Land remediation assessment in Woolston

Looking at factors influencing poor drainage at Trees For Canterbury and options for mitigating the affected area

Kate Macdonald, Josephine Turnbull, Luke Millar, Mujahid Musa & Rebecca Abiota

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UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha

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

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Executive Summary

- Inadequate drainage properties at the Trees for Canterbury site has meant that water at the surface is unable to drain and therefore waterlogging occurs in various areas. This poor drainage means water often pools at the surface all year round, even during dry periods, making it a health and safety issue for the workers.
- After discussion of the issue and a site visit, a research question was defined; *'What are the key factors influencing poor drainage at the TFC nursery and are there any options for mitigating the affected area?'*. A literature review of relevant articles was then completed to obtain a better understanding of the various aspects we assumed could be related to the sites poor drainage.
- The surface and subsurface were analysed by using GNSS surveying to generate topographic profiles across the site. A soil auger was then used to obtain samples of the layers in the subsurface. Various tests to investigate the properties (grain dize distribution and permeability) of each layer in the surface were then completed.
- Analysis of the topographic profiles showed a shallow gradient with a general high in the centre of the site and lows around the perimeter, with small depressions superimposed on this. Soil analysis showed an impermeable clay layer was present, with a thickness of approximately 80cm and reaching depths of 1.5m. Saturated samples at around 50cm depth suggested there was a perched watertable above the clay layer.
- Potential solutions for flooding remediation at the site include implementation of a soakhole that could drain water from the perched watertable, through the impermeable clay layer. Short term options for the site include the ongoing maintenance of swales.
- Limitations to the research include our lack of knowledge in specific fields such as hydrology, soil and engineering, which mean our analysis of things such as water movement in the subsurface, water tables and surface and/or hydraulic gradients is somewhat limited.
- It is recommended that in the future, more investigation should be done on finding the true elevation of the water table and monitoring potential seasonal varitiations in elevation by installing a piezometer on site. Obtaining more comprehensive mapping of the subsurface to identify thinner areas of clay to drill through to save resources and also shallow areas of clay which have less chance of interacting with the actual water table.

1.0 Introduction

Trees for Canterbury (TFC) is a community-based organisation which focusses on cultivating and nurturing native plants for revegetation projects and community plantings. TFC contributes to the community by providing a sense of involvement for physically, intellectually, socially disadvantaged and unemployed individuals. Through the daily activities that are offered at the nursery, individuals are able to earn a sense of belongingness, improve self-esteem and practice good work habits.

The site extends 1.5 hectares and backs onto the Charlesworth reserve, a tidal wetland restoration project of 20 hectares at the head of the Avon-Heathcote ihutai estuary (***Figure 1***). Since the sites development, the TFC nursery has experienced flooding issues. Inadequate drainage has meant that runoff from rainfall and irrigation is unable to drain, causing waterlogging to occur in various parts of the nursery. Not only is the waterlogging a hindrance to daily operations at the nursery, it is also a health and safety hazard for the workers.

Figure 1*: Google earth image of the location of the nursery in red square (Left) and a closer aerial photograph of the site (right) showing the site extent next to the reserve. Sourced from Google Earth.*

By using quantitative scientific analysis methods, we worked towards an answer for our research question: *What are the key factors influencing poor drainage at the TFC nursery and if there are any options for mitigating the affected area*? Our work takes into account that TFC is working with a low budget and so it would be preferable if the solution is one that can be implemented and maintained efficiently by its volunteers. Throughout this report, we will discuss related literature, our research methods as well as our findings and recommendations.

2.0 Literature Review

We looked at 5 main topics in our literature review and these topics were based on factors that we know could affect poor drainage and that we assumed we would be investigating later on in the research process. The topics we chose to investigate were; 1) Hydraulic gradient; 2) Soil characteristics; 3) Flooding effects on vegetation; 4) issues in urban agriculture; 5) Drainage solutions. Our findings conclude that drainage solutions and soil characteristics, are the most relevant topics to the investigation.

2.1 Drainage Solutions

Cities and Flooding (Jha, Bloch & Lamond, 2012) focused on drainage systems in the urban landscape and showcased a variety of drainage systems available. In this research, sustainable urban drainage systems (SUDS) are used to return the site to a more natural state. Jha et al. (2012) states that SUDs use infiltration and storage properties of swales and trenches. These devices are used as a slowdown catchment response to increased water levels, in turn reducing the peak outflow and lowering the risk of flooding. The use of such measures proved very effective, therefore these systems could be implemented to help improve drainage at TFC.

Olson et al., (2013) investigated the process of tilling to increase permeability in compact soils. The aim of this article was to monitor the effectiveness of tilling by adding compost to a control plot, and defining ways to measure the success. The results showed that the addition of compost to the top soil was the most effective way of improving the soil permeability and tillage was only really effective when applied with the aid of compost. The addition of compost leads to the increase in bulk density of the soil, increasing its permeability and allowing water to better flow through.

2.2 Soil characteristics

Sasal et al., (2006) aims to improve the understanding of soil properties, particularly in the study area of Argentinian Pampas. Pore characteristics are investigated (quantity, distribution, stability and orientation of pores) that are responsible for water dynamics in the subsurface under zero tillage (ZT) conditions. This involves an application of knowledge gained in the study of the Argentinian cropland area, in which the ZT system has already been adopted, and to use this knowledge to possibly reduce the soil loss caused by water erosion. Sasal et al. (2006) successfully used various ways to measure soil characteristics, and explained the assumptions and theories necessary when applying the method. Sasal et al. (2006) also referenced other research similar to theirs which both agree and disagree with their findings. The techniques Sasal et al. (2006) uses to measure soil characteristics in this experiment can be implemented to gain an understanding of the soil at TFC.

Permeability is a measure of ease in which water flows through a porous medium, which is dependent on properties of the water and characteristics of the unit (Masch & Denny, 1966). In most cases the properties of water (viscosity and specific weight) are essentially constant, so permeability can be seen primarily as a function of the unit characteristics (particle, size, shape, structure, degree of compaction and grain size distribution) (Masch & Denny, 1966). The size and number of pores has great importance in terms of infiltration (movement of water into soil) and percolation (movement of water through soil) rates and there is known relationships between grain size and pore space. Therefore sorting and grain size will be very important when looking at the factors influencing poor drainage at TFC.

In addition, Tavenas et al. (1983) tries to define the best method for testing and describing soil permeability parameters, particularly natural clays and identifying the effects of hydraulic conductivity in insitu conditions. The study showed that the permeability of intact soft clays at their insitu void ratios, was a function of void ratio and grain size but also was related to the plasticity and fabric of the clay. Methods and sampling techniques used in the past, that affected the validity and accuracy of the results were also discussed.

Although we cannot look at factors as in depth as these researchers have, their results have been able to guide when we were deciding what factors to investigate.

3.0 Methods

3.1 Methodological framework

Qualitative information was helpful in the early stages of the research process when we were choosing what areas on site to focus on and what parameters to actually investigate. With this knowledge, we predicted what factors could be influencing poor drainage on site and then identified several ways we could investigate them. Quantitative approaches were used in the later part of the research process to investigate factors such surface topography and soil characteristics and how these potentially influenced poor drainage.

3.2 Soil Data collection

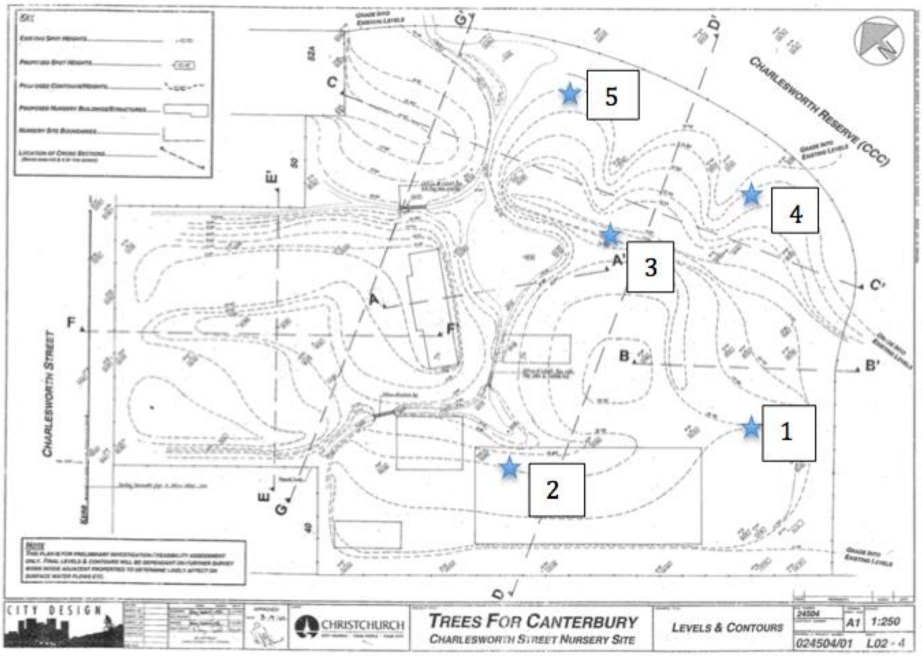


***Figure 2**: Map showing the locations of our drill sites at TFC, in chronological order*

On several different days, core samples were taken at the nursery with a soil auger to try and depict the sub-surface stratigraphy. The locations for each core were chosen by the ease of accessibility to the area and also by the severity of flooding (***Figure 2***). Areas were targeted that our community partner had indicated were "problem areas" and that had water present at the surface throughout previous site visits.

When taking the first soil core, we went as deep as possible and took samples every-time a change in lithology. This was so we could analyse grain size, permeability and sorting in the lab. Changes in lithology were identified by changes in colour, grain size, sorting and texture. In several layers, samples were taken throughout the thickness of the unit ie. From the top, middle and bottom of the unit to identify whether it had fining upwards or fining downwards sequences.

The stratigraphy was logged in a notebook and the depth of contacts were measured using a 2m ruler. When we drilled through a contact we measured the length of each unit in the auger and added that to the depth we measured in the hole to get the true depth of the contact. It's important to note that because the subsurface was moist, material kept collapsing in from the walls of the drill hole. Therefore when we were measuring depth, we would have been underestimating due to the added volume in the bottom of the hole. To try and reduce the effect of this, we tried to remove all loose excess material from the hole by sticking our arm down the hole and scooping it out.

3.3 Data Analysis

Once all 9 samples were at the lab we began choosing appropriate sample sizes, smaller grain sizes and better-sorted samples required smaller samples (30g), whereas samples with a large grain size distribution required larger samples (100-200g). Beakers were weighed before we weighed each sample to eliminate the weight of the beaker; this gave us a rough proxy on the numbers we should be receiving in analysis.

3.3.1 Wet Sieving

Most of the samples were moist and therefore smaller grain sizes had aggregated together and stuck to larger grains. So to separate all the grain sizes wet sieving was used, which involved passing all samples through 500um and 63um woven wire mesh sieves using squeeze bottles to separate the grain sizes into 2 categories (***Figure 3***) : 1) >63um ie. Sands, gravels, pebbles; 2) <63um ie. Clays and silts (mud). The finer grains (<63um) were placed into cylinders containing 1000ml of water. The coarser grains (>63um) were put into beakers in the oven overnight to remove excess water (***Figure 3***). During this process the organics were drained off the top, which we classed as things that didn't pass through the 63um sieve and floated in water due to being a low density, softer, and brown in colour. Calgon Solution with the concentration 50g/L, was added to samples that were more cohesive samples (containing clay) to help separate grains.

Figure 3*: LEFT: Separating the clays and silts from sands gravels and pebbles by wet sieving; RIGHT: Samples placed in the oven to remove excess water before further analysis*

3.3.2 Dry Sieving

The dried off samples were passed through sieves ranging from 63um-13200um. Each sample was placed on a sieve shaker for 5 minutes, which uses vibrations to accelerate the particles in the sieves, this increases the probability of grains to pass through the mesh (***Figure 4***). Grains collected in each sieve were weighed on a tarred beaker and the weights were recorded in a table in excel. Anything that passed through the 63um sieve was placed into the cylinders containing grains <63um from our wet sieve analysis.

Figure 4*: LEFT: Using the sieve shaker to sort the grain sizes in our sieves; RIGHT: Weighing the amount of sediment caught in each sieve size to get the amount of each corresponding grain size.*

3.3.3 Pipette Analysis

The pipette analysis allowed us to analyse the grain size distribution of grains finer than 63um (silts and clays) because of the relationship between settling velocity and grain size (Ahn, 2012). A spreadsheet was prepared with sample number, depth and times of withdrawal on it and 6 beakers per sample were labelled with the sample number and phi size (0.4, 0.5….0.9). Analysis began by stirring vigorously with a stirring rod for 20 seconds at the bottom of the cylinder to uniformly disperse all the grains throughout the water column. Using a stopwatch and 2 pipettes, 20ml samples were extracted at particular depths and time intervals and put into the corresponding 50ml beakers *(**Figure 5**)*.

