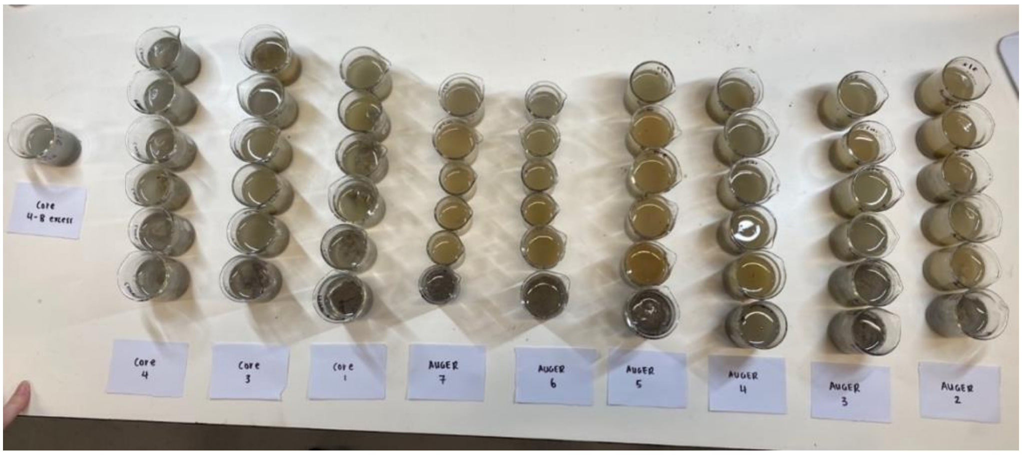

Figure 6. Sub-sample increments from each core sample suspended in distilled water and ready for analysis.

There were two methods available to analyse the samples. The first proposed method was a pipette analysis of muds from analytical sedimentology (Lewis & McConchie, 1994); this involves using a hydrometer, which would produce useful data on grain size. However, this method is time-consuming and takes more than 8 hours to complete per sample; it was therefore unreasonable to use due to the time restrictions of this project.

The other method utilises a Particle Size Analyser (PSA), a digital-based method centred around the distribution of particle sizes for a given sample. The PSA machine used was the Mastersizer Hydro LV 3000 (MSLV) in the University of Canterbury's civil engineering soil lab (Figure 7). The MSLV utilises Mie's theory of laser diffraction (Malvern Panalytical, 2021) to determine the distribution of particle sizes in each sample - this was the method chosen.

Figure 7. Mastersizer Hydro LV 3000 that was used.

The samples were suspended in distilled water and mixed on a magnetic stirrer (MSL 8 Magnetic stirrer) for ~2 minutes to ensure homogeneity of the samples. Following this, each sample was pipetted into the MSLV with particular attention given to the obscuration percentage to maintain the 8-12% threshold. The MSLV carried out three readings in its Malvern software for each sample tested, and then an averaged result was produced, minimising the influence of anomalies in the results.

4.2.2 GPS & GIS Methods

The GPS data collected by the Trimble GEO7x was downloaded to Trimble's Pathfinder Office and then post-processed to obtain a higher degree of accuracy. By using Land Information New Zealand's (LINZ) base stations in Wigram, Bromley, and Yaldhurst, the GPS data that had been collected could be triangulated bringing the accuracy of all the points down to ~1.5 m. These points were uploaded to ArcGIS Pro and layered on a Triangulated Irregular Network data model (TIN) of Riccarton Bush exported from OpenTopography software (Appendix A). Each GPS point on ArcGIS Pro stored the sorted nature and the phi (φ) mean at the 15cm increments of each sample site. To carry out the topographic analysis, open-source LiDAR data from OpenTopography was used to visualise any topographic variation, however, this was very limited.

4.3 Limitations to Methods

4.3.1 Limitations to Field Methods

In the fieldwork conducted for this study, several limitations were encountered that impacted the data collection process. The foremost limitation was the extremely dense ground conditions at the study site. The unexpected density made the process of core hammering particularly arduous, resulting in the core sampling being significantly slower than initially anticipated. The physical demands of driving the core into the ground were taxing on the team members, and extracting the soil cores presented its own challenges. The strenuous twisting and pulling motion required for core extraction placed a considerable physical strain on the team members, whilst also inadvertently tightening the metal cylinders encasing the core, making unscrewing the cylinders to access the soil core samples very time consuming.

Ultimately the ground conditions contributed to the unexpected failure of the AMS corer's hammer attachment, necessitating a switch to the alternative sampling method (auger). The limitations imposed by the dense ground underscore the importance of considering site-specific conditions and the physical demands of fieldwork in the planning and execution of similar studies.

4.3.2 Limitations to Lab Methods

Regarding the MSLV methodology, using Sodium Hexametaphosphate (Calgon) would decrease the chance of particle/sediment clumping, mitigating any potential skew of the PSA results. However, Calgon was only made available once the sample analysis had been completed. The distribution charts produced from the analysis showed no evidence of clumping, but Calgon would increase the confidence of the results.

