# Reids Canal Floodway Upgrading

## Stage 3

## (0m to 970m)

## Geotechnical Assessment


Prepared for

**Bay of Plenty Regional Council**

**June 2013**

ICE GEO & CIVIL

# Contents

# 1 Introduction

The Bay of Plenty Regional Council is progressively upgrading Reids Canal to improve its flood carrying capacity and the security of the stopbanks along it. This canal upgrading is part of on-going work to improve the security of the Rangitaiki River flood protection system. Ice Geo and Civil Ltd has been engaged to assess the geotechnical aspects of the canal improvements from close to its outlet into the Rangitaiki River to 970m upstream where the canal passes under Thornton Road (Figure 1). This section is Stage 3 of the canal upgrading project. Ice Geo has assessed four other sections of the canal and construction work has been completed on two of them (References 1 to 4). The upstream end of Stage 3 adjoins Stage 2; use has therefore been made of some of the testing information from Stage 2 near the interface.

Reids Canal lies to the east of the Rangitaiki River and is designed to take some of the river flow in floods with a return period above 40 years. The canal has its own catchment of drains with a mixture of pumped feeds and flap-gated culverts. The normal canal flows are contained in an incised channel between berms. Flood flows are contained between stopbanks. In the Stage 3 section of the canal the proposed improvement work consists of building a new stopbank up to about 30 to the west of the existing left stopbank and raising the right stopbank by 100 to 400mm. These improvements are designed to provide 300mm of freeboard in the design 100 year return period flood.

There is a history of stopbank failure within the Rangitaiki Plains. No obvious problems were observed along Reids Canal in the flood of July 2004 but the collapse of the Rangitaiki River stopbank further upstream and the consequent flooding of the land along the left side of the canal may have caused problems to go unnoticed. Water also ponded in the low area along the right side of this canal section during the July storm (Figure 2).

This report details the geotechnical investigations and analyses carried out to determine the work required to provide an acceptable level of security against stopbank failure in Stage 3 of the Reids Canal project and presents the following;

- information on the sub surface soil profile gained from in situ investigations,
- the results of seepage analyses for the estimated 100 year return period flood,
- the results of seepage analyses for tidal cycles in the canal,
- the results of some stability analyses,
- recommendations for the upgrading of the stopbanks,
- comment on the fill available on site for construction work and
- an assessment of the amount of stopbank settlement expected.

This report is the property of our client, the Bay of Plenty Regional Council and Ice Geo and Civil Ltd. The comments within relate only to the length of stopbank along Reids Canal from 0m to 970m.

The conclusions of this report are based on the interpretation of investigations carried out at isolated points only; therefore there could be ground or other conditions which have an effect on the integrity of the stopbanks that have not been identified.

## 2 Site and Upgrade Description

Figure 1 show the extent of the canal covered by this report and the LIDAR plot in Figure 2 shows the ground contours. The stopbank meterages referred to throughout the report are shown on Figure 1.

The new stopbank will have 4H:1V side batters and a 3m wide crest. A 5m wide berm will be left between the stopbank toe and the incised part of the channel. The invert of the incised portion will be at RL-2.0 and the cut along the left side of the channel will be made at 2H:1. The existing right stopbank will be raised and widened in areas where it is narrow. The berm between the stopbank and the incised part of the canal is at least 5m wide along the right bank except near the bridge at the start of the section where there is a broad continuous batter at about 2H:1V.

It can be seen from the LIDAR plot that this section of canal passes from an old stream levee across a peat filled basin, marginally above sea level and cuts across the end of an offset coastal sand dune complex. This offset can be seen more clearly in a larger scale LIDAR plot, Figure 3. It is likely that the fault which caused the sand dune offset is beneath the canal from 0m to 300m. There is a marshy dip behind the right stopbank at about -40m, beyond the road bridge. This marsh appears to be salty, indicating seepage from the salt water wedge extending from the river mouth up the river and lower canal.

The LIDAR plot shows some old stream channels intersecting the canal which are evident on the ground as slight depressions. There is an old stream levee forming higher ground between the canal and the river and it should be noted that all the houses in the area are on higher ground.

Rock scour protection has been placed along most of the incised channel due to sand being exposed in its sides and invert. Rock has also been placed on the top of the right stopbank from about 0 to 75m and more further upstream. Rabbit damage to the right stopbank can be seen between 300 and 360m indicating a sandy layer in the stopbank. There is a small depression at the inland toe of the right stopbank from 590m to 750m.

Many drains approach the stopbanks across the low lying basin and there is a pump station at 570m on the right bank.


Figure 1a

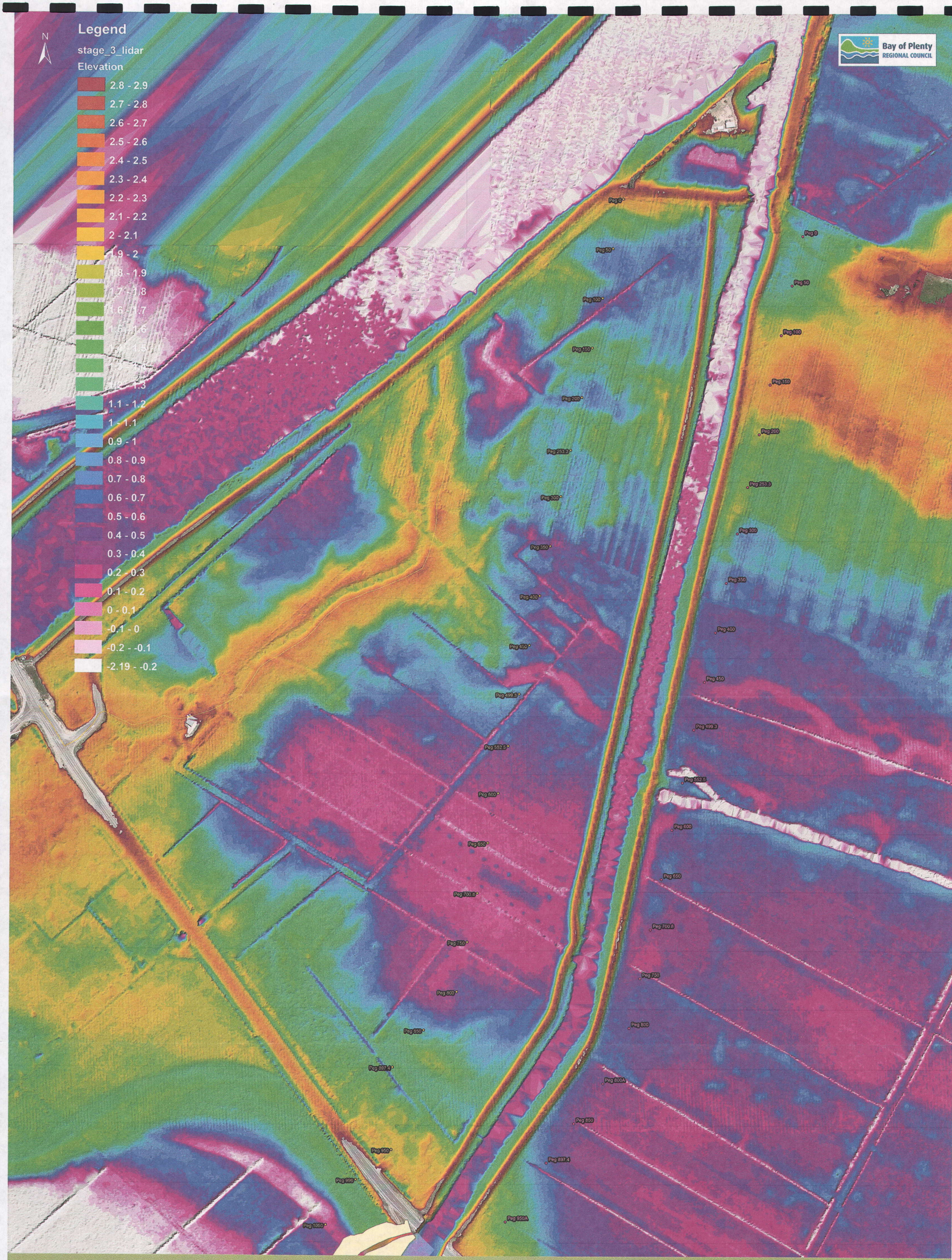
x borehole

/// overlay

— wick drains


Peg 499.3
Peg 450
Peg 499.3
Peg 552.5
Peg 552.5
Peg 600
Peg 600
Peg 650
BH4
Peg 650
Peg 700.8
BH5
Peg 700.8
Peg 750
Peg 750
Peg 800
Peg 850
Peg 800
BH6
Peg 897.4
BH9
Peg 800A
Peg 850
Peg 950
Peg 897.4
Peg 996
Peg 950A
Peg 1050

Figure 1b




# Map Title

Subheading/supporting text

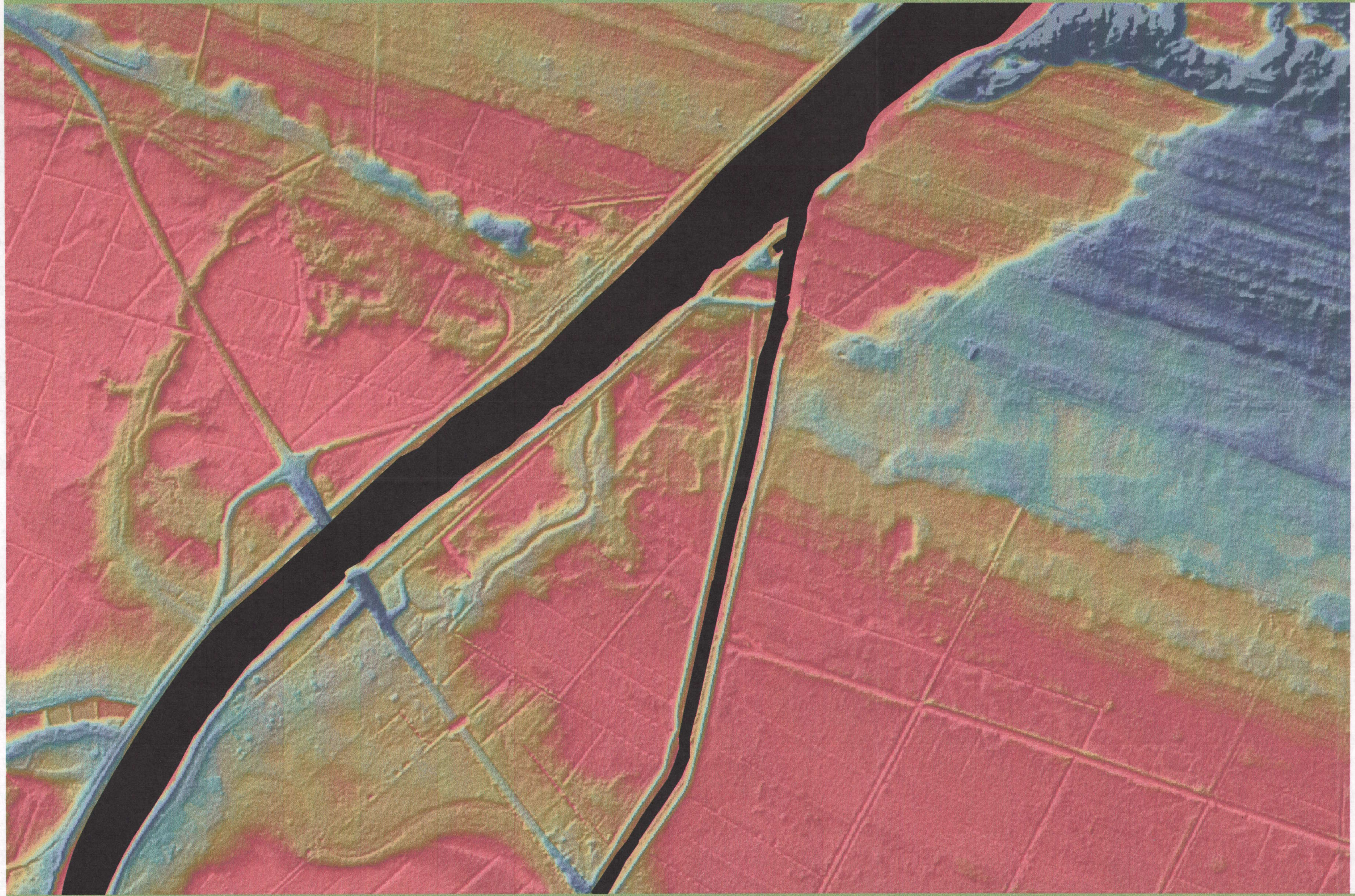
Figure 2



Plan Number / Date

# Surface Topography at the vicinity of the Rangitāiki River mouth

Bay of Plenty
REGIONAL COUNCIL



**Elevation (m)**

| | |
|---|---|
| -1.5 - 0.0 | 2.4 - 2.6 |
| 0.0 - 0.1 | 2.6 - 2.8 |
| 0.1 - 0.2 | 2.8 - 3.0 |
| 0.2 - 0.4 | 3.0 - 3.2 |
| 0.4 - 0.6 | 3.2 - 3.4 |
| 0.6 - 0.8 | 3.4 - 3.6 |
| 0.8 - 1.0 | 3.6 - 3.8 |
| 1.0 - 1.2 | 3.8 - 4.0 |
| 1.2 - 1.4 | 4.0 - 4.2 |
| 1.4 - 1.6 | 4.2 - 4.4 |
| 1.6 - 1.8 | 4.4 - 4.6 |
| 1.8 - 2.0 | 4.6 - 4.8 |
| 2.0 - 2.2 | 4.8 - 5.0 |
| 2.2 - 2.4 | 5.0 - 16.8 |