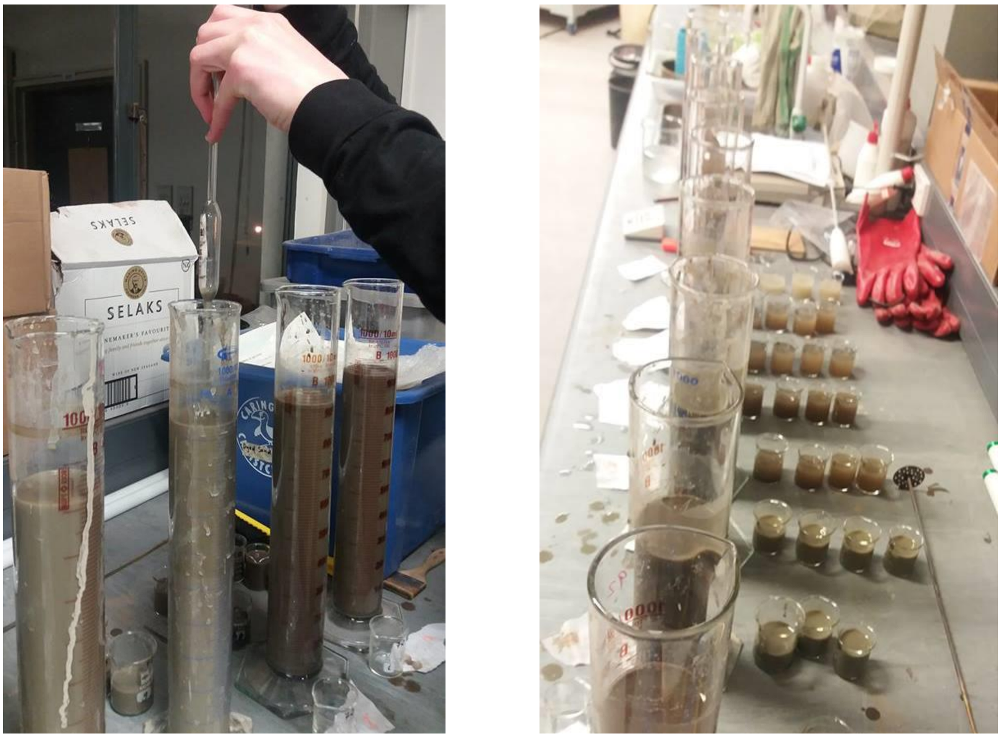


Figure 5*: LEFT: Using the pipette to withdrawal 0.4um clays and silts from sample G; RIGHT: 50ml beakers filled with specific grain sizes (0.4-0.9um)from each sample.*

In theory at the time of withdrawal all particles coarser than the given diameter will have settled past the point of withdrawal (Folk, 1974.). The pipette was then flushed with another 20ml of clean tap water to remove all residue from the inside of the pipette. All beakers were then placed in the oven until all water had been evaporated off. The remaining sediment was then weighed in a tarred beaker and the weights were recorded.

3.3.4 Permeability testing

A permeability test was a method used to indicate how long it takes water to infiltrate each layer. A catch tray, supporting sieve, steel cloth, a stopwatch and a blue cylinder [7.6 (diameter) x 15cm (height)] were used to measure the infiltration of water through the soil (***Figure 6***). For each sample sediment was packed into the cylinder until it was 50mm thick in a way which represented how it was packed in the subsurface at the site (generally this meant tightly packed). 400ml of water was then added to the cylinder and it was timed how long it took for all water to visibly disappear from the surface. Once the surface of the sample was cleared of pooled water, the timer was stopped and this time was noted.

Figure 6*: The setup of the permeability experiments; this photo shows the sand layer (sample c) being fully infiltrated after 31 minutes.*

3.4 GNSS Surveying

It was realised that the pooling of water at TFC, could be related to the surface gradient. A shallow surface gradient could mean that the water doesn't have enough driving force to encourage flow across and out of the site. This could also be a cause of why water remains stationary within the existing swales. During the redevelopment of the site in 2002, the Christchurch City Council used GNSS (Global Navigation Satellite System) surveying to develop a contour map of the site surveying along seven transects (A-G) (***Figure 7***). This also allowed them to create individual topographic profiles of each transect.

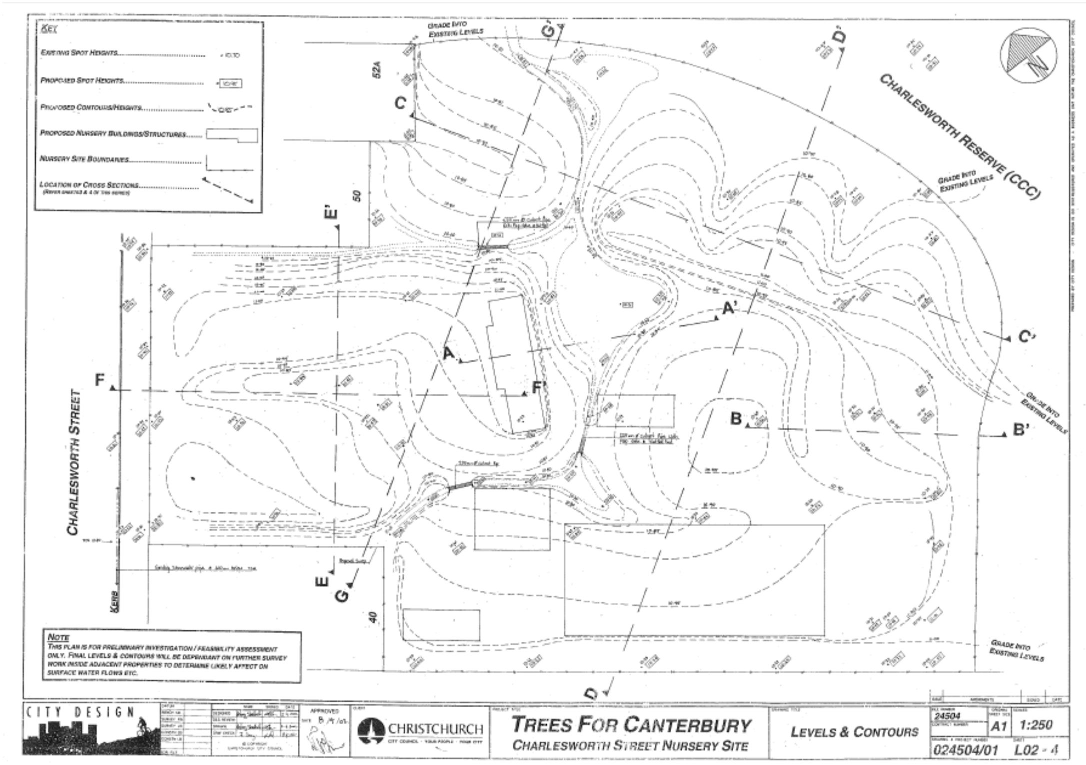


Figure 7*: Original Christchurch City Council Survey data from the site in 2002. The map shows the transects across the map which are detailed in Appendix B*

To investigate surface gradients, GNSS surveying was also completed by our group. The survey was executed along the seven transects developed by the Christchurch City Council in 2002, so we could easily compare elevation changes between the 2 transects. It was unknown as to which local trig station or pegs were used when surveying was performed in 2002 and so points were recorded by the group from an arbitrary base station elevation and location.

Data from the survey was then extracted into a Microsoft Excel spreadsheet where the data was collated into topographic profiles for each of the seven transects.

4.0 Results

4.1 Site core samples

The core samples taken from 5 different sites at the nursery showed a simple and rather consistent stratigraphy across the whole site (***Figure 8***). The stratigraphy consisted of four main units.

- 8-10cm of Top soil.
- 11-15cm AP40 – Poorly sorted AP40.
- 23-66cm Sand – Ranging from fine to medium grain sized with layers more saturated than others and lenses with granules and pebbles.
- 80cm Clay – highly impermeable layer.

The top soil and AP40 units were of a consistent thickness across the site. The Sand layers varied in thickness across the site and are always followed by a layer of highly impermeable clay.

A follow up site visit revealed that at site one the clay reached to a depth of at least 1.5m, giving the clay a thickness of at least 76cm. At a depth of 50cm the drill hole became extremely saturated and filling up with water. It is our interpretation that this is the depth of a perched water table which is a result of the underlying impermeable clay layer not allowing water to drain through it.

Swales tested in two different locations at the nursery both revealed that swales are situated within impermeable clay layer. The thickness of the clay layer in the swale at site 3 site was 80cm, and

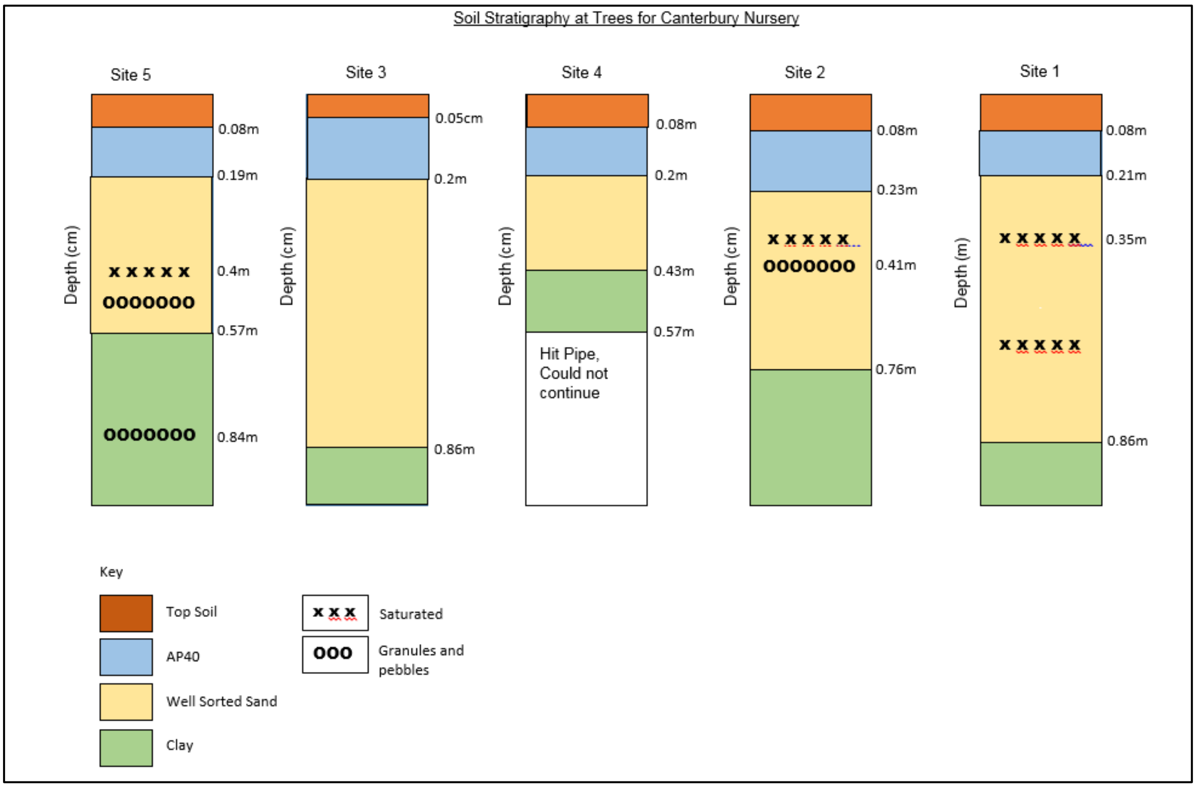


Figure 8: *Stratigraphic columns showing the thickness of the 4 main units at the 5 different locations tested at the TFC Nursery. The stratigraphic columns here end at 1m, but during follow up visits we ended up coring to a deeper depth through the clay layer, which ended up extending to 1.5m depth.*

underlying the clay layer was another fine grained sand layer. This pattern seems consistent across the site with the same sand layer that was seen above the clay, reappearing below the clay layer.

4.2 Dry Sieving Results

Nine samples were gathered from TFC, to undergo a series of dry and wet sieving to determine the grain size and grain size distribution ie. Sorting of each sample. These are generally a good indicator of the permeability within a unit (Masch & Denny, 1966). ***Figures 9-11*** are representative samples of the three of the main units on site. The topsoil did not undergo any dry or wet sieving due to its high organic content.