A further limitation of the soil analysis was the composite auger samples. As the auger could only take ~15cm samples at a time, this resulted in some auger bags from 0-12 cm and 12-28 cm, for example. To better represent the 15 cm increments, a combination of soil from each bag was used for testing at the 15 cm increment.

A limitation of the GIS lab work was the spatial resolution in the OpenTopography LiDAR data, as there were significant gaps in the point cloud data due to the dense tree canopy. The dense tree canopy of Riccarton Bush also limited the accuracy of the GPS points collected.

5.0 Results

For the following sections, 5.1 and 5.2, AMS Core 2 is removed from the results as an outlier because it was an incomplete sample (only ~40cm of a core profile was retained upon extraction). The Core 1 sample only has incremental measurements up to 75cm of depth as this was also conducted test run of the auger method, and sample depth was revised after this.

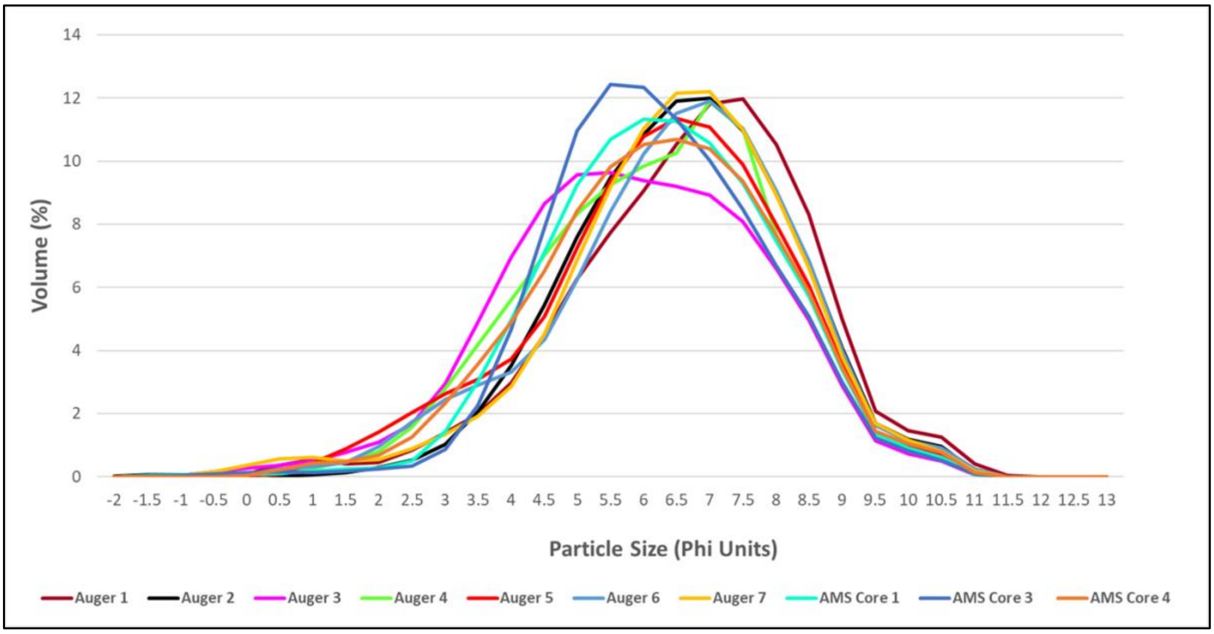

Figure 8. Average Particle size vs % Volume of each sample, is the average volume of each particle size across all increments.

5.1 Particle Size Distribution

Figure 8 shows the average sediment particle size against their relative abundance (%) in each of the 10 samples taken from Riccarton Bush. The average distribution curves were generated in excel via MasterSizer data processing and sorting of the volumes of each particle size at each incremental sample and calculating the average for the entire sample.

The curves observable in Figure 8 indicates that the particle size distribution of all the core samples is uniform. Eight of the ten core samples display a mean particle size value of 6.5-7.5 Phi. The AMS Core 3 and Auger 3 samples display lower mean values of approximately 5-5.5 Phi. The lower displayed mean value of these samples indicates a greater quantity of coarser sediment particles present in the two sample sites. The standard deviations associated with each of the 10 samples (Appendix D) returned values of greater than 1 for all. Values greater than 1, relate to and correspond with poor sorting characteristics of a medium.

5.2 Soil Composition

Figure 9 is a breakdown of the average contribution of materials across the depth profile of every core sample. Once again, the results in Figure 9 were produced through data processing and sorting MasterSizer data in Excel.

From the histogram, silt is the primary component of the soil profile down to 90cm in depth. Silt comprises over 75% of all the samples, with clay and very fine sands contributing between 5-12% each to their respective samples. Fine sands and coarser sand types contribute <5% to respective samples.