Figure 3

0 250 500 1,000 Meters

Scale = 1:7,500

N



r781 - 20 December 2010

# 3 Subsurface Investigations and Soil Profile

## 3.1 In Situ Test Programme

The in situ test programme consisted of nine machine boreholes, two in the existing left stopbank, two in the right stopbank, four down the proposed new left bank centreline and one in the dip behind the right bank at -40m. Hand augers and test pits were not used due to concern about finding water under pressure when being very close to sea level and in a predominantly sandy environment.

The boreholes through the stopbanks were used to determine the condition of the stopbank fills in addition to the underlying soils. The locations were chosen to try to investigate the different subsoils indicated by the LIDAR plot and are shown on Figure 1. Boreholes 3 and 8 were specifically located to investigate old stream channels. The boreholes, up to 12m deep, were drilled into the basement sands as deep as RL-8.8 to confirm the absence of any estuarine type deposits. The bore logs and photos are included in Appendix A with a summary table of the main layers found. The soils have been logged generally in accordance with the New Zealand Geotechnical Society Guidelines (December 2005).

The drilling was carried out by Perry Drilling Ltd of Tauranga. There was core loss in the predominantly sandy soils. Some SPT testing was carried out to obtain soil samples where there were continuous losses and to gain an appreciation of the sand density.

## 3.2 Stopbank Soil Profile

The stopbank fill was found to be mainly silt and sandy silt, with some silty sand layers. Overall the soils in the stopbanks are considered to be much better than found elsewhere along Reids Canal and suitable for reuse where required. A thin fine to medium sand layer was found at the base of the stopbank in BH1 at LB50m however this length of stopbank is to be removed. There may be some sand in the stopbank on the right bank between 300 and 360m. This should be investigated at the time of construction.

The interface between the stopbank soils and the natural ground has been defined by the presence of the natural surface silt. The interface was not always clear due to some mixing between layers.

## 3.3 In Situ Soil Profile

The natural soil profile typically consists of surface low permeability layers of silt, clayey silt and peat overlying sand with gradings varying from fine to coarse. Some thin sand layers, mainly Tarawera Ash, were found within the upper low permeability layers. The overall thickness of the upper layers varied from 0.4m in BH5 to 2.3m in BH8. In BH5, in the lowest part of the

basin, 1m of medium to coarse sand was found between layers of silt and peat. The soils here were similar to those found in BH6 which showed 1m more silt at the surface due to being on the edge of an old stream levee about 1m higher in elevation.

The thick silt layers found in BH8 could be due to the removal of sand in the old stream channel and the deposition of silt when stream flow was slowed or stopped.

The surface of the basement sand layers was found to vary between RL 0.2 in the end of a sand dune (BH2) and RL-2.0 (BH8) in the old stream channel.

### 3.4 Testing

Falling head in situ permeability tests were carried out in sand layers in five of the boreholes. The results are reasonably consistent with those from tests carried out in Stage 2 and along the river bank near Thornton School. The results are given in Table 1.

**Table 1:** In situ permeability test results

| BH | depth | soil | $k_h/k_v$ | $k_h$ |
|---|---|---|---|---|
| 1 | 3-4.5m | banded medium and coarse sand | 2 | $8 \times 10^{-5}$m/s |
| 3 | 2.5-3.0m | medium sand | 1 | $2 \times 10^{-4}$m/s |
| 4 | 4.0-4.5m | fine to medium sand | 1 | $4 \times 10^{-5}$m/s |
| 6 | 3.0-4.5m | fine to medium sand | 1 | $4 \times 10^{-5}$m/s |
| 9 | 3.2-3.3m | medium to coarse sand | 1 | $6 \times 10^{-5}$m/s |

Particle grading tests were carried out on four sand samples to assist with the estimation of permeabilities. The test results are included in Appendix B.

**Table 2:** Particle grading test results

| BH | depth | soil | $D_{10}$ (mm) | $D_{60}$ (mm) |
|---|---|---|---|---|
| 1 | 4.2m | fine to medium sand | 0.16 | 0.37 |
| 1 | 5.0m | medium sand | 0.17 | 0.40 |
| 5 | 0.5m | medium to coarse sand | 0.63 | 0.40 |
| 8 | 5.5m | medium to coarse sand | 0.18 | 0.42 |

# 4 Analysis Method

## 4.1 Discussion

The in situ investigations carried out provide subsoil profiles at isolated locations only. An effort has been made to build a degree of conservatism into the analysis of the stopbank cross sections discussed in the following sections; however the subsurface investigations show reasonable variation in the soil layers above the basement sands. It is therefore possible that in terms of the seepage response to a flood in the canal there are worse combinations of soil layers than those assumed.

The computer programme used to analyse the seepage through and under the stopbanks, Geo-Slope Seep/W (2012), is a two dimensional programme; therefore three dimensional effects such as seepage parallel to the canal or down old stream paths, cannot be accurately modelled. The seepage analyses carried out must therefore be considered indicative only.

Five possible problems could arise due to a flood in the canal:

- Excessive flows under the stopbank.
- The removal of soil particles due to high hydraulic gradients through or beneath the stopbank, resulting in piping and collapse of the stopbank.
- Heave of upper soil layers due to high water pressures developing beneath them; leading to the exposure of high permeability soils, rapid piping and stopbank collapse.
- Failure of either face of the stopbank due to high water level or draw down conditions.
- Over-topping of the stopbank causing rapid erosion of the stopbank.

The first four problems are addressed in this report.

The maximum hydraulic exit gradient considered acceptable with the light soils in this area is 0.4 (based on a critical gradient of 0.7). After a surface low permeability layer has been lifted and cracked, the concentration of flow in a small area means that average hydraulic gradients calculated from a 2D analysis as low as 0.1 could allow pipe formation to develop. The risk of piping can be reduced by preventing heave with the addition of overlays, by lengthening the seepage path, or by installing a drain in the area susceptible to piping to allow flow to the ground surface without the removal of soil particles.

There are considerable heave problems along this section of canal and it is considered that stopbank security in the design flood cannot be guaranteed without excessive expenditure. There are only a few structures at risk if the stopbank fails as flood waters will largely be contained by the natural

topography and the road formations. The remedial measures have therefore been designed to achieve a minimum factor of safety against heave just above 1.0 on the basis of the soil profiles identified in the investigations and conservative permeability assumptions.

The computer models allow seepage from the ground surface behind the stopbank as seepage of only small volumes of water from the ground surface can significantly reduce the uplift pressures acting on a low permeability surface layer.

Seepage analyses have been carried out on six cross sections at the test locations along the left stopbank and three cross sections along the right stopbank. Table 5, in Section 5.10, summarises the measures recommended to achieve a level of protection against stopbank failure due to heave and piping. The recommended remedial measures are also shown marked up on Figure 1.

## 4.2 Flood Hydrograph

Opus International Consultants Ltd (14 July 2011) has provided a hydrograph for the canal based on the following;

- a 100 year return period flood in the Rangitaiki River,
- a 20 year return period storm surge at the river mouth,
- high tide at the river mouth and
- an estimated 500mm sea level rise to 2090.

Figure 4 shows the seven day long hydrograph developed for the canal. In the analyses the hydrograph was adjusted to give 300mm freeboard at each cross section along the canal.

The initial water level in the canal was assumed to be RL0.5 (approximately half tide) and that inland RL-1.0, due to the water level being kept down by pumping.

In addition to transient flood analyses, further analyses were carried out to check how much flow there would be from a drainage system due to normal tidal fluctuations in water level in the canal. Figure 5 shows the average tide cycle assumed.

## 4.3 Soil Model

The soil layers found in the in situ investigations were simplified to form seepage analysis models for each of the stopbank cross sections. These are discussed in following sections and are shown in Appendix C.

Table 3 summarises the soils used and the permeabilities assumed. The permeabilities were based on the falling head and particle grading tests carried out within this and the Stage 2 area of the Rangitaiki Plains (Reference 3).