The samples were all relatively the same volume, however the graphs below are not inclusive of the clay content within the sample. Sample A shows a wide variety of grain sizes indicating very poor sorting. Not a lot of clay was extracted from this sample, with it mainly being made up of coarser grains. Sample C and G exhibit much better sorting in finer grain sizes, and it would be hypothesised from these results that these layers show impermeable characteristics due to the relationship between sorting, grain size and permeability, as seen by Masch & Denny (1966). These suggests that the AP40 was likely to be the most permeable and the sand would be permeable to some degree. The clay however would be relatively impermeable. A limitations of the dry sieving is that the permeability is not only a function of grain size and the degree of sorting but is also dependent on how the soil is packed at the site. These graphs can give some indication of permeability, but are not fully indicative of whether or not a unit is permeable or not.

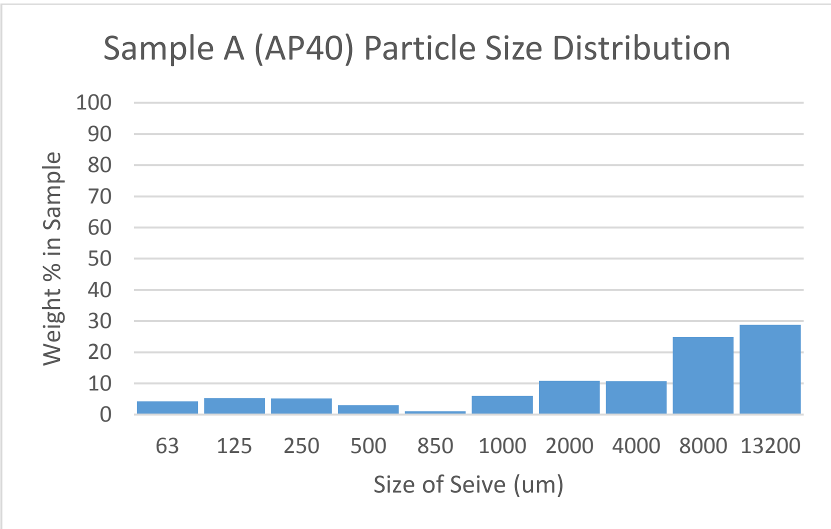


Figure 9: AP40 Particle size distribution showing poor sorting throughout the sample. The total sample weight excluding clay content was 179.89g.

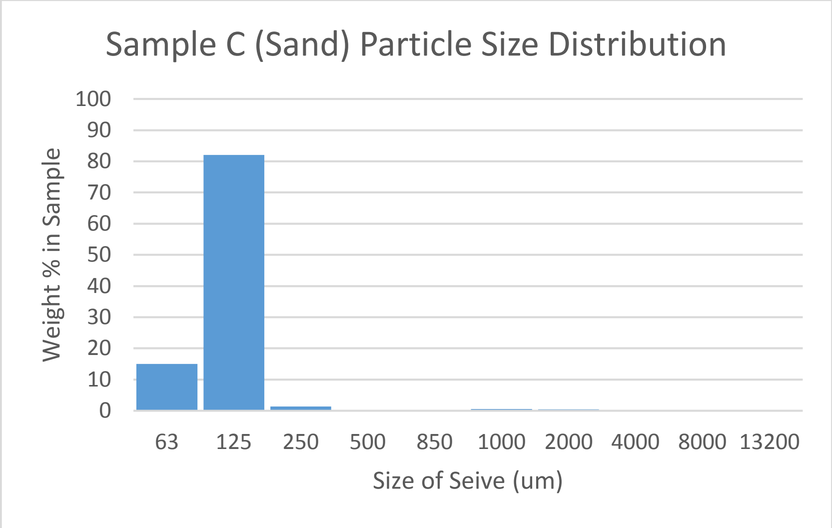


Figure 10: Representative Sand sample from the site showing well sorted sand sized particles. There was 55g of 125um sized particles in this sample.

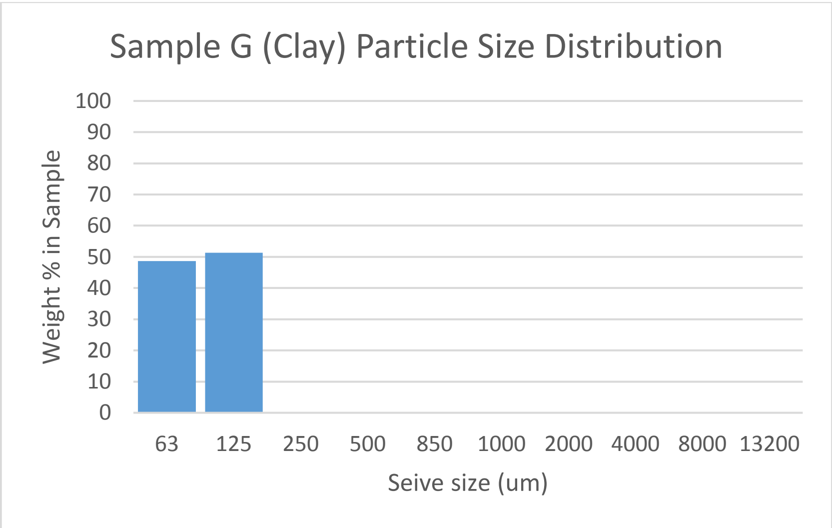


Figure 11: Representative clay sample from the site showing an equal amount of 125um and 63um sized particles. The weight total of these particles from the sample was 9.634g.

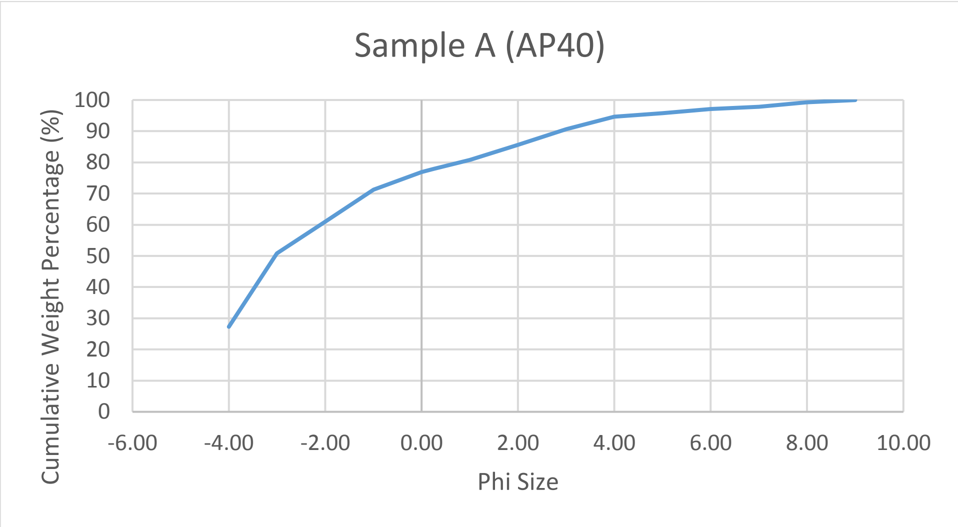
4.3 Pipette Analysis

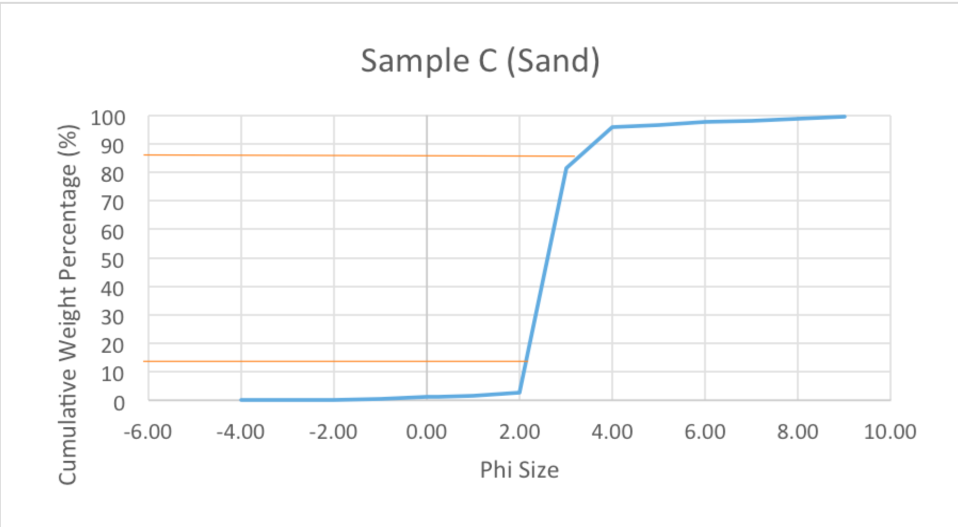
Pipette analysis allowed us to further obtain information about the weight percentage of clay within the sample. By combing the data from the dry sieving with the pipette analysis data, a relationship between particle sizes within the sample could then be established. The sorting and clay percentage were indicative as to how permeable the layer would be. These samples were analysed on the basis that between 84-16%, differences in phi sizes would indicate the degree of sorting (***Table 1***).

***Table 1**: Table showing how many phi sizes are indicative of the degree of sorting.*

Sorting description	84-16 phi value
very well sorted	0.5
well sorted	1.0
moderately sorted	1.0-2.0
poorly sorted	2.0-3.0
very poorly sorted	>3.0

The following graphs show the cumulative weight of each phi size (including sands and gravels) within the sample:





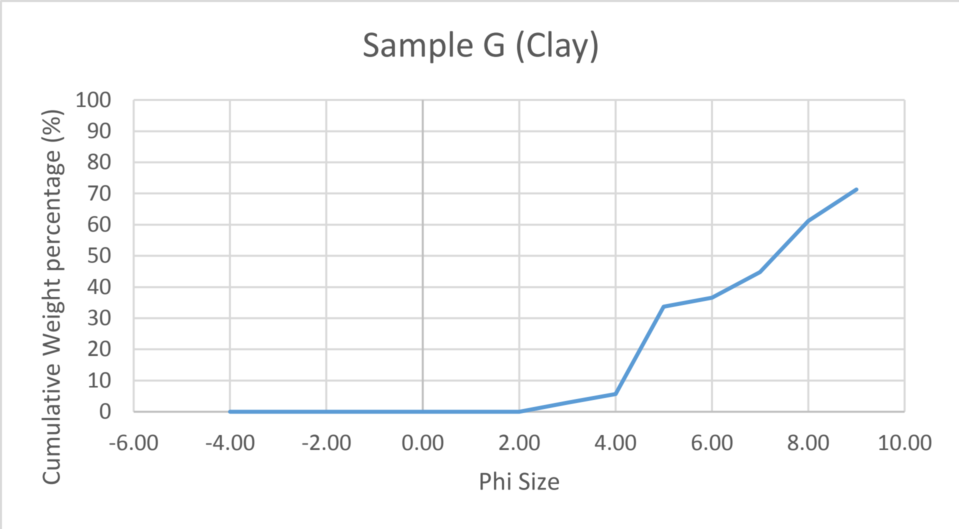


Figure 12*: The 3 Graphs show the cumulative weight of the particles within the sample from the dry and wet sieving. The orange lines on Sample C are the 16% and 84% marks which help when analysing sorting. This could not be performed on the clay graph as the cumulative total did not reach over 84%. We think this is due to the organics which were taken out of the sample.*

Results from the testing show that the sand was the most sorted out of the samples as the difference between the 16% and 84% points on the graph were 1 phi apart (***Figure 12***). The AP40 and the Clay sample did not show 16% and 84% values respectively on the graphs, however when projected on the graph it shows that both are poorly sorted. The clay sample poorly sorted in terms of phi sizes if the graph is projected. The clay is not considered poorly sorted in hand sample as observed there was only a very small sand content, with majority being mud and clay.

The cohesive nature of the clay as well as the fact it is poorly sorted across a very small grain size range indicates there are smaller pore sizes present. There is a significant difference between being poorly sorted across a -6 to -2 phi size range and being poorly sorted across a 4 to 8 phi size range; that being a -6 to -2 phi size range would have larger grain sizes which would leave larger pore spaces between them. The fact that the clay does not reach 100% on the graph is due to around 30% of the sample having a larger phi size than 9.0 which was not recorded.