From analysis of Figure 9, it can be identified that the auger samples with lower silt percentages, such as Auger 3 (pink bar) and Auger 4 (green bar), have a higher percentage contribution of very fine sand sediments but a lower percentage contribution of clays. For the auger samples with a high percentage of silt in their composition such as Auger 2 (black bar) and Auger 7 (yellow bar), the reverse is true to that of Auger 3 and 4 samples.

The three AMS Core samples (the top three bars) appear to have relatively high silt percentages compared to some of the auger samples. However, unlike the auger samples the AMS ones have roughly equal percentages of very fine sands and clays. This could be by chance or the result of the differing sampling methods, where AMS core samples remain more intact and preserve the structure of the soil profile. However, overall, the composition of the sample

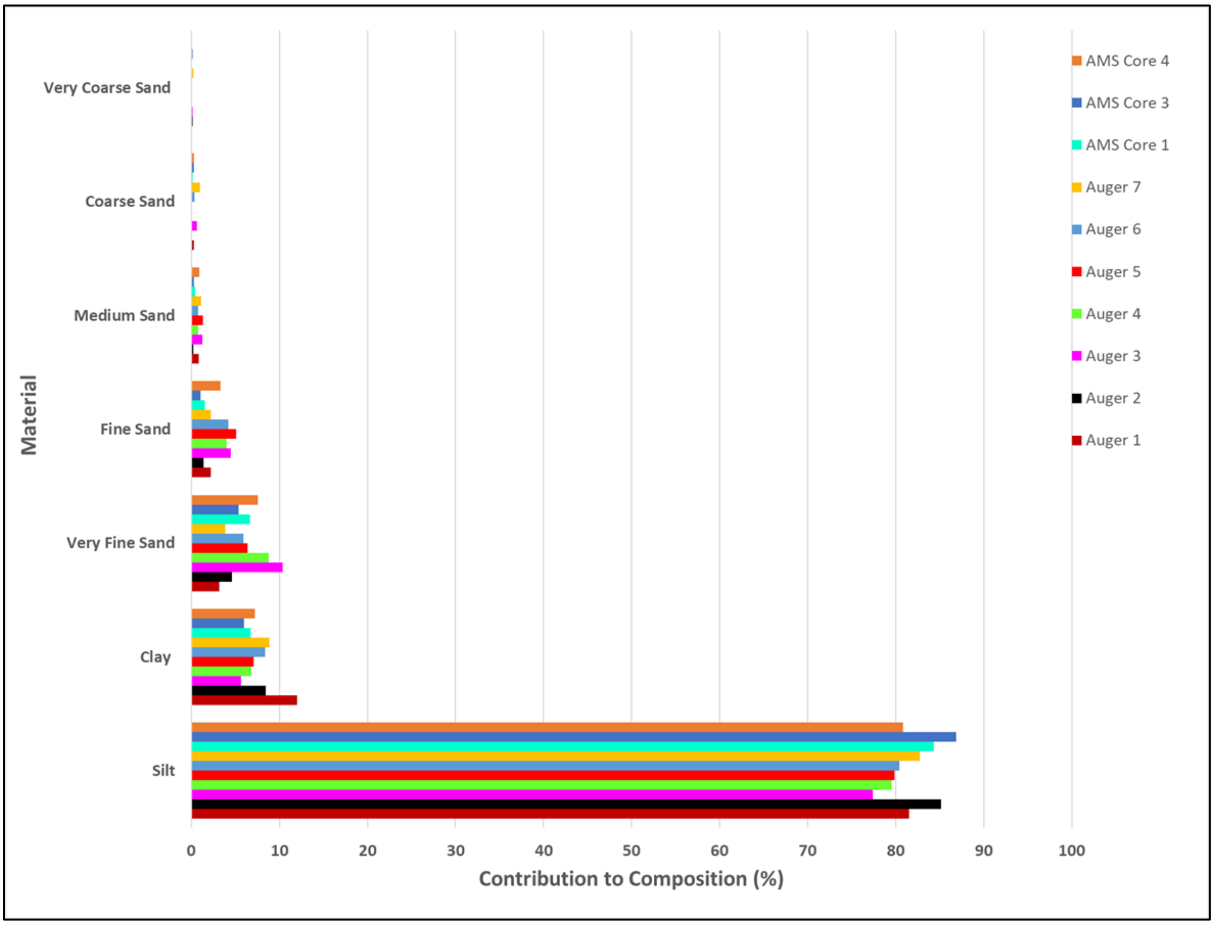

Figure 9. Material vs Average % Contribution to sample composition (out of 100%).

5.3 Vegetation Distribution

Table 1 is a summary of plants present and observable within a 10m radius of each sample site. Please note that results of this analysis are not as thorough or conclusive as were initialled anticipated during data collection. Largely due to the coring issues and limitations encountered which significantly limited time for other data collections.

However, from the data that was gathered, some basic inferences can be made. Firstly, it appears there is limited variation in the understory species (headed in orange) as all are present at every site, bar the Horopito plant, which is present at 6/10 locations. Secondly, the canopy species of Riccarton Bush (headed in pink) appear more spatially distributed throughout the woodland. With only the Kahikatea being present at all the locations.