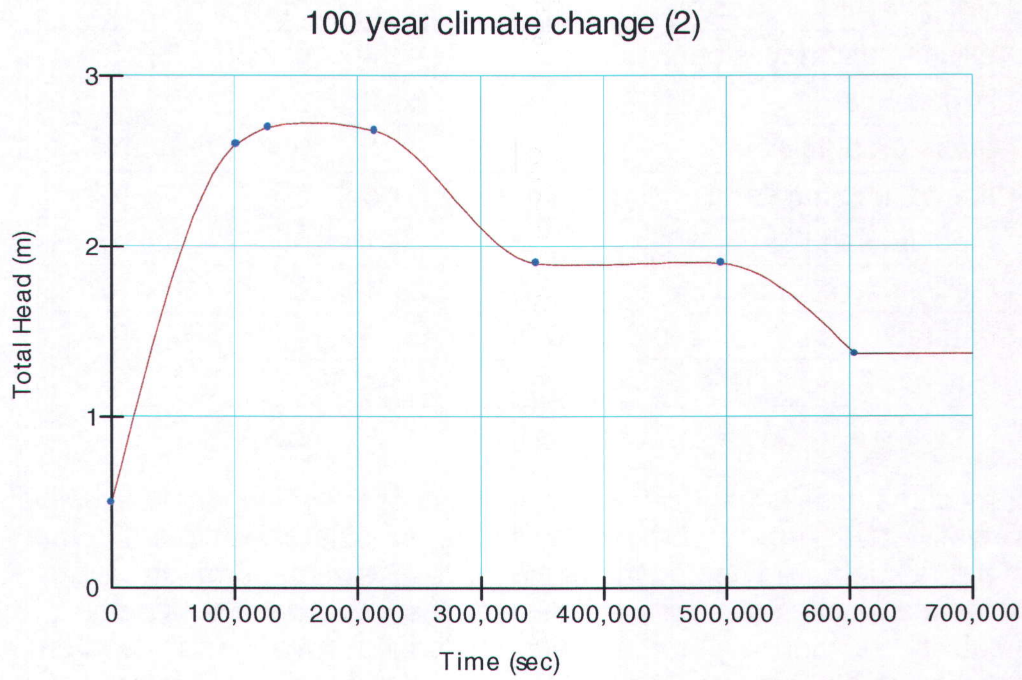



**Figure 4:** 100 year return period flood flow hydrograph

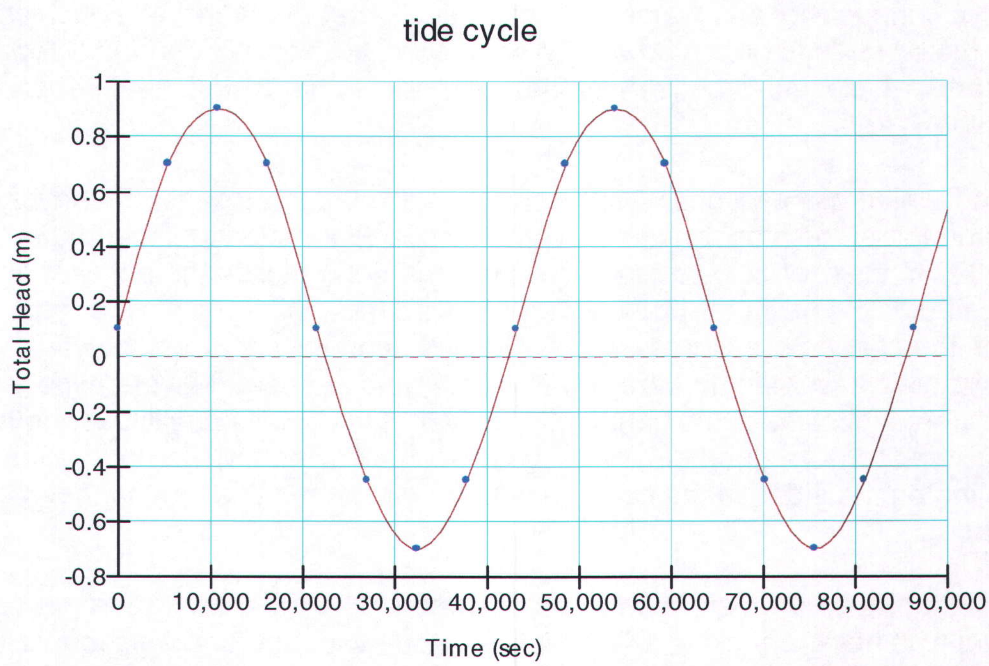



**Figure 5:** Average tide cycle

**Table 3:** Assumed soil permeabilities

| **soil** | $k_h$ (m/s) | $k_v$ (m/s) |
|---|---|---|
| existing and new stopbank fill | $4 \times 10^{-6}$ | $2 \times 10^{-6}$ |
| surface silt | $2 \times 10^{-7}$ | $2 \times 10^{-7}$ |
| peat / organic clay | $5 \times 10^{-8}$ | $5 \times 10^{-8}$ |
| fine to medium sand | $5 \times 10^{-5}$ | $5 \times 10^{-5}$ |
| medium sand | $1 \times 10^{-4}$ | $1 \times 10^{-4}$ |
| medium to coarse sand | $1 \times 10^{-4}$ | $1 \times 10^{-4}$ |
| banded medium to coarse sand | $2 \times 10^{-4}$ | $1 \times 10^{-4}$ |
| silty fine sand | $4 \times 10^{-6}$ | $4 \times 10^{-6}$ |

In terms of the assessment of the risk of heave of the soil upper layers, it is conservative to assume a permeability on the low side of that found from tests on the upper silts and on the high side for the more permeable sand layers beneath acting as aquifers. The relationship between horizontal permeability and vertical permeability for the various layers was based on observation of the core from the boreholes. It was assumed that the stopbanks would be made from sandy silt / silty sand and the compaction process would cause a greater horizontal permeability than vertical.

The Geo-Slope Seep/W (2012) computer package used for the seepage analyses contains a library of soil grading curves, with corresponding hydraulic conductivity and water content versus water pressure relationships. The particle gradings observed on site were compared to those in the Seep library and the closest fit chosen as the soil model to be used in the seepage analyses.

The stopbank cross sections were generally modelled to at least 50m beyond the inland toe of the stopbank to prevent any boundary effects on seepage patterns. An initial steady state analysis was carried out with the canal at an average height. The water pressures generated from this model were then used as the starting pressures for the transient flood flow analysis. It was conservatively assumed that there was no silt lying over sand layers exposed in the sides and invert of the canal. It is likely that there will be silt covering the invert at the start of a flood but it may be eroded away during the flood. The rock lining on the sides of the canal may help trap silt but this has not been relied upon.

The weight of the upper silt layers was assumed to be 15 kN/m$^3$ when heave potential was being checked; 14kN/m$^3$ has been assumed for pumiceous silt, 13kN/m$^3$ for pumiceous sand and 10.5kN/m$^3$ for peat.

Water is likely to pond in the low lying basin in a large storm. This water would reduce the head difference and relative seepage pressures across the

stopbanks in this area. Ponded water has not been allowed for in the analyses discussed below.

### 4.4 Drainage Wick Model

Pressure relief is needed along the stopbanks in all the areas where the inland ground level is below RL1.9 as the surface soils are light and there are high permeability sand layers close to the surface. Along about two thirds of the study length there is a positive pressure gradient from the canal into the low lying ground beyond the stopbanks under normal conditions, therefore the installation of conventional pressure relief trenches or wells would be very difficult.

As an alternative to conventional pressure relief systems it is proposed to use the vertical drainage wicks which were recommended for Stages 2 and 4 upstream (References 3 and 4). Drainage wicks can be installed without any excavation and consequent hole collapse or piping problems. These wicks are usually used to accelerate consolidation of soft layers by providing a horizontal drainage path and allowing excess water to flow relatively unimpeded to the ground surface. The design of the wick system usually allows the consolidation to take place over months, instead of the years required without them. Similar vertical drains can be used to relieve water pressures in an earthquake and prevent liquefaction. These drains are usually closely spaced and have a very high vertical flow capacity. The pressure relief system required during a flood needs permeability characteristics between that for consolidation acceleration and that for liquefaction prevention.

Kilometres of vertical drains have been installed for the Tauranga Eastern Link highway construction project. Local contractors are consequently geared up for their installation on a large scale by cranes or excavators. The length of the individual wicks required along sections of the canal can be installed with a 30 tonne excavator, making access along the stopbank and in the paddocks relatively easy.

The type of vertical wick drain that has been used on the Eastern Link is that made by Ceteau. It is has an inner ribbed plastic core wrapped in geotextile, producing outside dimensions of 100mm by 3mm. Details are given in Reference 3. As the wick is underground and away from UV light it has an indefinite life. The flow capacity of this wick is $6 \times 10^{-5}$ $m^3/s$ at a hydraulic gradient of 0.1, allowing for some kinks in the wick as the ground settles in a consolidation situation. If flow from the wick is unimpeded at the ground surface the vertical hydraulic gradient from a sand layer at depth would be 1, or more in a pressure relief situation.

Trials of seepage models were carried out varying the spacing of the wick drains to achieve an upwards flow capacity similar to a gravel filled trench. The result was two rows of wicks 650mm apart, with the wicks offset in each row 750mm apart. This produces a triangular grid of wicks at 750mm centres.

Calculations showing how the drainage system is modelled as a seepage element are included in Appendix D. If the wicks intercept a layer of fine sand with a permeability of 5 x $10^{-5}$m/s the equivalent vertical permeability of a 1m wide soil element is 1.6 x $10^{-3}$m/s, similar to a gravel filled trench. The horizontal permeability of the element is determined by the width of the element (how far water has to travel to get to a wick drain). An allowance was made for 3mm of smeared clay or peat on the surface of the wick after it is pushed through the overlying soil layers. In reality this smeared soil will probably be scraped off as the tip of the wick is pushed into the sand. For a 1m wide element in fine sand the resulting horizontal permeability is 7 x $10^{-6}$ m/s. The Seep/W programme requires the definition of vertical to horizontal permeability, which for this case is 224. Standard 1m wide drainage regions with these properties were used in the seepage analyses.

The same soil permeabilities were assumed up the wick to the ground surface even though the wick passes through different soils, usually with lower permeabilities than at the tip of the wick. This is considered acceptable as the calculation of the vertical element permeability makes no allowance for the permeability of the soil containing the wick. The horizontal permeability of the wick elements will be higher than that of most of the soils through which the wick passes, but this is considered acceptable as there is minimal horizontal flow in these soil layers compared to that in the sand layer being targeted. Different wick parameters could be set in each soil layer but this is considered unduly complex.

It is proposed that the water from the wick drains will flow into a 1.5m wide, geotextile wrapped trench filled with clean gravel containing two novaflo pipes with outlets into the paddocks at approximate 30m intervals (Figure 6).

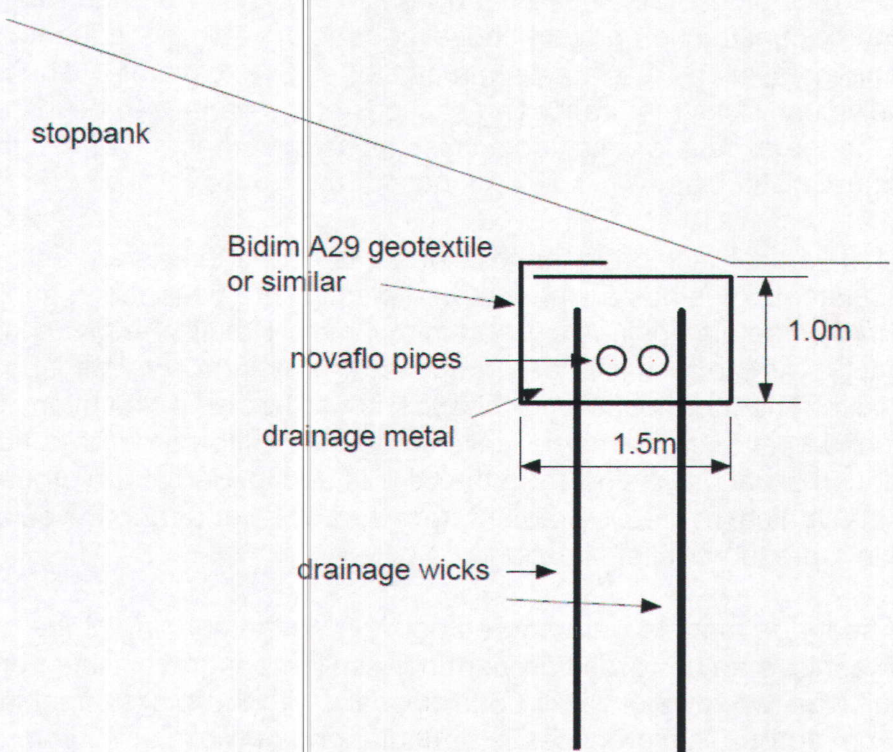



**Figure 6:** Drainage wick collector trench

## 4.5 Alternative Mitigation Measures

The stopbank along the Rangitaiki River adjacent to this section of Reids Canal has not yet been assessed for its security but it is expected that there will be significant heave and piping problems. The situation is complicated by the presence of effluent ponds and rubbish pits. Between this section of Reids Canal and the Rangitaiki River there are only three houses, a community hall and some farm buildings. The LIDAR plot shows that these buildings are all on ground above RL2.0 and could be protected from a flood by small bunds around them built to RL3.0. These low bunds, with a maximum head across them of only 0.7m, are unlikely to have any significant seepage problems.

The LIDAR plot also shows that the Thornton Road is above RL2.3. A small bund could therefore be built along the northern side of the road so that if the stopbank fails on the left side of the canal or along the river, the floodwaters could be ponded in this triangular area without major damage to structures. The local farmers could be warned when a significant flood is expected so that stock can be shifted to high ground. Stoplogs would need to be fitted to a cattle pass under the road to prevent water flowing upstream.

If the risk of stopbank failure is accepted and the precautions discussed above are undertaken, the drainage wicks and overlays along the left side of the canal discussed in the following sections and other work along the river would not be required.

# 5 Seepage Analysis Results

## 5.1 Left Bank 50m

At 50m the left stopbank will be 2.2m above the natural ground surface at RL0.8. On the basis of the BH1 results it has been assumed that there is 0.8m of silt overlying a medium to coarse grained sand.