4.4 Permeability Testing

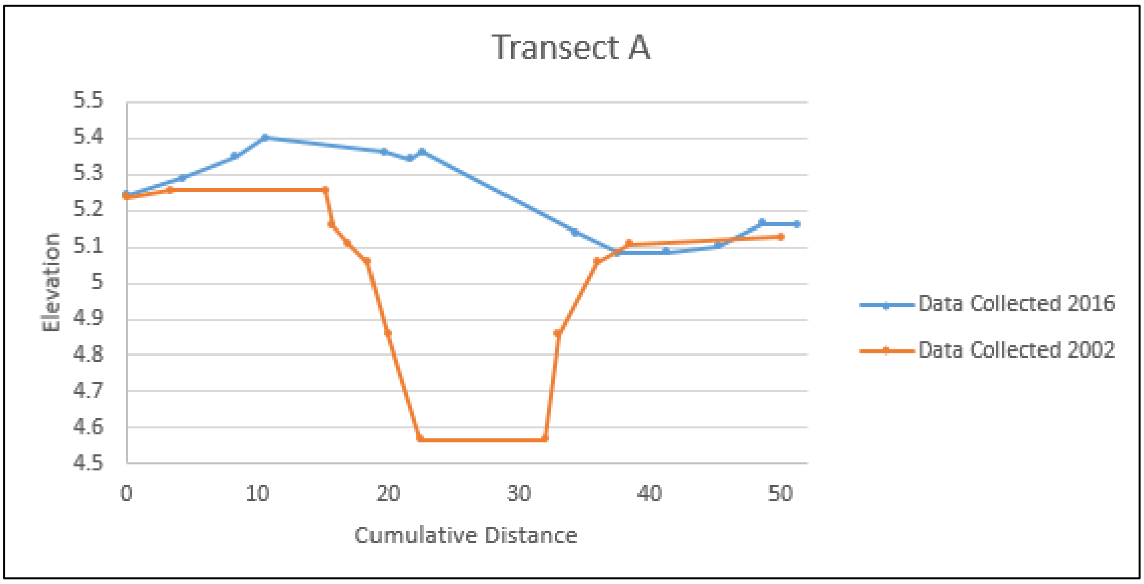
The results shows that infiltration of water through the soil was slower than expected through all samples except from the AP40 which infiltrated water in 7 minutes (***Table 2***). Water infiltrated through the sand samples at a mean of 31 minutes, and water was left to infiltrate through the clay layers overnight. The clay sample infiltrated a volume of 20.42ml over a 24 hour period, which means only 1/20 of the 400ml of water put in the cylinder drained overnight, hereby emphasising that the clay layer is extremely impermeable. The topsoil took over one hour to drain through, however we did not test layer for clay content. It is thought that the slow infiltration could caused by the large organic content in the soil which absorbed water instead of draining it through. Overall this test highlighted and confirmed the highly impermeable nature of the clay layer.

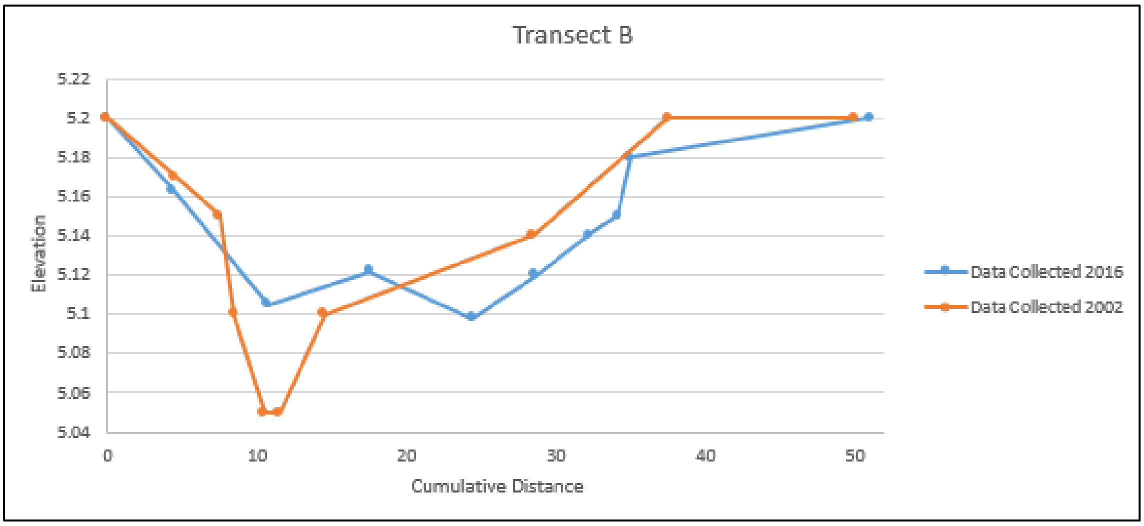
Table 2: Time taken to infiltrate 40ml water through a 50g soil sample. (hh:mm:ss:ss)

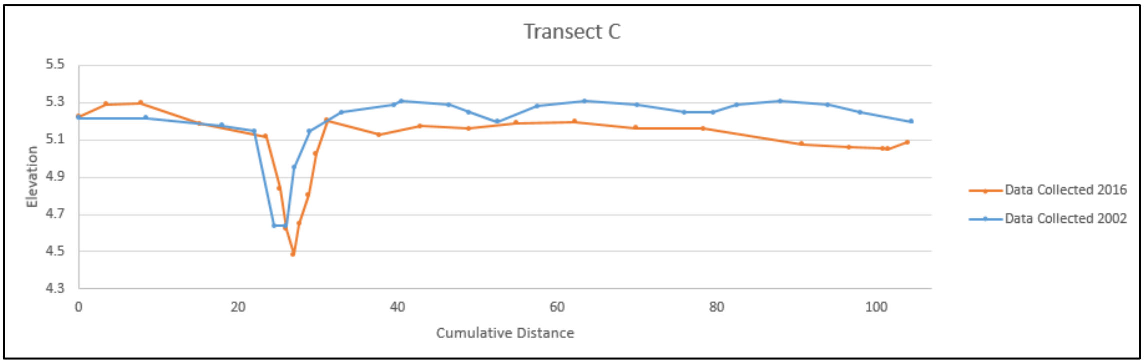
Sample	Time
Top Soil	01:07:58:00
AP40	00:00:07:31
Sand	00:31:54:00
Clay	24:34:00:00 to move 4.5mm of water

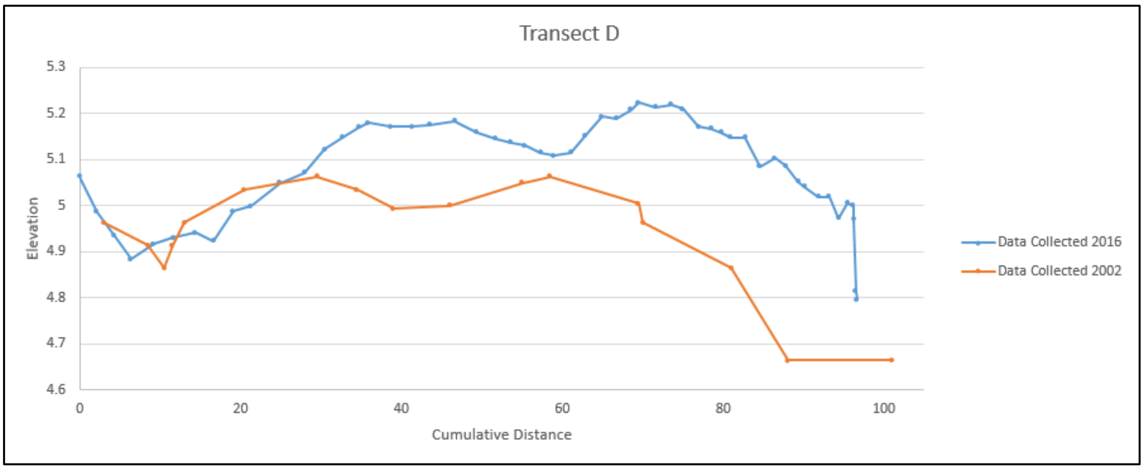
4.5 GNSS Surveying Analysis

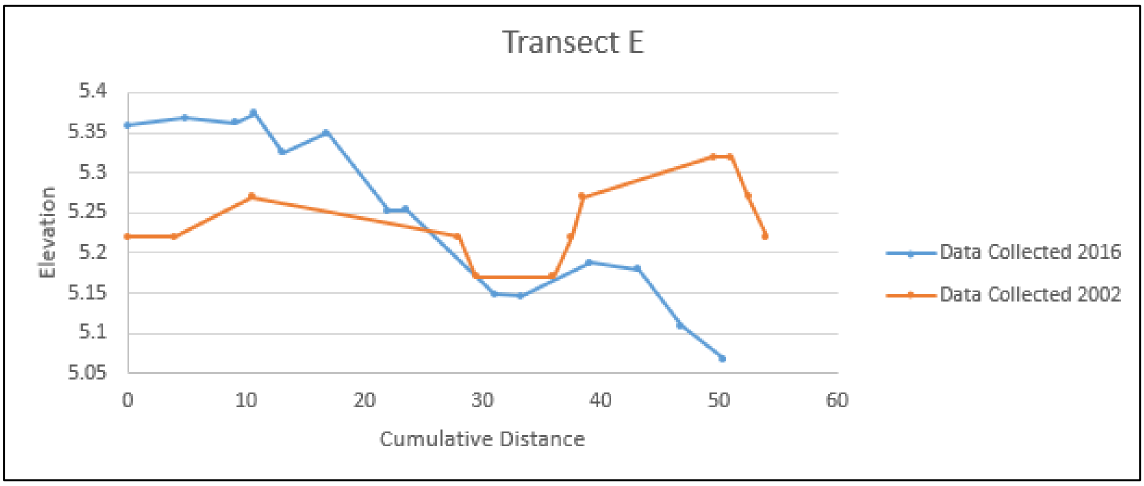
Following completion of the GNSS survey, data from the group's survey was imported into Microsoft excel. The transect data completed in 2002 was also entered. Topographic profiles of each transect were then created, overlaying the two data sets. The completed profiles are shown below (***Figure 13***):











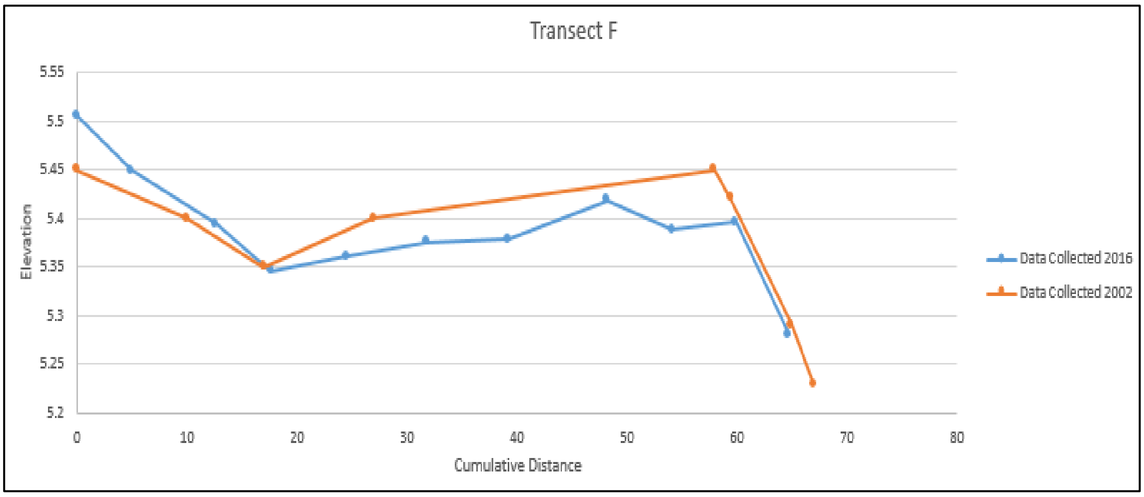


***Figure 13**: Comparable graphs showing the transects which the council collected in 2002, compared to the surveys undertaken by the group in 2016.*

Through analysis of the transects, it was found that there were many minor changes in elevation throughout the site. This could be related to land subsidence during the Canterbury Earthquake Sequence in which TFC had extensive liquefaction. Following this, the site was the leveled off as best as it could be. Another reason for this difference could be due to human error. Transects created by the Christchurch City Council were navigated to the best of the group's ability. Aspects of the environment hindered the group's capability to obtain confidence in our accuracy. An example of this is transect A in which surveying of the swale at approximately 20m-35m is incomplete due to dense vegetation obstructing the groups transect. Due to this inaccuracy, a more complete survey and research would be needed to investigate how much subsidence has occurred at the nursery. These minor changes and fluxuations in elevation have caused depressions and rises in locations on the site. Areas experiencing depressions are also known locations where pooling and waterlogging has occurred.