Table 1. Species presence at sample sites, species are separated into canopy and understory species.

		Plant Species													
		Cabbage Tree	Lemonwood (Saplings)	Bush Rice grass	Round-leaved Coprosoma	Pokaka	Kowhai	Horopito	Matai	Horoeka (Lancewood)	Whiteywood	Pikopiko (hen and chicken fern)	Kahikatea	Kaikomako	Totara
Sample	Core 1														
	Core 3														
	Core 4														
	Auger 1														
	Auger 2														
	Auger 3														
	Auger 4														
	Auger 5														
	Auger 6														
	Auger 7														

	Canopy Species (Tall and Mature trees)
	Understory Species (Shrubs)

5.4 Topographic Variation

Analysis of any topographic variation in the bush utilised Figure 10 & 11 which are the LiDAR point cloud graphics produced in OpenTopography software. Observable when the canopy layers in Figure 10 are stripped back uncovers many large black spaces on Figure 11 within the bounds of Riccarton Bush. These are data gaps where the LiDAR has been unable to penetrate through to the ground level because of the dense canopy of Riccarton bush. Therefore, it is inconclusive that there are any localised topography differences present. Although, in Figure 11 there is an ever so slight negative or downslope gradient from the top left corner of the 3D model where it is slightly peachier in colour, compared to the pink coloration in the bottom right. However, this elevation trend would be expected as it is consistent with the direction to the local Canterbury coastline. However, this elevation trend would be expected as it is consistent with the direction to the local Canterbury coastline.

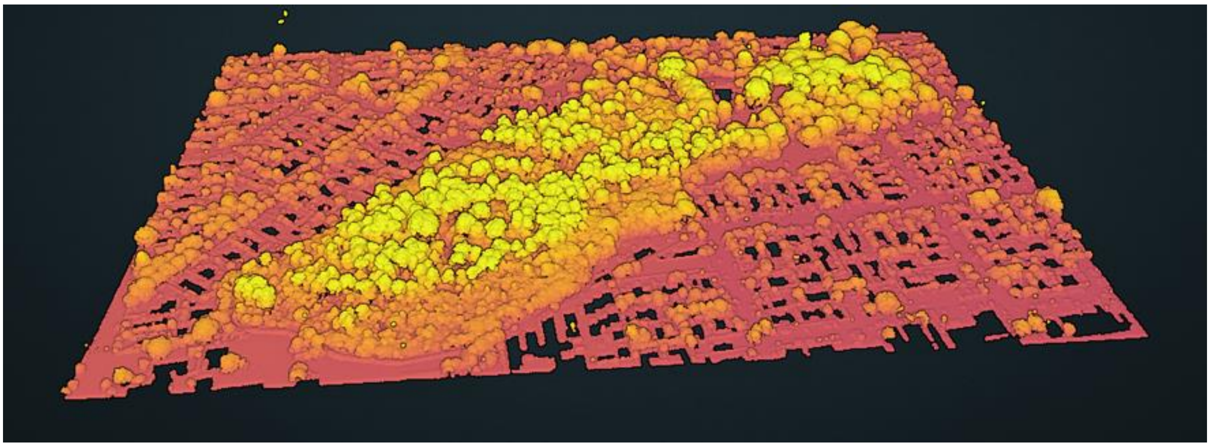

Figure 10. OpenTopography 3D visualisation of LiDAR point cloud data, showing all layers.