A transient analysis of the 100 year flood in the canal showed that there could be sufficient uplift pressure under the surface silt layer to lift it and hydraulic exit gradients at the inland toe of the stopbank high enough to cause piping. The introduction of drainage wicks down to RL-0.6 in the model produced a sufficient drop in uplift pressure to provide a small factor of safety against surface heave and to reduce hydraulic gradients to less than 0.4.The estimated flow from the drainage system over a seven day flood is 37m$^3$/m length.

The tide cycle shown in Figure 5 was run through the seepage model seven times to allow water levels within the model to adjust to the daily fluctuations. As the ground level is at RL0.8 there was no flow from the drain.

## 5.2 Left Bank 230m

At 230m the stopbank will be on the end of a sand dune and the ground level at RL1.3 is higher than just upstream and downstream. 1.1m of silt and organic material was found over 2.3m of fine to medium sand then medium to coarse sand. It was found in the transient flood flow analysis that drainage wicks down to RL-2.2 were required to prevent heave and piping problems.

The estimated flow from the drainage system over the seven day flood is 17m$^3$/m. The reduction in flow from the drainage system compared to that at the LB50 cross section is due to the higher ground level at the toe of the stopbank. As the ground level is above high tide level there would be no flow from the drains on a daily basis.

## 5.3 Left Bank 500m

The borehole at 500m (BH3) was in an old stream path evident as depression about 500mm deep. The basement sand was found at RL-0.4, only 0.6m below the ground surface and 0.6 to 1.6m above the basement sand level found in other boreholes in this part of the basin. The possibility of there being preferential seepage paths under stopbanks along old stream paths was therefore confirmed.

The transient flood flow analyses carried out showed that to provide some stopbank security, in addition to drainage wicks to RL-2.3, a 50m wide overlay was required to fill in the depression to RL0.6. The flow from the wick drainage system over the seven day flood was estimated at 36m$^3$ / m length of drain. As the top of the drainage system is at RL0.6 daily flows of 105 litres are expected due to tidal fluctuations in the canal.

## 5.4 Left Bank 650m

The ground level at 650m is only RL0.2. The head across the stopbank at peak flood will be 2.6m. It was difficult to determine the natural ground level in BH4, through the existing stopbank, due to some mixing of the soils. It has been estimated that there is about 0.7m of low permeability soils overlying the basements sands at the new stopbank location.

A flood flow seepage analysis with drainage wicks to RL-2.0 showed that the factor of safety against heave would be marginal and there could be 560 litres/m flow from the drains each day. The addition of a 50m wide overlay to RL0.6m reduces the daily flow from the wicks to 100 litres/m and the risk of uplift near the stopbank. At the end of the overlay however the factor of safety against heave remains marginal.

Another flood flow seepage analysis was carried out assuming that a hole had been created at the end of the overlay due to heave of the upper soil layers. The hydraulic gradients in the exposed sand layer beneath the hole were high enough to allow piping when the concentration of flow at a hole is considered. A second drainage system is probably the only realistic option to decrease the

risk of piping as the high permeability sand results in a very small reduction in water pressure with distance from the canal. It is considered that the thickness of the upper soils in this location be confirmed to determine if another drainage system is required.

## 5.5 Left Bank 720m

BH5 at 720m was in the lowest part of the basin at RL0.2. The same layers of organic and pumiceous silt were found at the ground surface as at BH3 but they are only 0.4m thick, compared to 0.6m in the old stream channel. The surface silts are underlain by 1m of medium to coarse sand and then another 0.2m thick silt sequence above the basement sands.

A transient seepage analysis showed that both silt sequences could be uplifted by high seepage pressures. The introduction of drainage wicks to RL-1.9 in the basement sand layer in the model provided a marginal factor of safety against heave of the lower silt layers but an insufficient drop in pressure under the upper layers. The addition of a 50m wide, 0.3m thick overlay provided adequate uplift protection in the overlay area but only marginal heave protection of the upper silt layer beyond it. Another analysis was carried out with a hole in the upper silt layer. The maximum hydraulic gradient in the sand layer at the hole was found to be 0.04. Allowing for three dimensional effects the gradient could be about 0.16, there is therefore a low risk of piping developing. As for the section at 650m, investigations should be carried out to confirm the thickness of the upper silt layer and whether further remedial measures are required.

The expected flow from the drainage system over a seven day flood is 33$m^3$/m and due to tidal fluctuations, 170 litres /m.

## 5.6 Left Bank 850m

This cross section is on the lower part of an old stream levee and the ground level is RL1.1. The intermediate sand layer found in BH5 at 720m was also found in BH6; however it is only 0.4m thick and is beneath 1.4m of surface silts. It is underlain by 0.9m of silt, clay and peat. Transient flood flow analyses showed that drainage wicks to RL-1.6 are required to prevent uplift of the low permeability layers. The flood flow from the drainage system was estimated at 19$m^3$/m.

## 5.7 Right Bank -40m

This cross section is downstream of the bridge on East Bank Road. As discussed in Section 2 there is a low basin here and the ground behind the stopbank appears to be salty. Only 0.6m of peat and silt was found above sand in BH7. The static seepage analysis with the canal at a typical level showed that there would be seepage at the inland stopbank toe under normal conditions.

The transient flood low analyses showed that drainage wicks down to RL-2.7 plus an overlay to RL 0.7 are required across the basin to provide a small factor of safety against heave and piping problems. The flood flow from the drains was estimated at $31m^3/m$ and the tidal flow 45 litres /m / day.

It can be seen from Figures 1 and 3 that there are no buildings in this basin and it is bounded by ground above the flood level to east and by the Rangitaiki River Stopbank and high ground to the north; therefore this length of stopbank could be left to fail provided the farm access track to the south is lifted by about 1.5m. Lifting the level of the farm track is likely to be less expensive that the drainage and overlay work.

## 5.8 Right Bank 440m

As discussed in Section 3 this section is through an old stream channel where the ground level (RL0.2) is 0.4 to 0.5m lower than the adjacent ground and the surface silt is quite thick (2.3m). A transient seepage analysis showed that drainage wicks to RL-2.7 would be sufficient to provide adequate protection against heave and piping; however as the thick silt layer could be quite localised it is recommended that the depression be filled to RL0.6 to 50m from the landside toe of the stopbank.

## 5.9 Right Bank 820m

The cross section at 820m is at the edge of a stream levee and the ground level is at RL0.4. The basement sands are at RL-1.1 but there is a 0.1m thick sand layer at RL-0.5 within a complex layering of peat and clayey silt. Various transient seepage analyses were carried out to derive a system to provide stopbank security. This system consists of drainage wicks to RL-2.0 and an overlay to RL0.6. The flood flow from the drainage system was estimated at $20m^3/m$ and the daily tidal flow 110 litres /m.

## 5.10 Seepage Analysis Summary

Table 4 summarises the remedial measures derived at each cross section analysed along the left and right stopbanks and the flows from the drainage system. The estimated total flows from the drainage system are:

- left bank flood flows — $26{,}000m^3$ over 7 days
- right bank flood flows — $16{,}000m^3$ over 7 days (not including the basin at -40m)

- left bank tidal flows — $70m^3$/day
- right bank tidal flows — $90m^3$/day

**Table 4:** Cross section analysis summary

| BH | Meterage | **ground level** (RL) | **overlay thickness** (m) | **overlay width** (m) | **wick tip** (RL) | **total flood flow** ($m^3/m$) | **tidal flow** (litres/m/day) |
|---|---|---|---|---|---|---|---|
| 1 | LB50 | 0.8 | | | -0.6 | 31.8 | 0 |
| 2 | LB230 | 1.3 | | | -2.2 | 17.2 | 0 |
| 3 | LB500 | 0.2 | 0.4 | 50 (dip) | -2.3 | 35.5 | 105 |
| 4 | LB650 | 0.3 | 0.3 | 50 | -2.0 | 39.6 | 560 |
| 5 | LB720 | 0.2 | 0.3 | 50 | -1.4 | 33.2 | 171 |
| 6 | LB850 | 1.1 | | | -1.6 | 19.4 | 0 |
| 7 | RB-40 | 0.2 | 0.5 | (basin) | -2.5 | 31.3 | 43 |
| 8 | RB440 | 0.3 | | | -2.7 | 32.8 | 420 |
| 9 | RB820 | 0.4 | 0.2 | 50 | -2.0 | 19.7 | 108 |

Table 5 summarises the recommended remedial measures along each stopbank. These are also shown marked up on Figure 1. It is considered that drainage wicks are required wherever the ground level is below RL1.9. Wherever the ground level is below RL0.6 and the depth to the sand is less than 1.2m, a 50m wide overlay to RL0.6 is required.

**Table 5:** Recommended remedial measures

| **Meterage** | **wick depth below ground level (m)** | **overlay width (m) (overlays to RL0.6)** |
|---|---|---|
| **left bank*** | | |
| 0 to150 | 2.0 | |
| 150 to 350 | 3.5 | |
| 350 to 800 | 3.0 | 50 |
| 800 to 940 | 3.0 | |
| | | |
| **right bank** | | |
| -50 to -20** | 3.0 | (basin) |
| 0 to 100 | 3.5 | |
| 150 to 350 | 3.5 | |
| 350 to 850 | 3.0 | 50 |
| 850 to 950 | 3.0 | |

*as discussed in Section 4.5 left bank remediation could be omitted and localised structure protection carried out.

** as discussed in Section 5.7 the farm access track could be lifted instead of carrying out this remediation work.

## 5.11 Side Drains and Pump Stations

Piping problems could develop where seepage from sand layers exposed in the sides of the drains is concentrated towards the end of the drains. It is considered that the hydraulic seepage gradients should be below 0.1 in the unprotected sides of drains to reduce the risk of piping. Planar seepage analyses were carried out on the sand layers that could be exposed in the sides of the drains to model the concentration of flow at the ends of the drains. It is considered that all the drains approaching the toe of both stopbanks should be lined with geotextile and rock along an 8m length nearest the stopbank.

There could be heave problems in the invert of drains where there is a thin low permeability layer in the invert of the drain. The only drain where this is likely to be a problem is that on the right bank at 450m. The uplift pressure beneath the invert was assessed assuming that the drain inverts are at RL-1.5. It was found that 8m of the drain nearest the stopbank needs to be lined with geotextile and rock to prevent heave causing piping problems. Therefore 8m of all of the drains should be lined. 300mm of rock should be placed on geotextile along the invert, tapering up the sides of the drains.

## 6.0 Stopbank Stability

Slope stability analyses have been carried out on the stopbank cross sections which had the greatest thickness of weak soils in the foundations. The left bank cross section at 650m and the right bank cross section at 450m were analysed. The soil models and strength parameters assumed are shown in Appendix E.

Stability analyses were carried out with the canal at an average level of RL0.5, for peak flood flow conditions and rapid drawdown conditions. Both the inland and canal sides of the stopbanks were considered. The pore water pressures used in the analyses were taken directly from the seepage analyses. The steepest drawdown conditions occur about 3 days into the flood.

The analyses with the canal at an average level showed a factor of safety of about 1.5 for the berm along the incised channel. No allowance was made for the rock lining along the canal, which will have a stabilising effect. The factor of safety of the stopbanks under these conditions is above 2.0.

The factor of safety of the canal side of the stopbanks is greater than 3.0 for both the peak flood conditions and the drawdown conditions.

The lowest stopbank factor of safety found was on the inland face 6 days into the flood when seepage has progressed through the stopbank. At LB650m the factor of safety was 2.0 and at RB450, 1.7. These factors of safety are all considered acceptable.

## 7.0 Stopbank Settlements

The new and upgraded stopbanks will undergo settlement due to the addition of load onto the soils below. The amount of settlement is dependent on the applied load and the nature of the soils. The thickness of compressible soil under the stopbanks along this section of the canal is less than in most of the areas previously assessed.

Due to the compressible layers being thin and underlain by high permeability sand, it is considered that about 80% of the total settlement will occur during construction. Table 6 gives the estimated total and post construction settlement. The settlement values given in the second column of Table 6 should be used when estimating the total volume of earthworks required and the value in the third column be used to adjust the design level of the stopbank crest at the end of construction to allow for on-going settlement.