Overall the site also showed as a general trend its highest points of elevation located at the centre of the site, with a small, decrease in elevation towards the perimeter. This small gradient should encourage flow of water towards the boundaries.

5.0 Discussion

Our results have given new knowledge about the subsurface stratigraphy at the TFC site. Due to the limited number of sites analysed, a lot of interpolation has been made in regards to the how the units change in depth, thickness and orientation across the site. Core samples showed an 80cm thick impermeable layer of clay across the site which begins at around 80cm of depth (***Figure 8***). This layer appeared at all sites we tested, so it is assumed that this layer will appear across the whole nursery. This assumption can also be supported by the geologically recent inundations depositing marine silts and fine sands on the east coast (Suggate, 1958), so it can be assumed that this sort of stratigraphy is consistently present at TFC and the nearby areas (***Figure 14***).

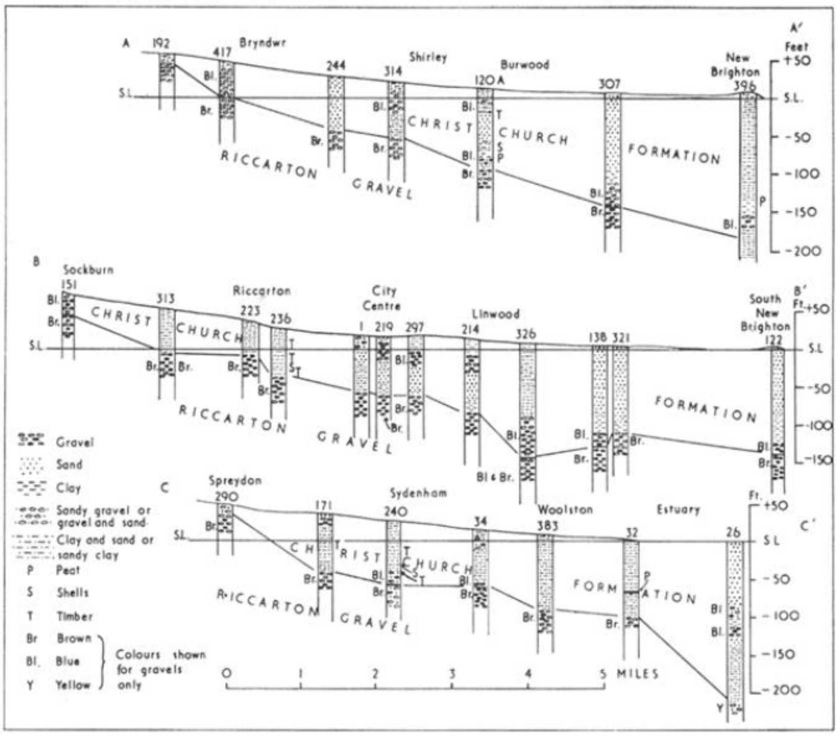


Figure 14: *Well logs illustrating the spatial variation of the Christchurch formation, deposited in the late Quatenary during marine inundation. Cross section C-C' shows a rough section that passes through the estuary and woolston which is where TFC is situated.*

From the permeability tests, not only was the clay impermeable, but the topsoil and sand units also showed very slow infiltration rates. Tavenas et al., (1983) found that the permeability of soft intact clay was a function of void ratio and grain size but also the plasticity and fabric of the clay. It is possible that the clay found at TFC has similar variables that are responsible for its impermeable nature, but more investigation would need to be done. The slow permeability rates are what we expected if we were to have finer grained, well sorted samples (Masch & Denny, 1966). With the fine grained, moderate-well sorted nature of most of the subsurface layers, it is not a surprise that the water can't successfully infiltrate. The characteristics of the sub-surface geology are essentially controlling the waterlogging issue at TFC as water can't infiltrate through the sub-surface fast enough. There seems to be a lack of infiltration into or beyond the impermeably clay layer which is causing water to sit or perch above the clay.

The water table became of interest when collecting soil samples, as both samples and the hole started becoming moist around 0.7m of depth (***Figure 8***). It is not yet understood whether this area of saturation is a perched water table created by water trapped above the clay layer, or if it is the height of the actual water table. Perched water tables occur when impermeable layers causes accumulations of ground water to become trapped above the actual water table in the unsaturated zone (Bonell & Gilmour, 1978). Council data has shown that the depth of the actual water table has fluxuated a lot in this area, from 0.7 down to 1.5m depth (ECAN, n.d.). Groundwater fluctuates with seasonality, becoming higher in wet seasons due to increase in water resources, and lower in dry seasons where the ground water resource becomes exhausted (Subba Roa, 2006). Seasonality would need to be taken into account when creating a drainage plan at the site.

Surveying results showed that there was small surface gradient from the centre of the site to the outer. It is our interpretation that the small fluctuations superimposed on the general overall surface elevation could lead to water pooling. Even small changes in topography which went against the gradient would result in pooling at the surface. A solution could potentially be to smooth and level out the ground surface, however this could be difficult in a site used for such purposes, as small events such as branches falling from trees and leaf litter could impact the pooling of water on such a shallow gradient.

6.0 Recommendations

Referring to our initial research question, we discovered key factors were which influenced the drainage at the site. This includes subsurface geology, and more specifically the 80cm thick clay layer, and also the small variations in elevation. These implications needed to be taken into account when looking at a solution for remediating the flooded site.

6.1 Drilling through the clay layer

One option for remediation would be to drill through the clay layer into the underlying sand layer to allow for surface water to drain through the subsurface and into the permeable sand layer beneath the clay, this method is further explained in Appendix I. It would involve drilling holes and putting in PVC pipe filled with coarse gravel. There is an implication here which is that this method would only work if the water table we reached at 50cm was a perched water table, as opposed to the actual water table which would ideally be located beneath the clay layer. We did not obtain enough substantial evidence to suggest that the water table we reached was a perched water table, and therefore cannot fully endorse this method of remediation.

There would need to be a significant amount of follow up research to ensure this method of remediation would promote positive results at the site, including but not limited to:

- Identifying the depth of the actual water table. This could be done by installing a bore hole and a piezometer to obtain records of groundwater fluctuation over a period of seasonal changes. This would give us the elevation fo the water table independent of the subsurface stratigraphy.
- Obtain further data about subsurface geology in terms of thickness of the clay layer. A thinner clay layer would mean less resources would be needed to drill through the clay layer, lowering costs. If the layer was thinner and closer to the surface, there would also be a less chance of the clay layer interacting with the water table below.
- It would need to be investigated how water would be moved across the surface to the locations where the clay layer is drilled through. This could be done through trenches or swales with a gradient.

6.2 Maintenance of swales

The maintenance of swales was emphasised in literature such as the Suds Manual and Cities and Flooding. Due to the swales being situated in the clay layer at the nursery, they cannot serve their main purpose which is to infiltrate water through. However because of the clays impermeable nature and the lack of infiltration that can occur in this layer, it would be possible to encourage the flow of water if a sufficient gradient was present. It is recommended that further investigation in undergone in terms of looking at the gradient specifically along the swales by GNSS surveying, and further to this, looking at how to create a gradient in the swale.

7.0 Conclusion

Analysis and investigating the nursery helped gain a better understanding of the problems faced at the TFC site. After discovering and analysing the thick clay layer, it was clear this was a key factor influencing the drainage issues at the nursery. Our research, including literature review, was useful in helping us come up with possible mitigation measures and solutions. On paper, the idea of drilling through the clay layer into the more permeable sand layer beneath seems like a tangible and efficient solution. However, the uncertainty regarding the true level of the water table means that the chance of this method being successful is still questionable. Further investigation should be conducted to figure out whether or not the actual water table is located at a distance beneath the clay layer. For now, maintenance of the swales is a viable mitigation measure that can be implemented straight away. To optimise the effectiveness of the swales, any vegetation should be removed and gradient should be considered during the creation of any new swales.

8.0 Acknowledgements

We would firstly like to thank our academic supervisor Heather Purdie for her guidance and feedback throughout the research project. Our community partner Steve Bush from Trees For Canterbury for giving us direction but also freedom with the project and allowing us access to him and his site for information. We would also like to thank Justin Harrison and Paul Bealing for providing us with equipment and helping us to analyse the data we collected.

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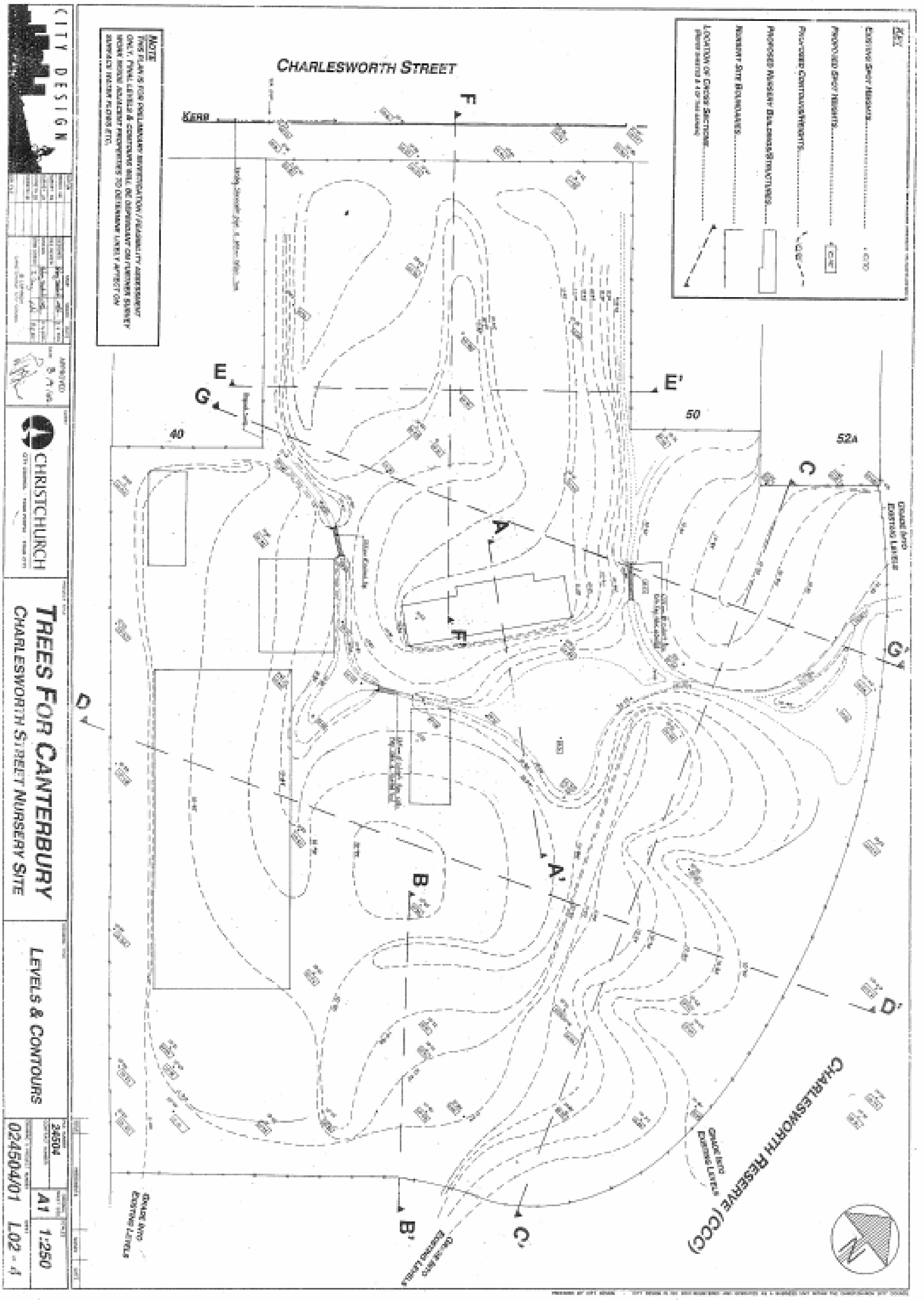
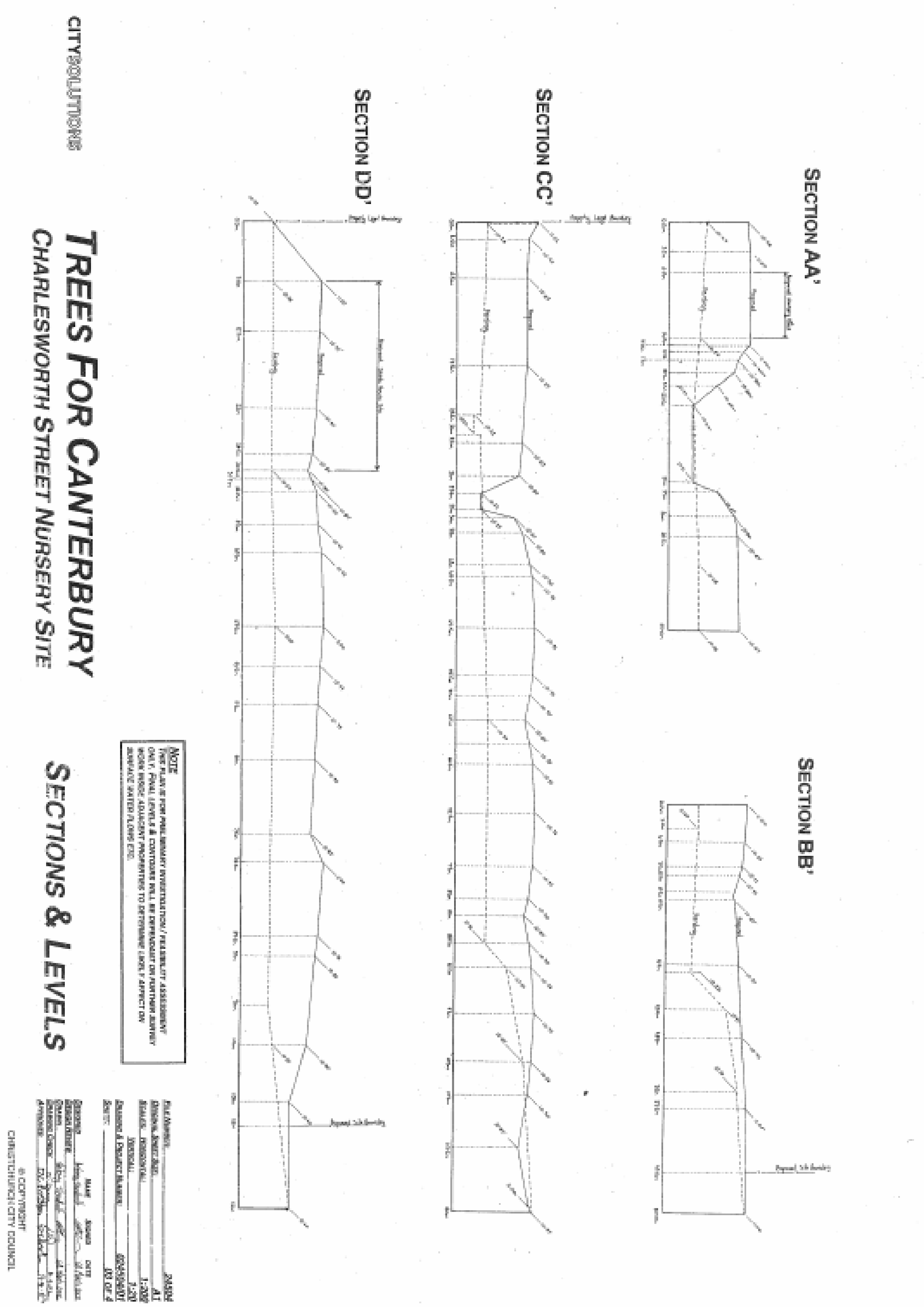
Appendix A