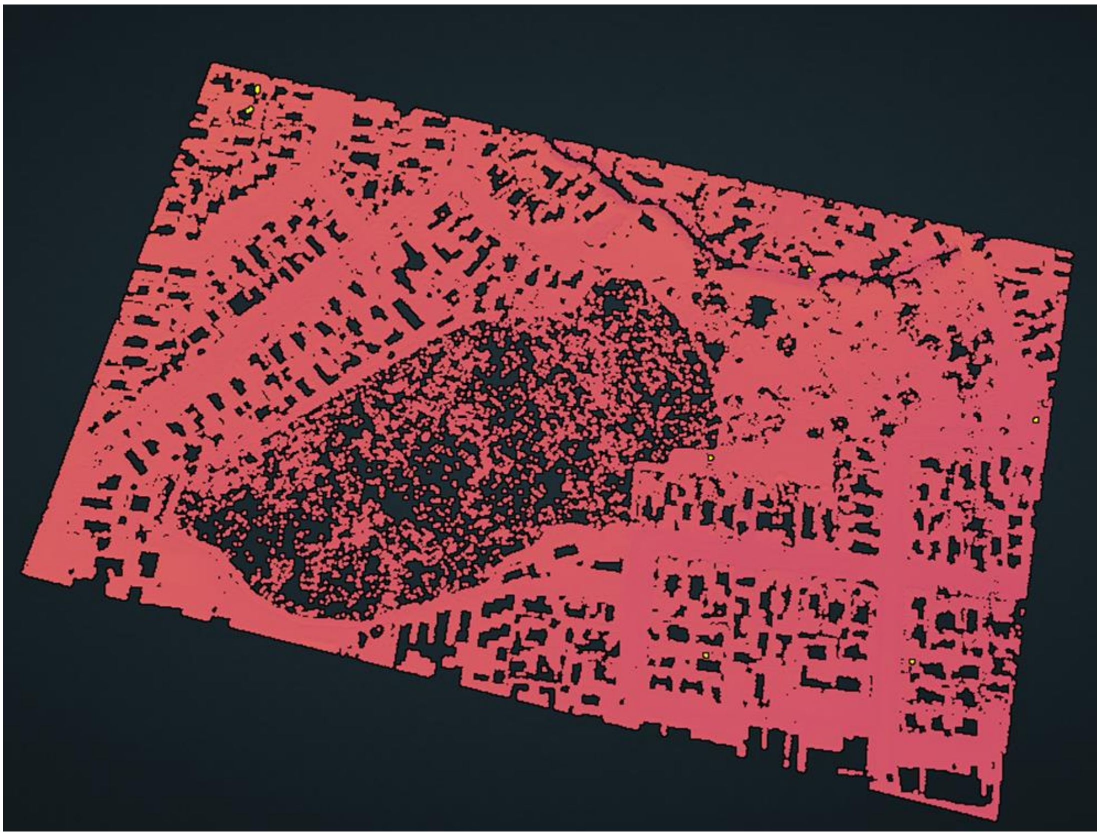

Figure 11. OpenTopgraphy 3D visualisation of LiDAR point cloud data, showing only the ground level layer.

5.5 GIS Map Tool

A primary goal of this project was to produce a simple but informative interactive GIS map for Mike the community partner, as shown by Figure 12 & Appendix A. On the GIS map there are a multitude of layers, the first being the GPS points of each sample site. The GPS points old information regarding observations and results collected at each depth increment for a sample site, as seen by the inset table in Figure 12. The walking tracks within Riccarton bush and the reserve boundary are also included as layers. The GIS map in Figure 12 is underlaid by a TIN model, exported from open topography, to provide some basic terrain and surface features as a base layer. Figure 12 & Appendix A.

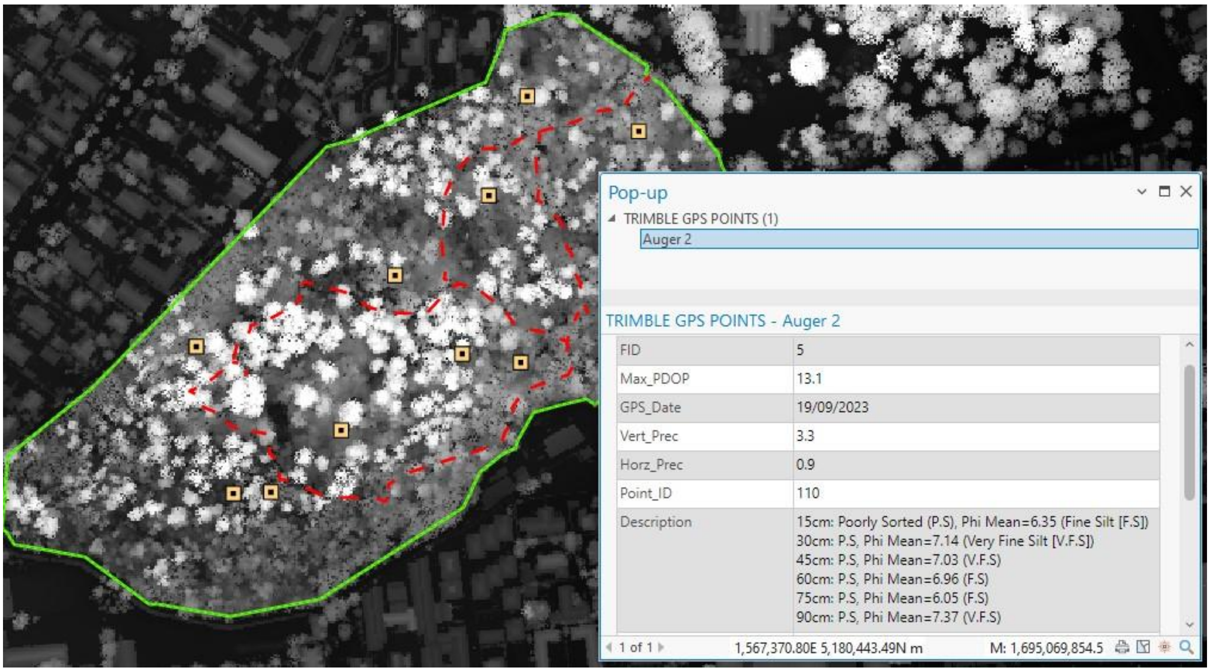

Figure 12. Capture from the GIS Map tool, showing the TIN layer and walking tracks, bush boundary and GPS point features. Inset is an example of what appears when a GPS point is selected.