**Table 6:** Estimated settlements

| meterage | estimated total settlement (mm) | estimated post construction settlement (mm) |
|---|---|---|
| **Left bank** | | |
| 0 to 450m | 100 | 20 |
| 450 to 950m | 200 | 40 |
| **Right bank** | | |
| start - 950m | minimal | - |

## 8.0 Stopbank Fill Availability

It is considered that all the soil in the existing left stopbank is suitable for mixing and re-using in the construction of the new stopbank except perhaps for some organic material in the stopbank at 650m.

**Table 7:** Estimated available fill thickness

| Left bank meterage | ground level (RL) | base of suitable soil (RL) |
|---|---|---|
| 50 | 0.8 | -0.9 |
| 230 | 1.3 | 0.2 |
| 500 | 0.2 | -0.3 |
| 650 | 0.3 | -0.5 (peat below this) |
| 720 | 0.2 | -0.2 |
| 850 | 1.1 | -0.3 (organics below) |

Most of the soil cut from the new channel will be sand, not suitable for stopbank construction; it could however be used in overlays with a topsoil cover. Consideration should be given to trying to place soil with some cohesion over the sand exposed in the top of the canal cut. Rock erosion protection will be required below permanent (or tidal) water level. The thickness of silty soil suitable for fill or spreading over the sand varies as is shown in Table 7.

## 9 Conclusions

1. The geology along this section of Reids Canal includes peat swamp, stream levees and sand dunes.

2. A system of drainage wicks and overlays is required along both sides of the canal to improve the security of the stopbanks.

3. It is considered that further investigations are required before or during construction to confirm the presence of a sandy layer in the right stopbank between 300 and 350 and to determine the thickness of the surface silts on the left bank between 600 and 800m.

4. It is considered that if the farm track on the right bank at 0m is lifted no remedial work is required on the right bank further downstream.

5. Significant flows are expected from the drainage system due to daily tidal fluctuations in the canal.

6. Large flows are expected from the drainage system during the design 100 year return period flood.

7. An alternative to installing a drainage system and overlays along the left bank is to build small flood protection bunds around the houses and along the highway.

8. Small post construction settlements of the stopbanks are expected.

9. Most of the existing left stopbank soils are suitable for re-use in the new stopbank.

10. Rock lining will be required along the nearby drains to reduce the risk of piping and heave in flood conditions.

**M. O'Halloran** 18 June 2013
BE, PhD, Dip BA, MIPENZ (Geotechnical), CPEng IntPE

## References

1. Ice Geo and Civil (Oct. 2009) Reids Canal left bank upgrading, Geotechnical Assessment.

2. Ice Geo and Civil Ltd (Aug. 2011) Geotechnical assessment of Reids Canal Floodway widening, left bank 2950m to 3650m, right bank 2550m to 3390m.

3. Ice Geo and Civil Ltd (Oct. 2012) Reids Canal floodway widening (1050m to 2900m), Geotechnical Assessment.

4. Ice Geo and Civil Ltd (May 2013) Reids Canal floodway upgrading Stage 4 (3650m to 7000m), Geotechnical Assessment.

5. Redaelli, M. (2012) Reliability of flood embankments; a new methodology, ICE Journal of Geotechnical Engineering, Vol. 165, GE3.

**Reids Canal Stage 3 Borehole Summary (in terms of permeability) (RL m)**

| **Test** | **BH1** | **BH2** | **BH3** | **BH4** | **BH5** | **BH6** | **BH7** | **BH8** | **BH9** |
|---|---|---|---|---|---|---|---|---|---|
| Soil \ meterage | 50LB | 230LB | 500LB | 650LB | 720LB | 850LB | -40RB | 440RB | 820RB |
| **stopbank soils** | | | | | | | | | |
| gravel | | | | | | | | | 2.7 |
| silty sand and silt | 2.2 | | | 2.5 | | | | 2.7 | 2.1 |
| **fine to medium sand** | **0.0** | | | | | | | | |
| | | | | | | | | | |
| **natural soils** | | | | | | | | | |
| silt | -0.2 | 1.3 | 0.2 | | 0.2 | 1.1 | | | |
| sandy silt/ silty fine sand | | 1.2 | | | | | | | 0.6 |
| peat | | | | | | | 0.2 | | |
| clayey silt | | 0.75 | | | | | | | 0.4 |
| organic clay / clayey silt | | | 0.1 | 1.0 ? | | | | 0.4 | 0.35 |
| **medium sand** | | | | **0.4?** | | | | | |
| sandy silt | | | | 0.35 | | | | | |
| pumiceous silt | | 0.5 | -0.25 | -0.25 | 0.0 | | -0.1 | 0.0 | -0.2 |
| **medium to coarse sand** | | | | | **-0.25** | -0.3 | | **-0.15** | **-0.5** |
| organic clay / peat | | | | -0.5 | | | | -0.2 | |
| pumiceous silt | -0.8 | | | -0.8 | -1.2 | -0.7 | | -1.1 | |
| organic clay / peat | | | | | -1.3 | -0.8 | | | -0.6 |
| **fine to medium sand** | | **0.2** | | | **-1.45** | **-1.6** | **-0.4** | **-2.0** | |
| **medium sand** | | | **-0.4** | | | | | | |
| **medium to coarse sand** | **-0.95** | **-2.2** | | **-1.0** | | | | **-2.7** | **-1.1** |
| **fine to medium sand** | **-1.3** | | | **-1.1** | | | | | **-1.5** |
| **medium sand** | **-2.3** | | | **-2.0** | **-1.9** | **-2.7** | **-2.5** | | |
| | | | | | | | | | |
| **base RL(m)** | **-8.8** | **-2.7** | **-4.3** | **-8.5** | **-4.3** | **-3.4** | **-2.8** | **-6.0** | **-4.1** |

Bold layers have high permeability

# Bore Hole Log

## Borehole: BH1

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940535 North 5796206
Elevation: 2.2 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|
| 0.00 | | | **SILT**, trace sand, brown, stiff, dry | | | | | |
| | 1.90 | | **silty fine to medium SAND**, brown, dense, dry | | | | | |
| 0.50 | 1.60 | 100 | **SILT**, grey mottled, stiff | | | | | |
| | 1.30 | | **silty fine to medium SAND**, brown, dense, dry | | | | | |
| 1.00 | 1.25 | | **SILT**, grey mottled, stiff | | | 4 | | |
| | 1.05 | | **silty fine to medium SAND**, brown, dense, dry | | | 4 4 3 4 4 | | |
| | 0.95 | | **sandy SILT**, dark brown with grey inclusions, hard, dry | | | 15 | | |
| 1.50 | | | | | | | | |
| 2.00 | 0.00 | 100 | **fine to medium SAND**, some silt, brown, moderately dense | | | | | |
| | -0.20 | | **SILT**, some sand and organic material, mottled grey and dark brown, damp | | | | | |
| 2.50 | -0.45 | | **SILT**, grey, stiff, damp to moist | | | | | |
| 3.00 | -0.80 | | pumiceous **SILT**, some fine fibres, light brown / grey | | | | 29/14 | |
| | -0.95 | | pumice medium to coarse **SAND**, grey | | | | | |
| 3.50 | -1.30 | 50 | **banded medium SAND and fine to medium SAND** some silt, grey | | | | | |
| 4.00 | -1.90 | | organic material, dark brown | 4.2 | dis | | | |
| | -1.95 | | fine to medium **SAND**, dark brown / grey | | | | | |
| 4.50 | -2.30 | | medium **SAND**, grey | | | | | |
| 5.00 | | 45 | | 5 | dis | | | |
| 5.50 | | | | | | | | |
| 6.00 | | | | | | | | |
| 6.50 | | | | | | | | |

Observations:
drilling mud from 4.5m depth, wash drilled from 7.5m, falling head test 3 - 4.5m kh/kv=5 kh=7x10-5m/s

| | | |
|---|---|---|
| Vane no. 218<br>Core Dia. 68mm | Rig: Marooka<br>Contractor: Perry Tim | Date started: 12/03/2013<br>Date finished: 12/03/2013<br>Logged by: MO'H |

# Bore Hole Log

**Borehole: BH1**

ICE GEO & CIVIL

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940535 North 5796206
Elevation: 2.2 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 6.50 | | 30 | | | | | | | | |
| 7.00 | | | | | | | | | | |
| 7.50 | | | | | | | | | | |
| 8.00 | | 0 | | | | | | | | |
| 8.50 | | | | | | | | 3 4 5 6 7 25 | | |
| 9.00 | | | | | | | | | | |
| 9.50 | | 0 | | | | | | | | |
| 10.00 | | | | | | | | 4 5 6 10 13 40 | | |
| 10.50 | -8.30 | | | | medium **SAND**, some fine shell fragments, grey, beach | | | | | |
| 11.00 | -8.80 | | | | | | | | | |
| 11.50 | | | | | | | | | | |
| 12.00 | | | | | | | | | | |
| 12.50 | | | | | | | | | | |
| 13.00 | | | | | | | | | | |

Observations:
drilling mud from 4.5m depth, wash drilled from 7.5m, falling head test 3 - 4.5m kh/kv=5 kh=7x10-5m/s

| | | |
|---|---|---|
| Vane no. 218<br>Core Dia. 68mm | Rig: Marooka<br>Contractor: Perry Tim | Date started: 12/03/2013<br>Date finished: 12/03/2013<br>Logged by: MO'H |


Borehole 1

# Bore Hole Log

**Borehole: BH2**

ICE GEO & CIVIL

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940483 North 5796052
Elevation: 1.3 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 1.20 | | | | **sandy organic SILT**, dark brown | | | | | |
| | | | | | **fine sandy SILT / silty fine SAND**, grey, dry, dense | | | | | |
| 0.50 | 0.75 | | | | **clayey SILT**, grey with Fe staining, firm, moist | | | | | |
| | 0.55 | 100 | | | **organic CLAY**, black, soft, moist | | | | | |
| | 0.50 | | | | pumiceous **SILT**, light grey, stiff, damp | | | | | |
| 1.00 | 0.20 | | | | fine to medium **SAND**, grey, dense | | | | | |
| 1.50 | | | | | | | | | | |
| 2.00 | | 50 | | | | | | | | |
| 2.50 | | | | | | | | | | |
| 3.00 | | | | | | | | | | |
| 3.50 | -2.20 | 100 | | | medium to coarse **SAND**, grey, minor fine black sand | 3.5 | dis | | | |
| 4.00 | -2.70 | | | | EOB | | | | | |
| 4.50 | | | | | | | | | | |
| 5.00 | | | | | | | | | | |
| 5.50 | | | | | | | | | | |
| 6.00 | | | | | | | | | | |
| 6.50 | | | | | | | | | | |

Observations:
falling head test 2.5 - 3.0m kh=kv=2x10-4m/s

| | | |
|---|---|---|
| Vane no.<br>Core Dia. 68mm | Rig: Marooka<br>Contractor: Perry Tim | Date started: 13/03/2013<br>Date finished: 13/03/2013<br>Logged by: MO'H |


Borehole 2

# Bore Hole Log

**Borehole: BH3**

ICE GEO & CIVIL

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940426 North 5795978
Elevation: 0.2 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.15 | 100 | | | **organic SILT**, dark brown, firm, damp | | | | | |
| | 0.05 | | | | **SILT,** grey with Fe staining, stiff, damp | | | | | |
| | -0.25 | | | | **organic CLAY**, dark brown / black, soft, moist | | | | | |
| 0.50 | -0.35 | | | | pumiceous **SILT**, grey, firm to stiff, moist | | | | | |
| | -0.38 | | | | **organic CLAY**, brown, soft, spongy, moist | | | | | |
| 1.00 | | 10 | | | medium **SAND**, trace silt, grey, mod. dense | | | | | |
| 2.00 | | 45 | | | | | | | | |
| 3.00 | -2.80 | 0 | | | | | | | | |
| 4.50 | -4.30 | | | | EOB | | | | | |