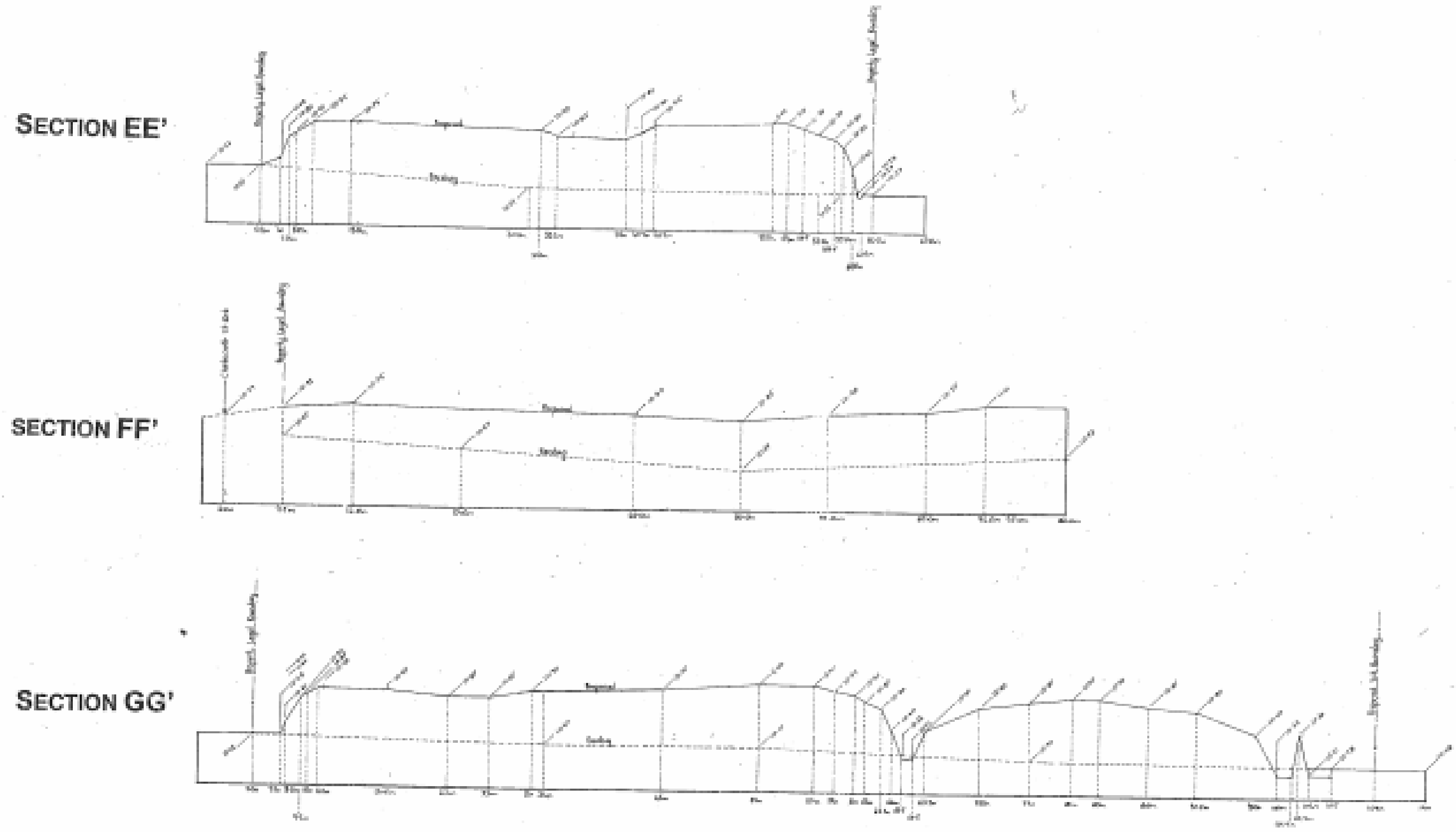
Christchurch City Council original map of the site 2002. The map shows the topographic lines around the site highlighting areas or elevation. The lines across the image represent the transects which are shown in cross sectional view in Appendix B.



Appendix B

Original Transects across the site taken in 2002 by the Christchurch City Council. These transects were compared to transects taken in our study.





NOTE
THIS PLAN IS FOR PRELIMINARY INVESTIGATION / FEASIBILITY ASSESSMENT ONLY. FINAL LEVELS & CONTOURS WILL BE DEPENDANT ON FURTHER SURVEY WORK INSIDE ADJACENT PROPERTIES TO DETERMINE LIKELY AFFECT ON SURFACE WATER FLOWS ETC.

FILE NUMBER:	24504
ORIGINAL SHEET SIZE:	A1
SCALES: HORIZONTAL:	1:200
VERTICAL:	1:20
DRAWING & PROJECT NUMBER:	024504/01
SHEET:	04 OF 4

CITYSOLUTIONS

TREES FOR CANTERBURY
CHARLESWORTH STREET NURSERY SITE

SECTIONS & LEVELS

	NAME	SIGNED	DATE
DESIGNED:	[illegible]	[illegible]	[illegible]
DESIGN REVIEW:			
DRAWN:	[illegible]	[illegible]	[illegible]
DRAWING CHECK:	[illegible]	[illegible]	[illegible]
APPROVED:	[illegible]		[illegible]

Appendix C

Original Sample descriptions taken from the site. Sample A-G were taken from the sample hole at site 1. Sample H was taken at site 2. The descriptions mainly show a simple description and class them into one of the 4 main units at the site – top soil, AP40, sand and clay.

Sample A – AP40

Sample B - Well sorted sands with a few coarse rounded sand sized grains at 21cm depth.

Sample C – A saturated sample B.

Sample D - The sand is slightly finer eg. gone from medium to fine sand grains. Now less granules and coarse sand grains.

Sample E – Wet fine sand with organics present.

Sample F – Clay, highly impermeable. Lot of organics and roots present.

Sample G – Clay with interfingering Sand.

Sample H – 'Sandy' Clay.

.

Appendix D

Grain sizes in Microns and Phi used to define the different classes within a grain size class, and to define sieve sizes used for dry and wet sieving.

Source: http://maps.unomaha.edu/maher/ESSlectures/ESSlabs/lab6sediments.html

Millimeters		µm	Phi (φ)	Wentworth size class	
			-20		
	4096		-12	Boulder (-8 to -12φ)	
	1024		-10		
	256		-8		
	64		-6	Pebble (-6 to -8φ)	
	16		-4	Pebble (-2 to -6φ)	
	4		-2		Gravel
	3.36		-1.75		
	2.83		-1.50	Gravel	
	2.38		-1.25		
	2.00		-1.00		
	1.68		-0.75		
	1.41		-0.50	Very coarse sand	
	1.19		-0.25		
	1.00		-0.00		
	0.84		0.25		
	0.71		0.50	Coarse sand	
	0.59		0.75		
1/2	0.50	500	1.00		
	0.42	420	1.25		
	0.35	350	1.50	Medium sand	Sand
	0.30	300	1.75		
1/4	0.25	250	2.00		
	0.210	210	2.25		
	0.177	177	2.50	Fine sand	
	0.149	149	2.75		
1/8	0.125	125	3.00		
	0.105	105	3.25		
	0.088	88	3.50	Very fine sand	
	0.074	74	3.75		
1/16	0.0625	63	4.00		
	0.0530	53	4.25		
	0.0440	44	4.50	Coarse silt	
	0.0370	37	4.75		
1/32	0.0310	31	5	Medium silt	
1/64	0.0156	15.6	6	Fine silt	
1/128	0.0078	7.8	7	Very fine silt	
1/256	0.0039	3.9	8		Mud
	0.0020	2.0	9		
	0.00098	0.98	10		
	0.00049	0.49	11	Clay	
	0.00024	0.24	12		
	0.00012	0.12	13		
	0.00006	0.06	14		

Appendix E

Raw Data from Dry Seiving A - H. The data here shows the weight of the sediment measured in each sieve (left column) and the weight percent of this within the total sample (right). The sieve sizes are in reference to appendix D. The total weight is not inclusive of the clay content.