6.0 Discussion

Infiltration impedances in Riccarton Bush were assessed after a comprehensive PSA analysis, which revealed that the soils in the area exhibited poor to very poor sorting (Appendix D). The presence of a wide range of grain sizes within these soils leads to a tightly packed arrangement, significantly limiting the available pore space (Xu & White, 1995). Consequently, this tight packing increases the density, hindering the efficient movement of water through the soil, as the medium's permeability is reduced, which could be feasible as a contributing factor to the compaction and density issues observed in the soil. The compaction and density factors of the soil composition may cause a reduction in the soil's permeability and infiltration properties and lead to water pooling in certain areas of Riccarton Bush.

Regarding species competition, in line with secondary succession processes outlined by Walker et al. (2009), post-flooding of the Waimakariri River, an initial covering of shrubs and low trees would first develop, followed by local birds' dispersion of Kahikatea seeds. The low shrubs and trees would shelter the Kahikatea seedlings, eventually developing into dense forests like Riccarton Bush (Duncan, 1991). Research by Freer-Burton et al. (2022) identified Riccarton Bush tree species, their locations, and the broader vegetation types. Their research aligned with visual observations of the coverage of tree species at Riccarton Bush outlined in this report.

However, Kahikatea development is characterised by reduced trees because of inter-specific competition between individuals for limiting factors such as light, soil nutrients and water (Czortek et al., 2018). With a change in environmental conditions due to the drainage of the bush, other podocarp species may begin to dominate the area, such as Rimu and Totara, which are currently quite spatially distributed in the bush to this day. Despite this, the drier weather conditions in the Christchurch area prove to slow down the usually faster-growing rates of other competing tree species. The Kahikatea trees in Riccarton Bush are likely to have post-dated fire and deforestation events and thus survived until recent conservation efforts. The future of the Kahikatea Forest looks dire as seed sources are non-existent. Even if Kahikatea seeds were to regenerate, the current adventive species would quickly swamp the site and prevent any foundation from being established (Molloy, 1995).

Due to dense tree canopy, the LiDAR data lacked accuracy for bare earth returns. While the data identifies a higher elevation side, this change is minor at the Riccarton House side of the bush. A more accurate small-scale analysis of topography could assist in explaining differences in soil moisture content. In the context of this project, it is unrealistic to try to gather primary LiDAR data of Riccarton bush. While a total station would be a reasonable way to gather a topographic profile, Riccarton bush is too densely vegetated for an unobstructed path from the total station to the reflector when taking these measurements. Terrestrial laser scanning (TLS) solves the dense tree canopy issue by achieving the accuracy of LiDAR. It can be taken under the tree canopy, providing the spatial resolution that cannot be achieved with standard airborne LiDAR collection. (Baltensweiler, et al, 2017).

7.0 Conclusions

Overall, to 90cm depth, the cores display relatively uniform soil profiles, compositions, and particle size distributions. Allowing for the inference that there is very limited spatial variation in the soil type in Riccarton Bush to the sample depth. Due to its consistently poorly sorted nature, the soil density could be expected to impede any water infiltration processes, potentially explaining surface water pooling during periods of irrigation.

From the vegetation results, the understory species and the primary benefactors of the irrigation measures in place display limited spatial variation. The taller tree canopy species exhibit more significant variation but have less need for irrigation as their tree roots likely intercept the water table. Therefore, the observed varying distribution of pooled surface water is unlikely to result from differing vegetation and vegetation requirements in Riccarton Bush as the plant species it supplies do not exhibit significant spatial variability.

The topographic analysis only yielded limited results, as the density of the bush canopy hindered the ability to acquire informative and conclusive details, such as high or low points on the ground. However, the influence of terrain may still be viable in explaining surface water distributions caused by the irrigation system. However, the unsatisfactory results cannot be accepted or rejected from our analysis.

Finally, the distribution of surface water present in Riccarton Bush after periods of irrigation and rain is not significantly influenced by soil or vegetation distribution themselves, as these appear constant. However, a possibility could be that a combination of ineffective irrigation not accounting for plant needs and water infiltration impedances due to the soil density is the issue.

8.0 Recommendations

The findings from this report must be made clear to the community partner and the engineers tasked with designing and establishing a new irrigation system. The GIS Map results provide a concise and comprehensive overview of soil, plant, and terrain features and results. By making this information easily accessible, projects of a similar nature can utilise the pre-existing information—lastly, some future suggestions for the community partner to consider for inclusion in Riccarton Bush.

8.1 Sprinkler/Irrigation changes

The current rotary sprinkler system in Riccarton Bush provides a uniform water distribution and is typically set to run for an unspecified amount of time-based on the weather. Alternative sprinkler heads, such as targeted drip irrigation or misting sprinklers, could be more effective, as some plants potentially demand less or more water than others. Drip irrigation delivers water directly to the plant's root zone, ensuring that each plant receives sufficient water, whilst misting sprinklers can replicate a damp, rainy climate. Likely benefits include increased time and water efficiency and the ability to become automated.