Depth scale (m): 0.00, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50, 6.00, 6.50

Observations:
in depression about 500mm deep

Vane no.
Core Dia. 68mm

Rig: Marooka
Contractor: Perry Tim

Date started: 13/03/2013
Date finished: 13/03/2013
Logged by: MO'H


Borehole 3

# Bore Hole Log

**Borehole: BH4**

ICE GEO & CIVIL

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940419 North 5795645
Elevation: 2.5 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 2.40 | | | | **silty fine to medium SAND**, dark brown, dense | | | | | |
| | | | | | fine **sandy SILT**, brown, stiff, dry | | | | | |
| 0.50 | | 100 | | | | | | | | |
| | 1.70 | | | | **silty fine to medium SAND**, brown grey | | | | | |
| | 1.65 | | | | **SILT,** minor fine sand, grey with FE mottling, stiff, dry | | | | | |
| 1.00 | | | | | | | | | | |
| 1.50 | 1.05 | | | | **silty fine to medium SAND**, brown grey | | | | | |
| | 1.00 | | | | **organic clayey SILT**, dark brown, stiff, damp | | | | | |
| 2.00 | | | | | 2.0 soft to firm, moist | | | | | |
| | 0.40 | | | | fine to medium **SAND**, some silt, brown grey | | | | | |
| | 0.35 | 100 | | | fine **sandy SILT**, brown, some grey inclusions to 5mm, stiff, damp | | | | | |
| 2.50 | ▼ | | | | | | | | | |
| | -0.25 | | | | pumiceous **SILT**, light brown grey, stiff, damp | | | | | |
| 3.00 | -0.50 | | | | **organic CLAY / amorphous PEAT**(H6), firm, spongy, moist | | | | | |
| | -0.80 | 100 | | | pumiceous **SILT**, grey, firm to stiff, moist | | | | | |
| 3.50 | -1.00 | | | | medium to coarse **SAND**, grey | | | | | |
| | -1.10 | | | | fine to medium **SAND**, brown | | | | | |
| | -1.20 | | | | | | | | | |
| 4.00 | | 0 | | | | | | | | |
| 4.50 | -2.00 | | | | medium **SAND**, grey | | | | | |
| 5.00 | | | | | | | | | | |
| | | 40 | | | | | | | | |
| 5.50 | | | | | | | | | | |
| 6.00 | | | | | | | | | | |
| 6.50 | | | | | | | | | | |

Observations:
falling head test 4 - 4.5m kh = kv = 4x10-5m/s

Vane no.
Core Dia. 68mm

Rig: Marooka
Contractor: Perry Tim

Date started: 12/03/2013
Date finished: 12/03/2013
Logged by: MO'H

# Bore Hole Log

**Borehole: BH4**

ICE GEO & CIVIL

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940419 North 5795645
Elevation: 2.5 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 6.50 | | 40 | | | | | | | | |
| 7.00 | | | | | | 7 | dis | | | |
| 7.50 | -5.00 | | | | | | | | | |
| 8.00 | | 0 | | | | | | | | |
| 8.50 | | | | | | | | | | |
| 9.00 | | | | | | | | | | |
| 9.50 | | 0 | | | | | | | | |
| 10.00 | | | | | | | | 6 9 11 12 12 13 48 | | |
| 10.50 | -8.00 | | | | medium **SAND**, grey | | | | | |
| 11.00 | -8.50 | | | | | | | | | |
| 11.50 | | | | | | | | | | |
| 12.00 | | | | | | | | | | |
| 12.50 | | | | | | | | | | |
| 13.00 | | | | | | | | | | |

Observations:
falling head test 4 - 4.5m kh = kv = 4x10-5m/s

Vane no.
Core Dia. 68mm

Rig: Marooka
Contractor: Perry Tim

Date started: 12/03/2013
Date finished: 12/03/2013
Logged by: MO'H


Borehole 4

# Bore Hole Log

**Borehole: BH5**

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940373 North 5795553
Elevation: 0.2 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.15 | 100 | | | **organic SILT**, dark brown, firm, damp | | | | | |
| | 0.00 | | | | **SILT**, grey with Fe staining. stiff, damp | | | | | |
| | -0.25 | | | | pumiceous **SILT**, grey, firm to stiff, damp | | | | | |
| 0.50 | | | | | medium to coarse pumice **SAND**, grey | 0.5 | dis | | | |
| 1.00 | | 50 | | | | | | | | |
| | -1.20 | | | | pumiceous **SILT**, grey, firm to stiff, damp | | | | | |
| 1.50 | -1.30 | | | | **clayey SILT,** grey, soft, moist | | | | | |
| | -1.35 | | | | **organic CLAY**, brown, spongy, soft | | | | | |
| | -1.45 | | | | **SAND** fine to medium, trace silt, grey | | | | | |
| 2.00 | -1.90 | 75 | | | medium **SAND**, grey | | | | | |
| 2.50 | | | | | | | | | | |
| 3.00 | -2.80 | | | | | | | | | |
| 3.50 | | 0 | | | | | | | | |
| 4.00 | | | | | | | | | | |
| 4.50 | -4.30 | | | | EOB | | | | | |
| 5.00 | | | | | | | | | | |
| 5.50 | | | | | | | | | | |
| 6.00 | | | | | | | | | | |
| 6.50 | | | | | | | | | | |

Observations:

Vane no.
Core Dia. 68mm

Rig: Marooka
Contractor: Perry Tim

Date started: 13/03/2013
Date finished: 13/03/2013
Logged by: MO'H


Borehole 5

# Bore Hole Log

**Borehole: BH6**

ICE GEO & CIVIL

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940330 North 5795427
Elevation: 1.1 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 1.00 | | | | **SILT**, with organics, dark brown, firm | | | | | |
| | | 100 | | | **SILT**, grey with Fe staining, firm, damp | | | | | |
| | -0.10 | | | | **SILT**, varved, grey, stiff, damp | | | | | |
| | -0.30 | | | | medium to coarse **SAND**, grey | | | | | |
| | -0.70 | | | | **SILT**, green grey, soft, moist | | | | | |
| | -0.75 | | | | pumiceous **clayey SILT**, grey, firm, damp | | | | | |
| | -0.85 | 100 | | | fibrous **PEAT**, dark brown, (H3) soft, moist | | | | | |
| | -1.40 | | | | **organic CLAY**, brown, soft, spongy, moist | | | | | |
| | -1.60 | | | | coarse pumice **SAND**, grey | | | | | |
| | -1.65 | 100 | | | fine to medium pumice **SAND**, mod. dense | | | | | |
| | -2.70 | | | | medium **SAND**, grey | | | | | |
| | -3.40 | | | | EOB | | | | | |

Depth scale: 0.00, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50, 6.00, 6.50

Observations:
falling head test 3 - 4.5m kh=kv=4x10-5 m/s

Vane no.
Core Dia. 68mm

Rig: Marooka
Contractor: Perry Tim

Date started: 13/03/2013
Date finished: 13/03/2013
Logged by: MO'H


Borehole 6

# Bore Hole Log

**Borehole: BH7**

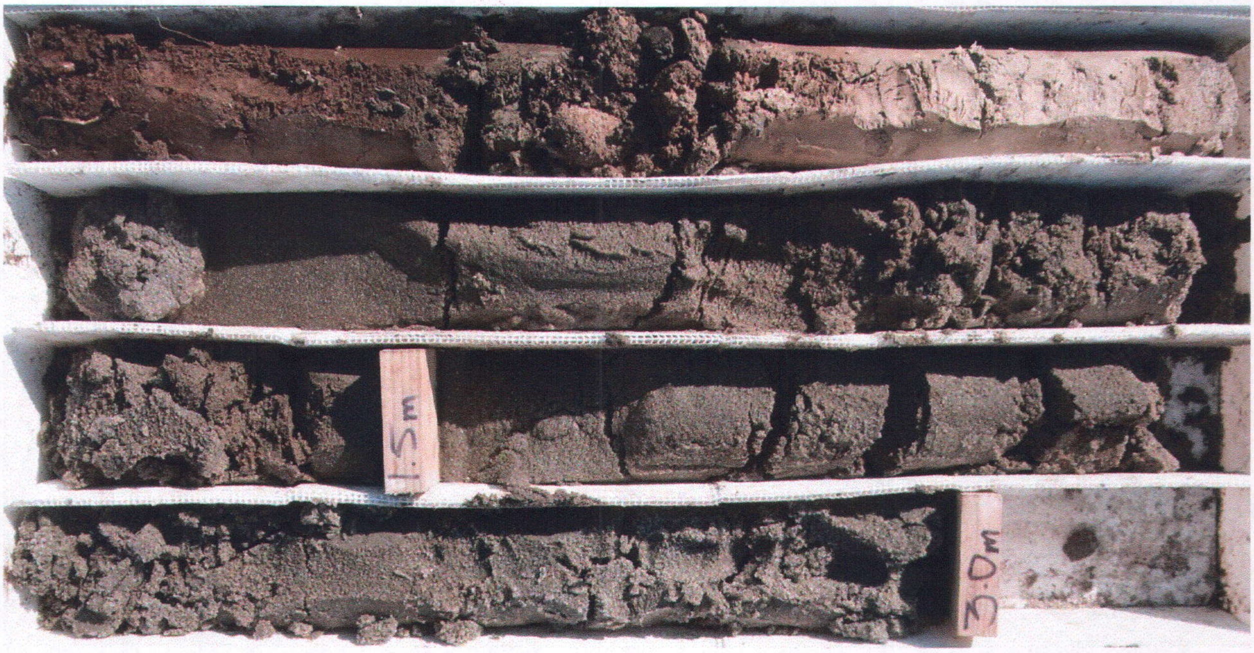
Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940636 North 5796308
Elevation: 0.2 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | | | | | **clayey fibrous PEAT**, dark brown, firm, moist | | | | | |
| | 0.00 | | | | **clayey SILT**, grey, firm, plastic, moist | | | | | |
| | -0.05 | | | | black charcoal and pumice gravel to 30mm | | | | | |
| | -0.10 | | | | **SILT**, light grey brown, firm, moist | | | | | |
| 0.50 | -0.40 | 100 | | | fine to medium **SAND**, rare shell fragments, grey | | | | | |
| 1.00 | | | | | | | | | | |
| | -1.10 | 0 | | | | | | | | |
| 1.50 | -1.30 | | | | fine to medium **SAND**, rare shell fragments, grey | | | | | |
| 2.00 | | 40 | | | | | | | | |
| 2.50 | -2.50 | | | | medium **SAND**, grey | | | | | |
| 3.00 | -2.80 | | | | EOB | | | | | |
| 3.50 | | | | | | | | | | |
| 4.00 | | | | | | | | | | |
| 4.50 | | | | | | | | | | |
| 5.00 | | | | | | | | | | |
| 5.50 | | | | | | | | | | |
| 6.00 | | | | | | | | | | |
| 6.50 | | | | | | | | | | |

Observations:

| | | |
|---|---|---|
| Vane no.<br>Core Dia. 68mm | Rig: Marooka<br>Contractor: Perry Tim | Date started: 14/03/2013<br>Date finished: 14/03/2013<br>Logged by: MO'H |




Borehole 7

# Bore Hole Log

**Borehole: BH8**

ICE GEO & CIVIL

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940513 North 5795836
Elevation: 2.7 Datum: Moturiki