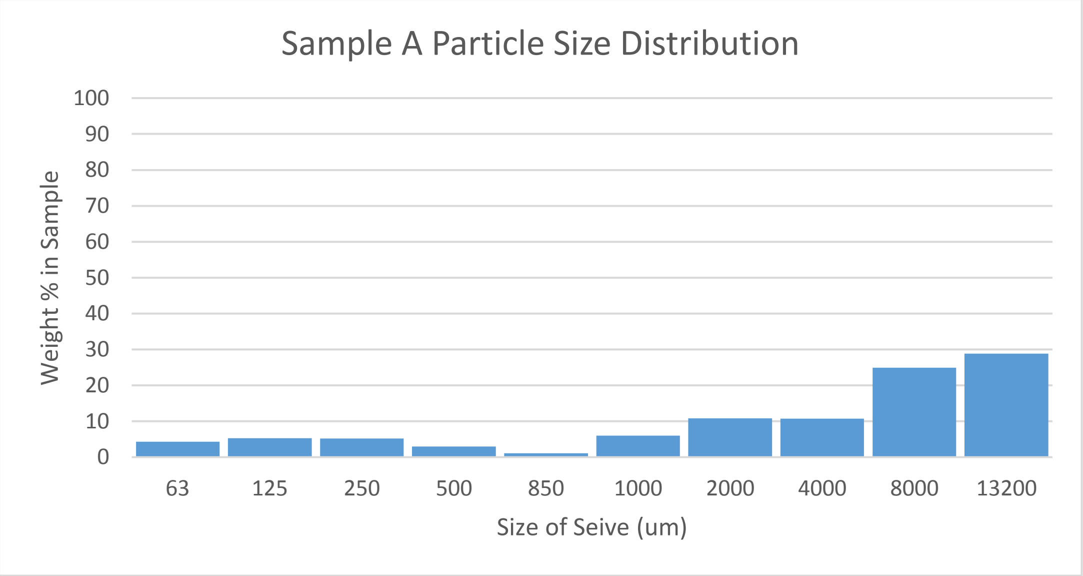
	Sample					
Seive Size (um)	a	%	b	%	c	%
63	7.628	4.259335	11.072	13.1598	10.215	15.01323
125	9.427	5.263863	68.916	81.91121	55.852	82.08701
250	9.243	5.161121	1.512	1.797112	0.935	1.374192
500	5.361	2.993484	0.308	0.366078	0.187	0.274838
850	1.882	1.050874	0.125	0.148571	0.094	0.138154
1000	10.733	5.99311	0.382	0.454032	0.369	0.542328
2000	19.426	10.84712	0.603	0.716705	0.282	0.414462
4000	19.207	10.72484	1.217	1.446485	0.106	0.155791
8000	44.596	24.90159	0	0	0	0
13200	51.586	28.80467	0	0	0	0
Total	179.089	100	84.135	100	68.04	100

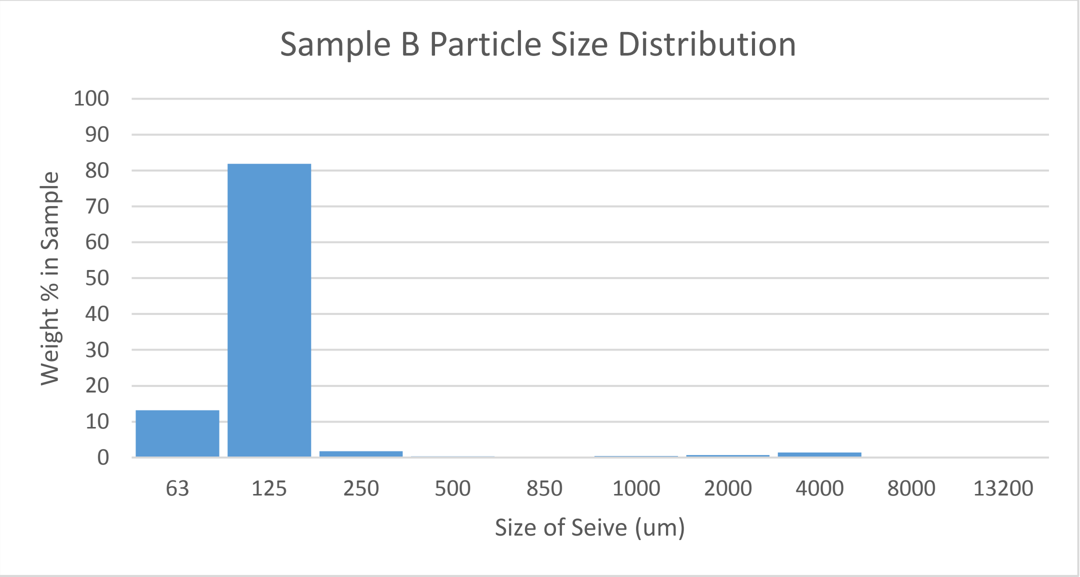
	Sample					
Seive Size (um)	d	%	e	%	f	%
63	13.939	11.59419	17.715	13.05617	5.637	26.81349
125	98.444	81.88382	116.349	85.75061	14.934	71.03648
250	1.686	1.402382	1.394	1.027395	0.452	2.150026
500	0.375	0.311918	0.116	0.085493	0	0
850	0.108	0.089832	0.02	0.01474	0	0
1000	0.472	0.3926	0.089	0.065594	0	0
2000	0.577	0.479937	0	0	0	0
4000	4.623	3.845322	0	0	0	0
8000	0	0	0	0	0	0
13200	0	0	0	0	0	0
Total	120.224	100	135.683	100	21.023	100

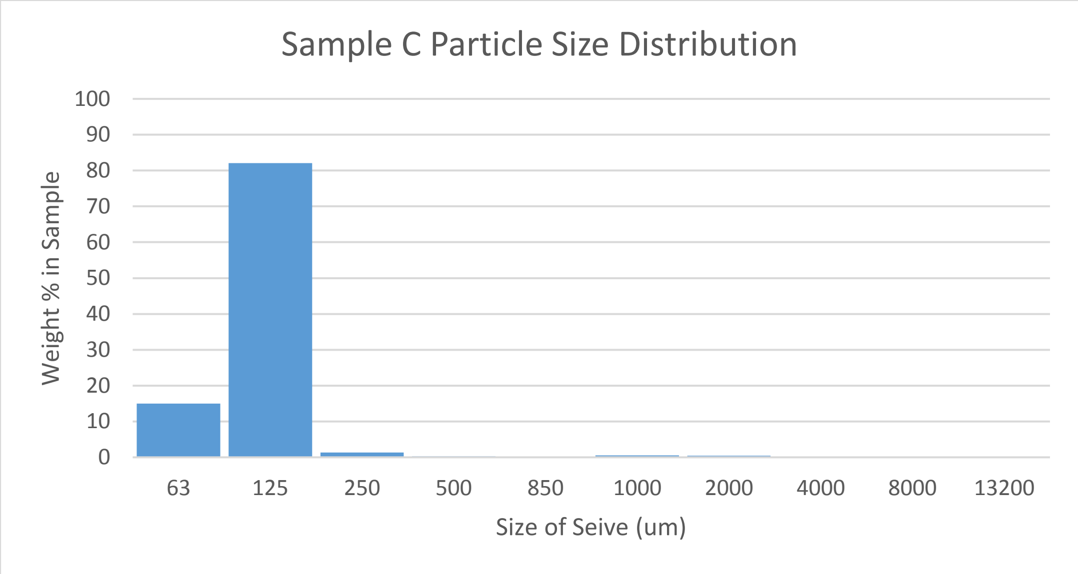
	Sample			
Seive Size (um)	g	%	h	%
63	4.685	48.62985	5.281	20.67818
125	4.949	51.37015	19.325	75.66859
250	0	0	0.933	3.653236
500	0	0	0	0
850	0	0	0	0
1000	0	0	0	0
2000	0	0	0	0
4000	0	0	0	0
8000	0	0	0	0
13200	0	0	0	0
Total	9.634	100	25.539	100

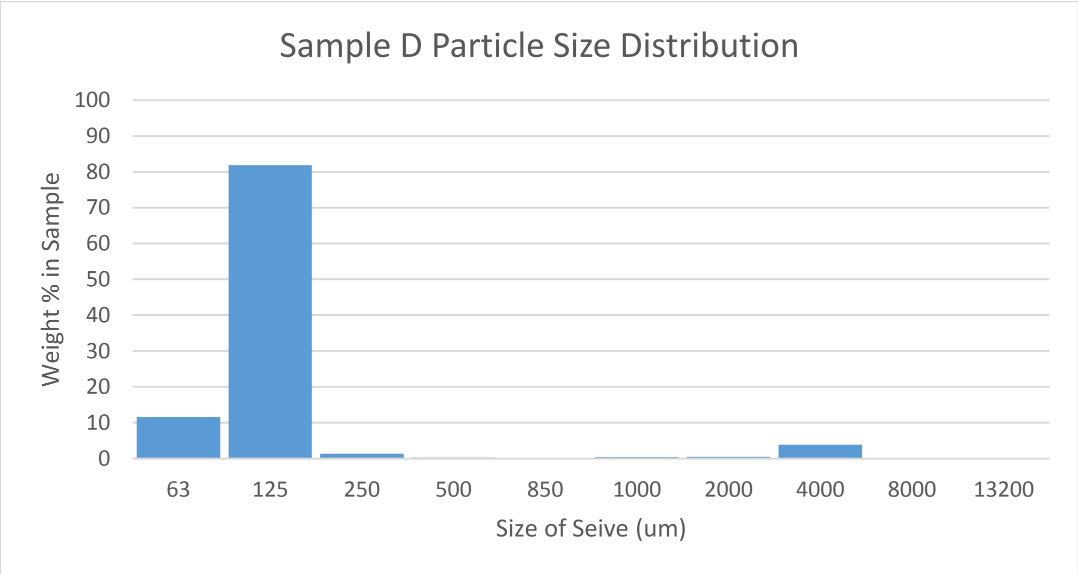
Appendix F

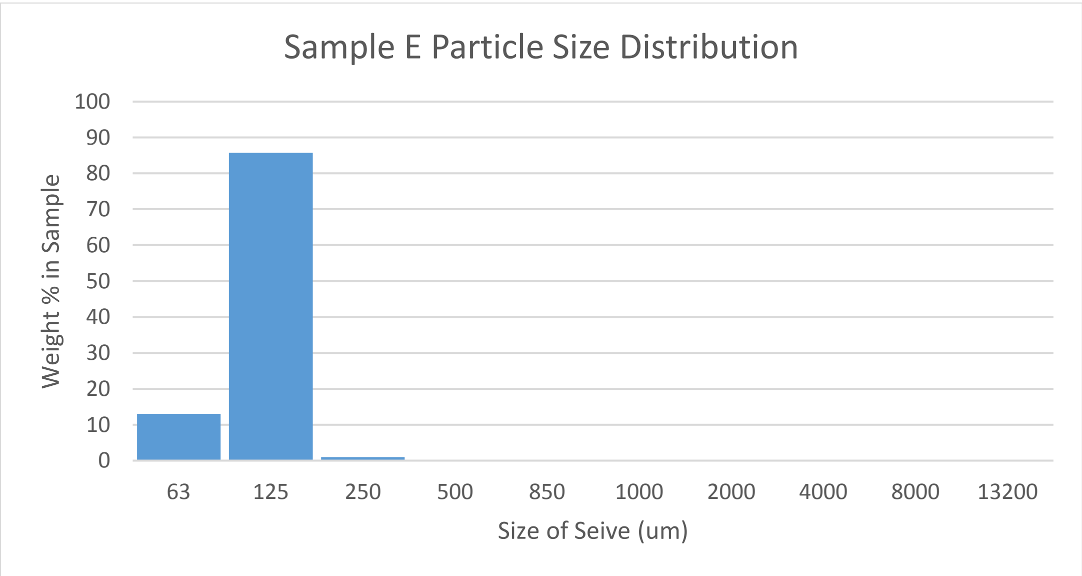
Graphs of all sample results from the dry sieving tests. The graphs show the weight percent within the sample. The main purpose of the graphs is to display how sorted the samples were. The sorting ranged from poor sorting (sample a) to well sorting in the sand and clay samples. Poorly sorted is when there are particles in majority of the sieve sections.