Another option is incorporating a sprinkler system that operates automatically using a moisture probe. A probe would continuously monitor the moisture level in certain priority regions of the bush and turn the irrigation on or off based on the moisture levels recorded. This system would also automate the process, thus saving water that might otherwise be wasted in over-watering areas. This approach would carry added costs attributed to the moisture probes.

8.2 Groundwater Investigation

The groundwater table beneath Riccarton Bush may also be important and interesting. It is likely the water supply to mature tree species, such as the native Kahikatea in the bush. It may also explain the observed surface water distributions, as a high water table would increase soil saturation close to the surface, limiting infiltration quantities.

Because our cores only go to a depth of 90cm, gathering the necessary data on the water table height and attributes would be challenging. Such an analysis would require more time, research, and, most likely, deeper cores. A better understanding of the groundwater table would be beneficial in focusing irrigation efforts and finding evidence to reintroduce the natural springs.

9.0 Acknowledgments

We would like to acknowledge and thank our community partner, Mike Steenson, the Ranger for the Riccarton Bush Trust, for this research opportunity and his assistance during the data collection phase. Thank you to the technical staff who aided our project also, from Justin Harrison for his equipment recommendations and use of his lab space, Gorden Jiang for his assistance with GIS and Chris Grimshaw, Aude Thierry, Tonya Arkhangelskaya for their aid during the sample processing and analysis phase. Lastly to Matt Wilson and Sarah McSweeney for their tips and advice along the way.

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11.0 Appendices

Appendix A: Layout of GIS map tool.

Riccarton Bush Soil Variability Investigation

N
W E
S

Legend

- TRIMBLE GPS POINTS
- Predator Perimeter Fence
- Walking Tracks

TIN of Riccarton Bush

Value

112.37

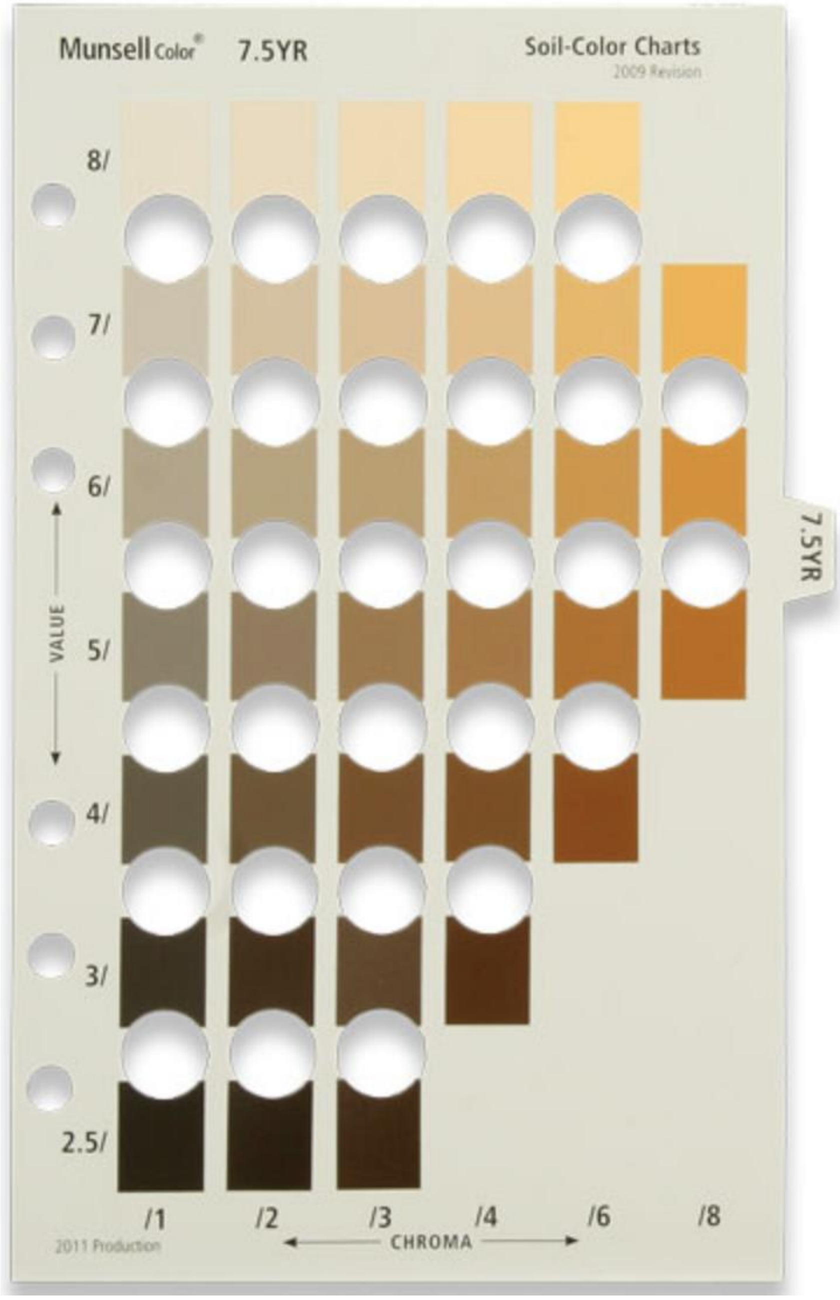
-8.838

Coordinate System: NZGD 2000 New Zealand Transverse Mercator
Datum: NZGD 2000
Units: Meter