Depth scale (m): 0.00, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50, 6.00, 6.50

| elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **SILT,** some fine sand, grey Fe stained, stiff, dry | | | | | |
| 2.20 | | | | **silty fine to medium SAND**, brown, stiff | | | | | |
| 2.15 | | | | fine **sandy SILT**, brown, stiff | | | | | |
| 2.10 | 100 | | | **fine sandy SILT**, grey with brown mottles, hard, damp | | | | | |
| 1.10 | 100 | | | **fine sandy SILT**, blue grey, firm, moist | | | | | |
| 0.40 | | | | **clayey SILT**, minor sand, grey, soft, moist | | | | | |
| 0.35 | | | | **sandy clayey organic SILT**, brown, soft, moist | | | | | |
| 0.00 | | | | pumiceous **SILT**, grey, stiff, damp | | | | | |
| -0.15 | | | | medium to coarse **SAND**, black, Tarawera Ash | | | | | |
| -0.18 | | | | fibrous **PEAT**, dark brown, (H4), soft, moist | | | | | |
| -0.30 | | | | **clayey SILT**, brown, soft, moist | | | | | |
| -0.50 | | | | amorphous fibrous **PEAT**, dark brown / black, (H6), firm, moist | | | | | |
| -1.00 | 100 | | | timber | | | | | |
| -1.10 | | | | pumiceous **SILT**, grey, stiff, sensitive, moist | | | | | |
| -2.00 | 100 | | | **organic clayey SILT**, dark brown, soft, moist | | | | | |
| -2.02 | | | | fine to medium **SAND**, trace silt, dark brown | | | | | |
| -2.20 | 0 | | | | | | | | |
| -2.70 | 100 | | | medium to coarse **SAND**, grey, dense | 5.5 | dis | | | |

Observations:

Vane no.
Core Dia. 68mm

Rig: Marooka
Contractor: Perry Tim

Date started: 14/03/2013
Date finished: 14/03/2013
Logged by: MO'H

# Bore Hole Log

# Borehole: BH8

ICE GEO & CIVIL

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940513 North 5795836
Elevation: 2.7 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 6.50 | | | | | | | | | | |
| | | 100 | | | | | | | | |
| 7.00 | | | | | | | | | | |
| 7.50 | | | | | | | | | | |
| 8.00 | | 100 | | | | | | | | |
| 8.50 | | | | | | | | | | |
| | -6.00 | | | | EOB | | | | | |
| 9.00 | | | | | | | | | | |
| 9.50 | | | | | | | | | | |
| 10.00 | | | | | | | | | | |
| 10.50 | | | | | | | | | | |
| 11.00 | | | | | | | | | | |
| 11.50 | | | | | | | | | | |
| 12.00 | | | | | | | | | | |
| 12.50 | | | | | | | | | | |
| 13.00 | | | | | | | | | | |

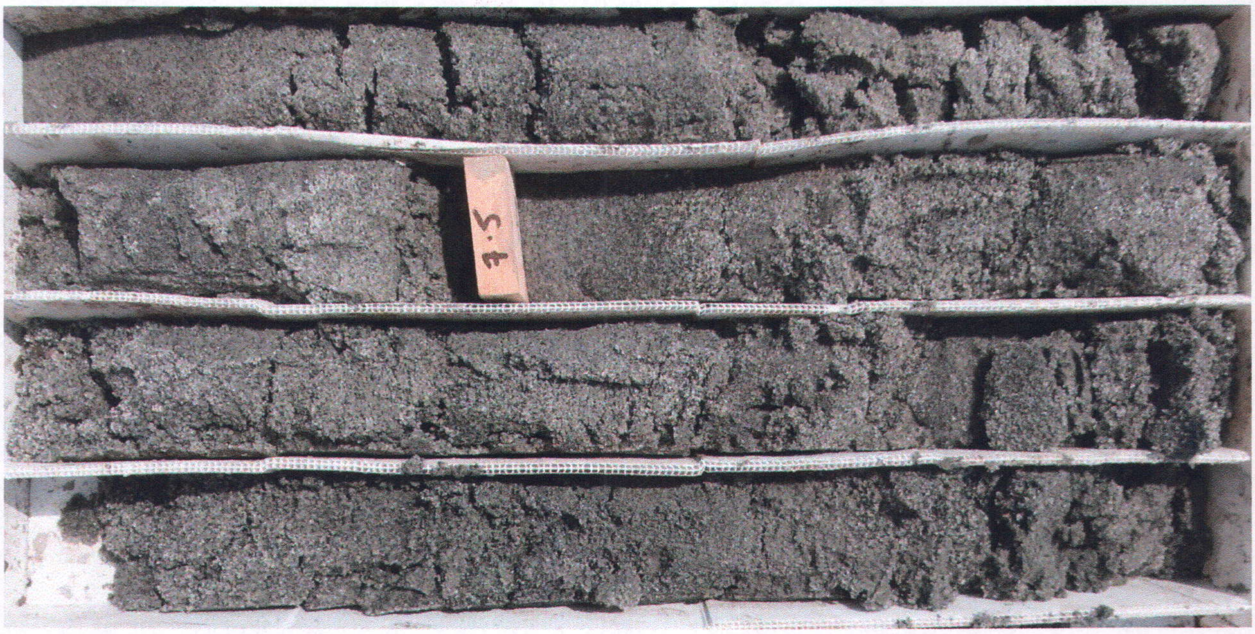
Observations:

Vane no.
Core Dia. 68mm

Rig: Marooka
Contractor: Perry Tim

Date started: 14/03/2013
Date finished: 14/03/2013
Logged by: MO'H


Borehole 8




Borehole 8

# Bore Hole Log

**Borehole: BH9**

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940405 North 5795425
Elevation: 2.7 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|
| 0.00 | | | **SILT and ROCK** to 100mm, brown, hard, dry | | | | | |
| | 2.40 | | **SILT** and angular **GRAVEL** to 20mm, brown, hard | | | | | |
| 0.50 | 2.10 | 100 | **sandy SILT**, some rounded gravel to 3mm, brown, hard | | | | | |
| 1.00 | | | | | | | | |
| 1.50 | | | | | | | | |
| 2.00 | 0.60 | | | | | | | |
| | 0.45 | 100 | **silty fine to medium SAND**, brown, dense, damp | | | | | |
| | 0.35 | | **clayey SILT**, grey brown, soft, moist | | | | | |
| 2.50 | 0.33 | | medium to coarse **SAND**, black, Tarawera Ash | | | | | |
| | 0.30 | | **clayey SILT**, grey brown, soft, moist | | | | | |
| | 0.10 | | amorphous **PEAT**, black, (H6), soft, moist | | | | | |
| | 0.05 | | **clayey SILT,** trace fine sand, brown, soft, moist | | | | | |
| 3.00 | -0.08 | | amorphous **PEAT**, black, (H6), soft, moist | | | | | |
| | -0.20 | | **clayey SILT,** trace fine sand, brown, soft, moist | 3.2 | dis | | | |
| | -0.30 | | pumiceous **SILT**, light grey brown, firm, moist | | | | | |
| | -0.50 | | **SILT**, varved, grey, firm, damp | | | | | |
| 3.50 | -0.60 | | medium to coarse pumice **SAND**, grey | | | | | |
| | -0.90 | | amorphous **PEAT / organic CLAY**, (H9), dark brown, soft, spongy, moist | | | | | |
| | -1.05 | 100 | **clayey SILT**, grey, firm, plastic, moist | | | | | |
| | -1.10 | | **organic CLAY**, brown, soft, moist | | | | | |
| 4.00 | -1.50 | | medium to coarse pumice **SAND**, grey, mod. dense | | | | | |
| 4.50 | | | fine to medium **SAND**, dark grey, dense | | | | | |
| 5.00 | | 100 | | | | | | |
| 5.50 | | | | | | | | |
| 6.00 | | | | | | | | |
| 6.50 | | | | | | | | |

Observations:
augered to 0.3m depth falling head test 3.2 - 3.3m kh=kv=6x10-5m/s

| | | |
|---|---|---|
| Vane no.<br>Core Dia. 68mm | Rig: Marooka<br>Contractor: Perry Tim | Date started: 14/03/2013<br>Date finished: 14/03/2013<br>Logged by: MO'H |

ICE GEO & CIVIL

# Bore Hole Log

**Borehole: BH9**

Project: **Reids Canal Stage 3**
Client: **EBoP**

Location: **Downstream Thornton Road**
Co-ordinates: East 1940405 North 5795425
Elevation: 2.7 Datum: Moturiki

| depth (m) | elevation (m) | recovery (m) | graphic log | Classification | description | samp depth (m) | sample type | SPT result | Vane result (kPa) | other |
|---|---|---|---|---|---|---|---|---|---|---|
| 6.50 | | | | | | | | | | |
| | -4.10 | | | | EOB | | | | | |
| 7.00 | | | | | | | | | | |
| 7.50 | | | | | | | | | | |
| 8.00 | | | | | | | | | | |
| 8.50 | | | | | | | | | | |
| 9.00 | | | | | | | | | | |
| 9.50 | | | | | | | | | | |
| 10.00 | | | | | | | | | | |
| 10.50 | | | | | | | | | | |
| 11.00 | | | | | | | | | | |
| 11.50 | | | | | | | | | | |
| 12.00 | | | | | | | | | | |
| 12.50 | | | | | | | | | | |
| 13.00 | | | | | | | | | | |

Observations:
augered to 0.3m depth falling head test 3.2 - 3.3m kh=kv=6x10-5m/s

| | | |
|---|---|---|
| Vane no.<br>Core Dia. 68mm | Rig: Marooka<br>Contractor: Perry Tim | Date started: 14/03/2013<br>Date finished: 14/03/2013<br>Logged by: MO'H |


Borehole 9

# Appendix B

## Grading Test Results

# PARTICLE SIZE DISTRIBUTION
# TEST REPORT

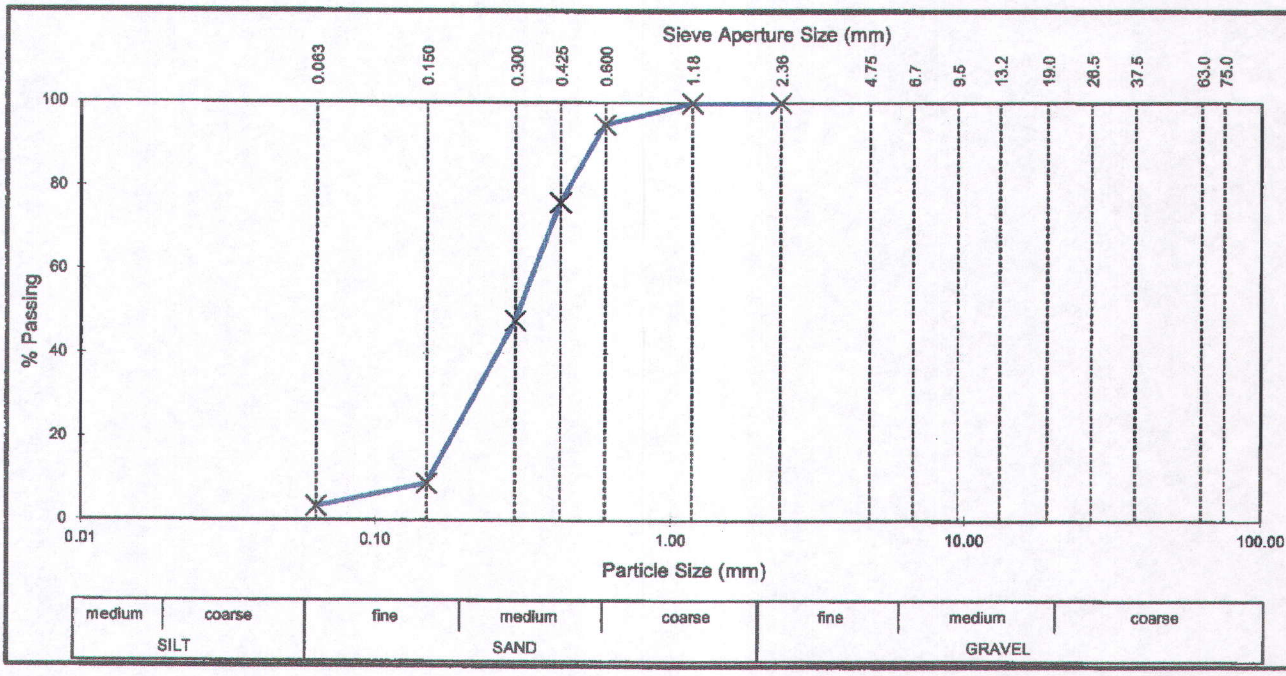
OPUS

| | |
|---|---|
| Project : | **Reids Canal Stage 3** |
| Location : | **Thornton** |
| Client : | **Ice Geo & Civil** |
| Contractor : | **N/A** |
| Sampled by : | **Marriane O'Halloran (Ice Geo & Civil)** |
| Date sampled : | **April 2013** |
| Sampling method : | **Borehole** |
| Sample description : | **Fine - coarse SAND with a trace of Silt** |
| Sample condition | **Natural State (as received)** |
| Bore hole no : | **1** |
| Depth : | **4.2 Metres** |

| | |
|---|---|
| **Project No :** | **255549.00/0TL** |
| **Lab Ref No :** | **13/306A** |
| **Client Ref No :** | **--** |