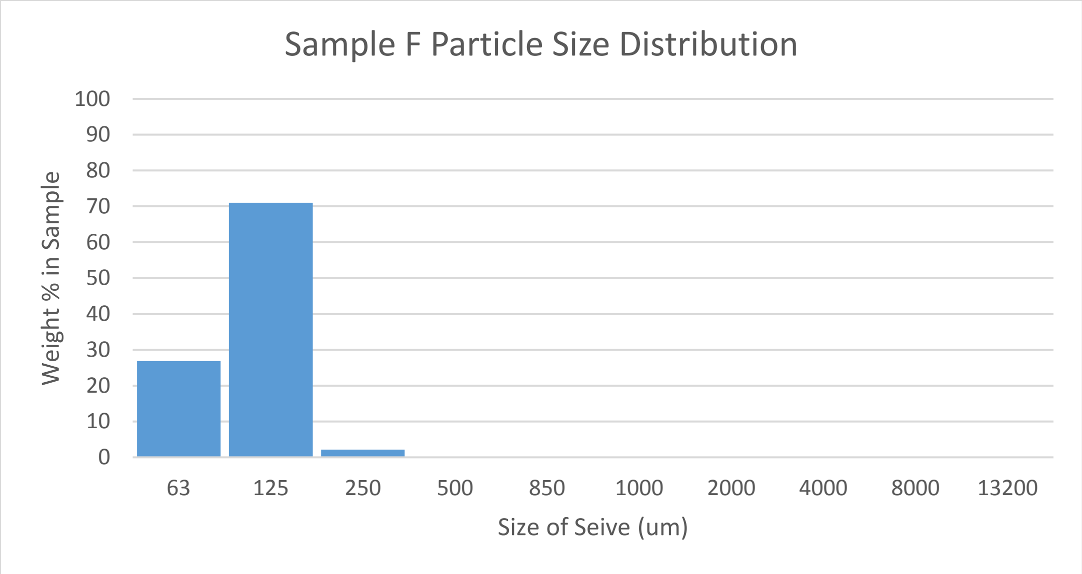


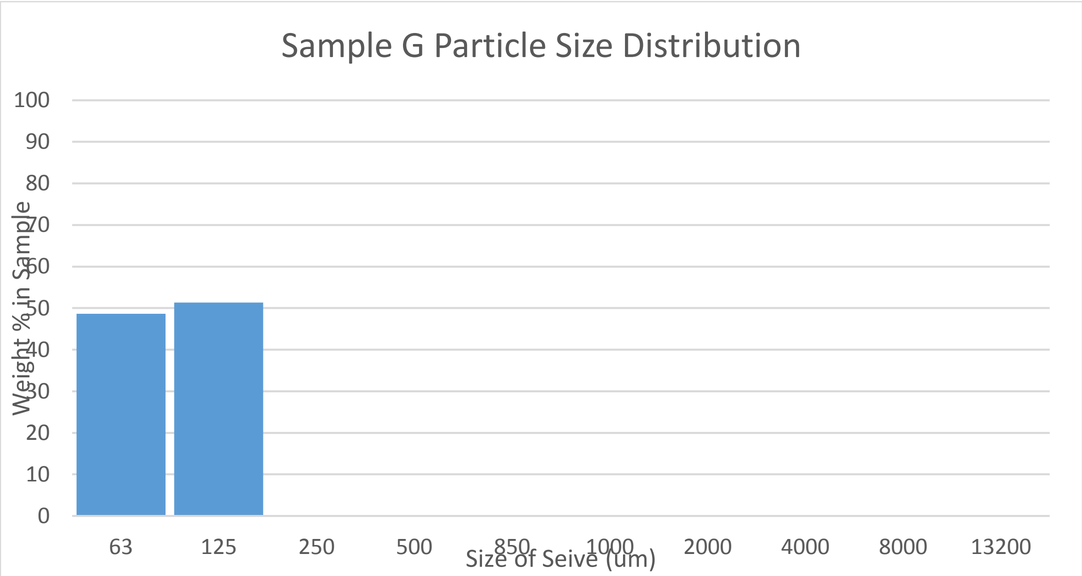



Sample C Particle Size Distribution
Weight % in Sample
100
90
80
70
60
50
40
30
20
10
0
63
125
250
500
850
1000
2000
4000
8000
13200
Size of Seive (um)


Sample D Particle Size Distribution
Weight % in Sample
100
90
80
70
60
50
40
30
20
10
0
63
125
250
500
850
1000
2000
4000
8000
13200
Size of Seive (um)


Sample E Particle Size Distribution
Weight % in Sample
100
90
80
70
60
50
40
30
20
10
0
63
125
250
500
850
1000
2000
4000
8000
13200
Size of Seive (um)


Sample F Particle Size Distribution
100
90
80
70
60
50
40
30
20
10
0
Weight % in Sample
63
125
250
500
850
1000
2000
4000
8000
13200
Size of Seive (um)


Sample G Particle Size Distribution
100
90
80
70
60
50
40
30
20
10
0
Weight % in Sample
63
125
250
500
850
1000
2000
4000
8000
13200
Size of Seive (um)

Appendix G

Raw data from pipette analysis. The table shows the weights for each sample taken, with a total weight for clay in the sample at the bottom. With the lighter clay settling out later in the period the samples were taken, and therefore those weighing less and being the smaller clays.

	Sample					
Phi Size	a	b	c	d	e	f
0.4	0.202	0.094	0.06	0.134	0.105	1.879
0.5	0.161	0.061	0.047	0.091	0.071	1.804
0.6	0.109	0.043	0.031	0.064	0.051	1.614
0.7	0.084	0.034	0.028	0.06	0.041	1.325
0.8	0.029	0.02	0.015	0.036	0.026	0.929
0.9	0.001	0.008	0.006	0.027	0.02	0.683
Total (g)	0.586	0.26	0.187	0.412	0.314	8.234

	Sample		
Phi Size	g	h	i
0.4	3.197	1.909	1.228
0.5	2.253	1.8	1.156
0.6	2.156	1.698	1.069
0.7	1.879	1.417	0.94
0.8	1.326	0.96	0.667
0.9	0.988	0.722	0.472
Total (g)	11.799	8.506	5.532

Appendix H

Raw Data for Permeability results. The results show the time it took for 400ml to infiltrate through 50mm thick of packed sediment. The slowest infiltration rates were the clays which moved 2-4mm overnight, and the fastest being the AP40 which moved the water through it in 7.31seconds.

Permeability timing	400ml water through approximately 50mm thick sediment	
	h/m/s/s	
Sample	Time	
Top Soil	01:07:58:00	
a	00:00:07:31	
b	00:23:41:97	
c	00:31:54:00	
d	00:38:50:00	
f	20:50:00:00	Started at 1.5cm from the top lip at 12:36pm, Measured from the lip 1.7cm -moved 2mm overnight.
g	24:34:00:00	Started 1cm from the lip, went down 4.5mm overnight

Appendix I

Engineering solutions to remediate the land.

This method would involve coring through the clay layer and putting pipe through then filling the pipe with gravel (***Figure 1***). The pipe would allow water from the surface to be able to drain through the clay layer into the underlying sand layer where it will infiltrate through the sub surface. Implications of this method are the depth of the water table. The two diagrams below show how the set up would work at different depths of the water table. The set up would ideally creating a few areas around the site where pipes could be put in place, and then methods to move the water across the surface would be put in place to move the water to these smaller areas of drainage. This could be done through creating low points where the pipes would be placed at the bottom, or by moving the water through the current means of movement at the nursery which is trenches and swales.

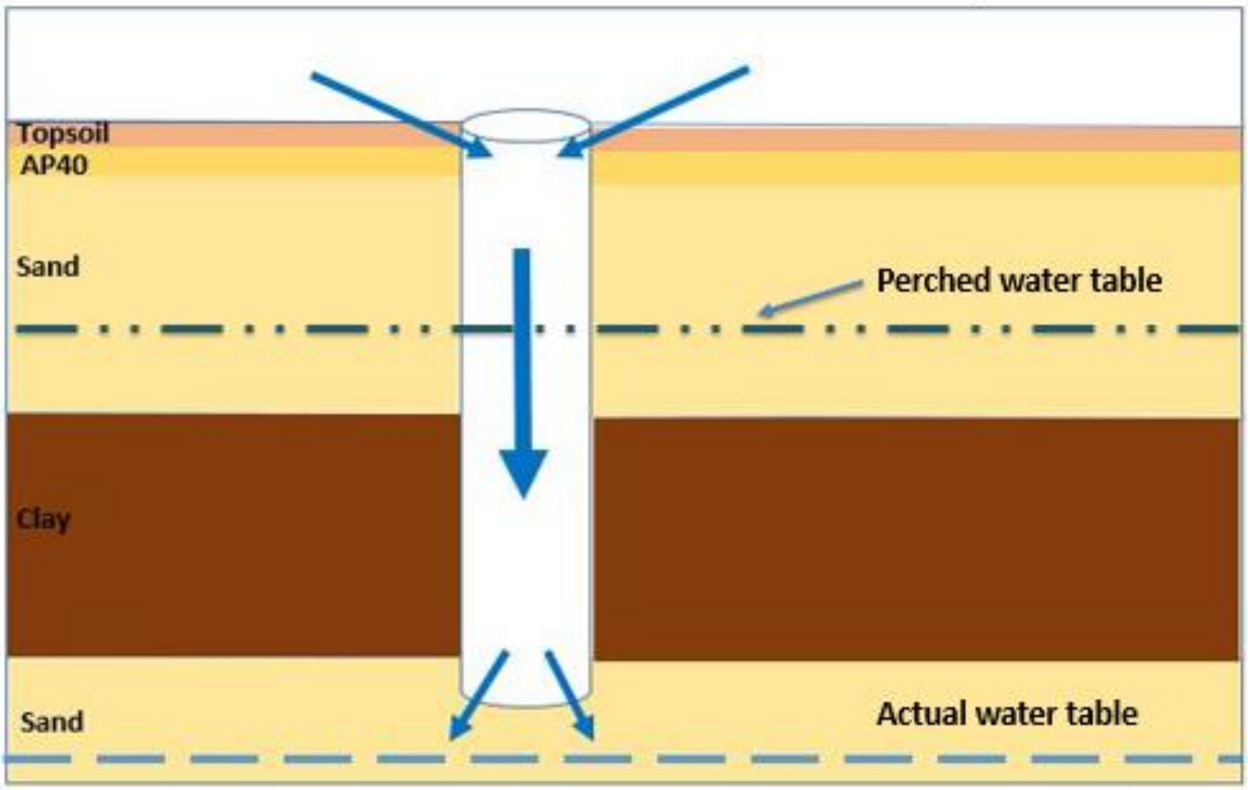


Figure 15*: if the water table is perched then water can drain through the clay layer to the underlying sand layer.*

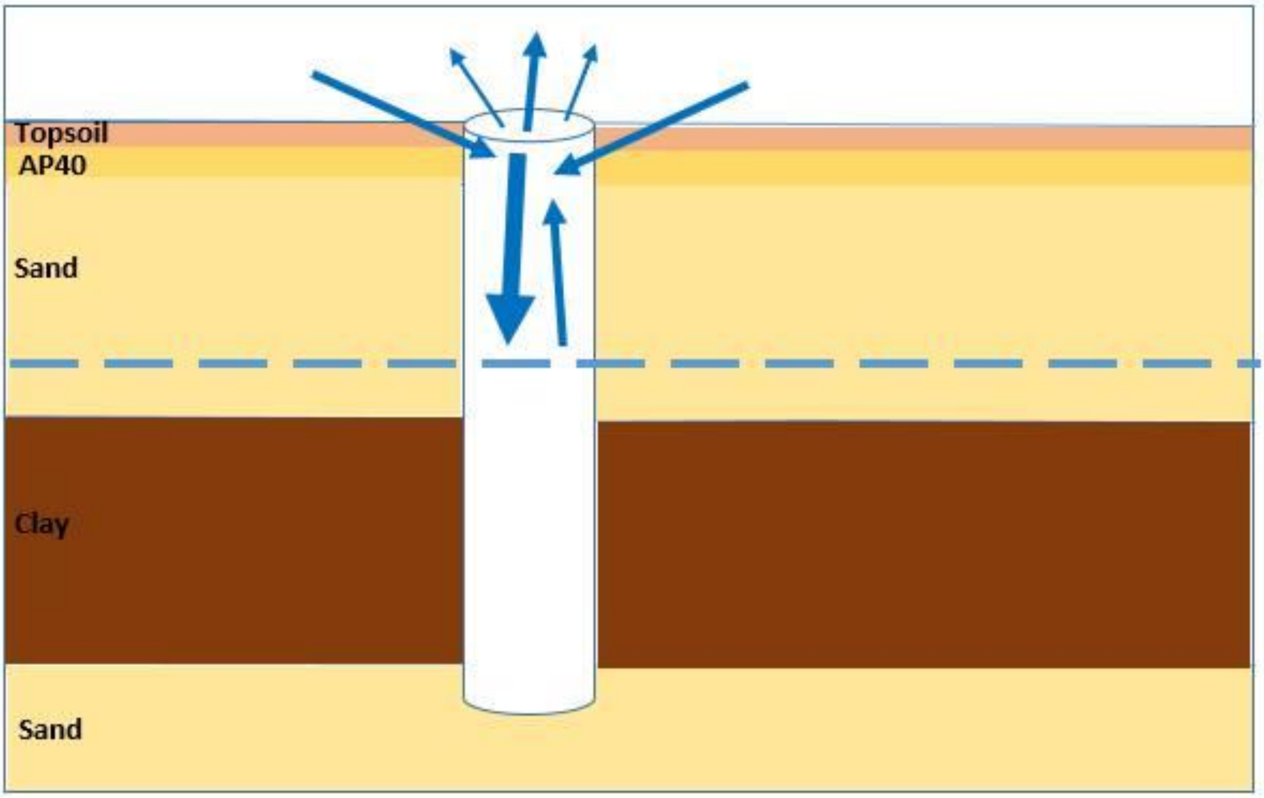


Figure 16: *if what has been interpreted as a perched water table as the actual water table, then drainage method will not be effective and could create more flooding.*