0 50 100 200 300 400 Meters

Author: Finn Seeds

Appendix B: Munsell Colour Chart 7.5 YR. From Munsell Soil Colour YR-Kit, n.d. (https://www.torso.de/en/Color-Standards/Munsell-Colors/Munsell-Scientific-Colors/Munsell-Soil-Color-YR-Kit::417.html).



Appendix C: Results of colour change present in cores 1, 3, and 4 and augers 1-7 in reference to Munsell colour chart 7.5 YR (Appendix B).

	0-15 cm	16-30 cm	31-45 cm	46-60 cm	61-75 cm	76-90 cm
Core 1	6/4 Light Brown	5/2 Brown	5/2 Brown	5/2 Brown	4/1 Dark Grey	3/1 Very Dark Grey
Core 3	4/1 Dark Grey	4/1 Dark Grey	5/4 Brown	5/4 Brown	5/4 Brown	4/1 Dark grey
Core 4	4/2 Brown	5/1 Grey	5/1 Grey	4/6 Strong Brown	5/1 Grey	4/1 Dark Grey
Auger 1	5/1 Grey	5/2 Brown	5/2 Brown	5/2 Brown	5/2 Brown	6/3 Light Brown
Auger 2	4/1 Dark Grey	5/3 Brown	4/3 Brown	5/2 Brown	5/2 Brown	5/2 Brown
Auger 3	3/1 Very Dark Grey	4/1 Dark Grey	4/2 Brown	4/2 Brown	4/2 Brown	4/3 Brown
Auger 4	3/1 Very Dark Grey	4/1 Dark Grey	4/2 Brown	4/2 Brown	4/3 Brown	5/3 Brown
Auger 5	4/1 Dark Grey	5/3 Brown	6/2 Pinkish Grey	6/3 Light Brown	5/4 Brown	4/1 Dark Grey
Auger 6	4/1 Dark Grey	5/2 Brown	5/3 Brown	5/1 Grey	4/1 Dark Grey	4/1 Dark Grey
Auger 7	3/1 Very Dark Grey	4/2 Brown	5/3 Brown	4/3 Brown	4/2 Brown	4/1 Dark Grey

Appendix D: Standard deviation values and corresponding sorting of particle sizes of each increment from the MSLV.

	15 cm	30 cm	45 cm	60 cm	75 cm	90 cm
Core 1	1.7 Poorly Sorted	1.5 Poorly Sorted	1.4 Poorly Sorted	1.48 Poorly Sorted	1.4 Poorly Sorted	1.43 Poorly Sorted
Core 3	1.72 Poorly Sorted	1.42 Poorly Sorted	1.42 Poorly Sorted	1.44 Poorly Sorted	1.39 Poorly Sorted	1.79 Poorly Sorted
Core 4	1.62 Poorly Sorted	1.44 Poorly Sorted	1.49 Poorly Sorted	1.68 Poorly Sorted	1.87 Poorly Sorted	1.87 Poorly Sorted
Auger 1	2 ***Very*** Poorly Sorted	1.48 Poorly Sorted	1.84 Poorly Sorted	1.17 Poorly Sorted	1.21 Poorly Sorted	
Auger 2	1.74 Poorly Sorted	1.41 Poorly Sorted	1.42 Poorly Sorted	1.51 Poorly Sorted	1.7 Poorly Sorted	1.38 Poorly Sorted
Auger 3	1.83 Poorly Sorted	1.7 Poorly Sorted	1.8 Poorly Sorted	1.72 Poorly Sorted	1.83 Poorly Sorted	2.29 ***Very*** Poorly Sorted
Auger 4	1.88 Poorly Sorted	1.71 Poorly Sorted	1.94 Poorly Sorted	1.77 Poorly Sorted	1.51 Poorly Sorted	1.43 Poorly Sorted
Auger 5	2.01 ***Very*** Poorly Sorted	1.78 Poorly Sorted	1.56 Poorly Sorted	1.45 Poorly Sorted	1.46 Poorly Sorted	1.43 Poorly Sorted
Auger 6	1.81 Poorly Sorted	1.79 Poorly Sorted	1.5 Poorly Sorted	1.33 Poorly Sorted	1.9 Poorly Sorted	2.25 ***Very*** Poorly Sorted
Auger 7	1.81 Poorly Sorted	1.54 Poorly Sorted	1.42 Poorly Sorted	1.39 Poorly Sorted	1.49 Poorly Sorted	2.33 ***Very*** Poorly Sorted