**Sieve Analysis**

| Size (mm) | % Passing | Size (mm) | % Passing | Size (mm) | % Passing | Size (mm) | % Passing |
|---|---|---|---|---|---|---|---|
| 75.00 | - | 19.00 | - | 4.75 | - | 0.425 | **76** |
| 63.00 | - | 13.20 | - | 2.36 | **100** | 0.300 | **48** |
| 37.50 | - | 9.50 | - | 1.18 | **100** | 0.150 | **9** |
| 26.50 | - | 6.70 | - | 0.600 | **95** | 0.063 | **3** |




| Test Method | Notes |
|---|---|
| NZS 4402:1986 : Test 2.8.1 | Percentage passing the finest seive was obtained by difference.<br>This report may only be reproduced in full. |

Date tested : 24 April 2013
Date reported : 2 May 2013

**IANZ Approved Signatory**

All tests reported herein have been performed in accordance with the laboratory's scope of accreditation

Designation : *Laboratory Manager*
Date : 2 May 2013

PF-LAB-099 (1/09/12)



Opus International Consultants Ltd
Tauranga Laboratory
Quality Management Systems Certified to ISO 9001

278 Chadwick Road, Greerton
PO Box 9057, Tauranga 3142, New Zealand

Telephone +64 7 578 5425
Facsimile +64 7 578 3382
Website www.opus.co.nz

# PARTICLE SIZE DISTRIBUTION TEST REPORT

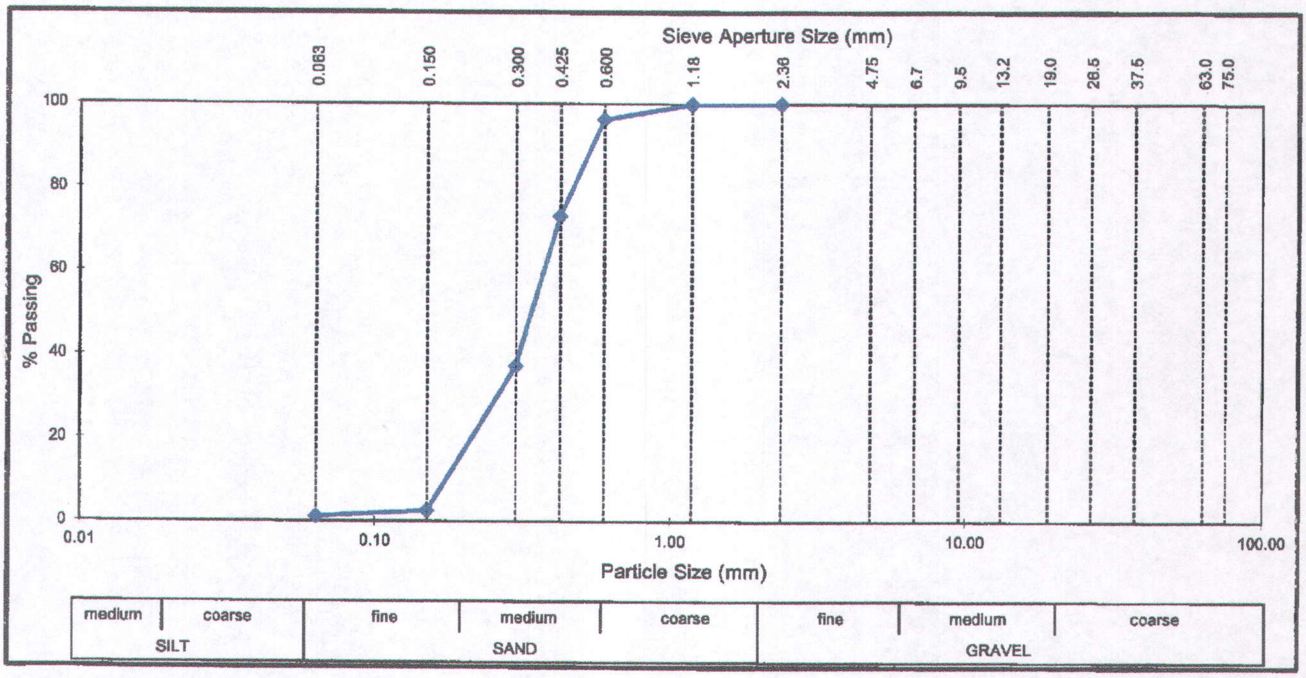
OPUS

| | |
|---|---|
| Project : | **Reids Canal Stage 3** |
| Location : | **Thornton** |
| Client : | **Ice Geo & Civil** |
| Contractor : | **N/A** |
| Sampled by : | **Marriane O'Halloran (Ice Geo & Civil)** |
| Date sampled : | **April 2013** |
| Sampling method : | **Borehole** |
| Sample description : | **Fine - coarse SAND** |
| Sample condition | **Natural State (as received)** |
| Bore hole no : | **1** |
| Depth : | **5.0 Metres** |

| | |
|---|---|
| **Project No :** | **255549.00/0TL** |
| **Lab Ref No :** | **13/306B** |
| **Client Ref No :** | **--** |

**Sieve Analysis**

| Size (mm) | % Passing | Size (mm) | % Passing | Size (mm) | % Passing | Size (mm) | % Passing |
|---|---|---|---|---|---|---|---|
| 75.00 | - | 19.00 | - | 4.75 | - | 0.425 | **73** |
| 63.00 | - | 13.20 | - | 2.36 | **100** | 0.300 | **37** |
| 37.50 | - | 9.50 | - | 1.18 | **100** | 0.150 | **3** |
| 26.50 | - | 6.70 | - | 0.600 | **96** | 0.063 | **1** |




| **Test Method** | **Notes** |
|---|---|
| NZS 4402:1986 : Test 2.8.1 | Percentage passing the finest seive was obtained by difference.<br>This report may only be reproduced in full. |

Date tested : 24 April 2013
Date reported : 2 May 2013

**IANZ Approved Signatory**

Designation : *Laboratory Manager*
Date : 2 May 2013

ianz laboratory — All tests reported herein have been performed in accordance with the laboratory's scope of accreditation

PF-LAB-099 (1/09/12)



Opus International Consultants Ltd
Tauranga Laboratory
Quality Management Systems Certified to ISO 9001

278 Chadwick Road, Greerton
PO Box 9057, Tauranga 3142, New Zealand

Telephone +64 7 578 5425
Facsimile +64 7 578 3382
Website www.opus.co.nz

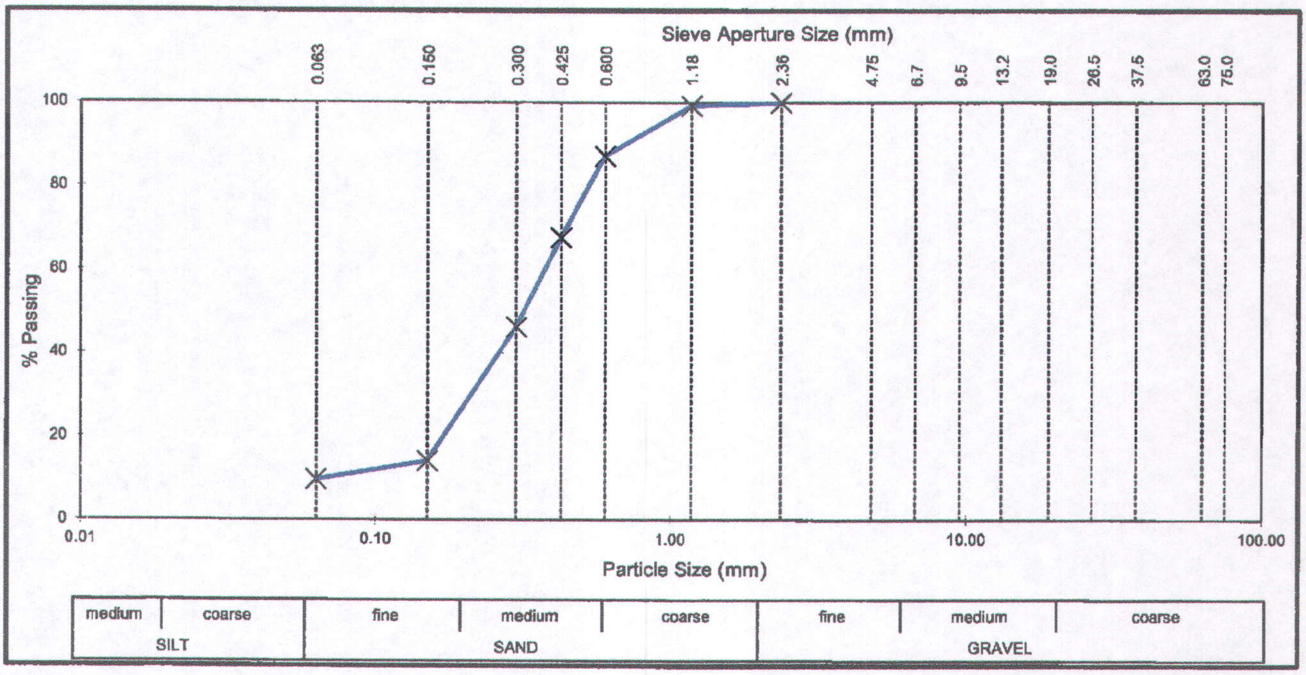
# PARTICLE SIZE DISTRIBUTION TEST REPORT

| | |
|---|---|
| Project : | **Reids Canal Stage 3** |
| Location : | **Thornton** |
| Client : | **Ice Geo & Civil** |
| Contractor : | **N/A** |
| Sampled by : | **Marriane O'Halloran (Ice Geo & Civil)** |
| Date sampled : | **April 2013** |
| Sampling method : | **N/A** |
| Sample description : | **Fine - coarse SAND with minor Silt** |
| Sample condition | **Natural State (as received)** |
| Bore hole no : | **5** |
| Depth : | **0.5 Metres** |

| | |
|---|---|
| **Project No :** | **255549.00/0TL** |
| **Lab Ref No :** | **13/306C** |
| **Client Ref No :** | **--** |

**Sieve Analysis**

| Size (mm) | % Passing | Size (mm) | % Passing | Size (mm) | % Passing | Size (mm) | % Passing |
|---|---|---|---|---|---|---|---|
| 75.00 | - | 19.00 | - | 4.75 | - | 0.425 | **68** |
| 63.00 | - | 13.20 | - | 2.36 | **100** | 0.300 | **46** |
| 37.50 | - | 9.50 | - | 1.18 | **99** | 0.150 | **14** |
| 26.50 | - | 6.70 | - | 0.600 | **87** | 0.063 | **10** |




| Test Method | Notes |
|---|---|
| NZS 4402:1986 : Test 2.8.1 | Percentage passing the finest seive was obtained by difference.<br>This report may only be reproduced in full. |

Date tested : 24 April 2013
Date reported : 2 May 2013

**IANZ Approved Signatory**

All tests reported herein have been performed in accordance with the laboratory's scope of accreditation

Designation : *Laboratory Manager*
Date : 2 May 2013




Opus International Consultants Ltd
Tauranga Laboratory
Quality Management Systems Certified to ISO 9001

278 Chadwick Road, Greerton
PO Box 9057, Tauranga 3142, New Zealand

Telephone +64 7 578 5425
Facsimile +64 7 578 3382
Website www.opus.co.nz

## PARTICLE SIZE DISTRIBUTION
## TEST REPORT

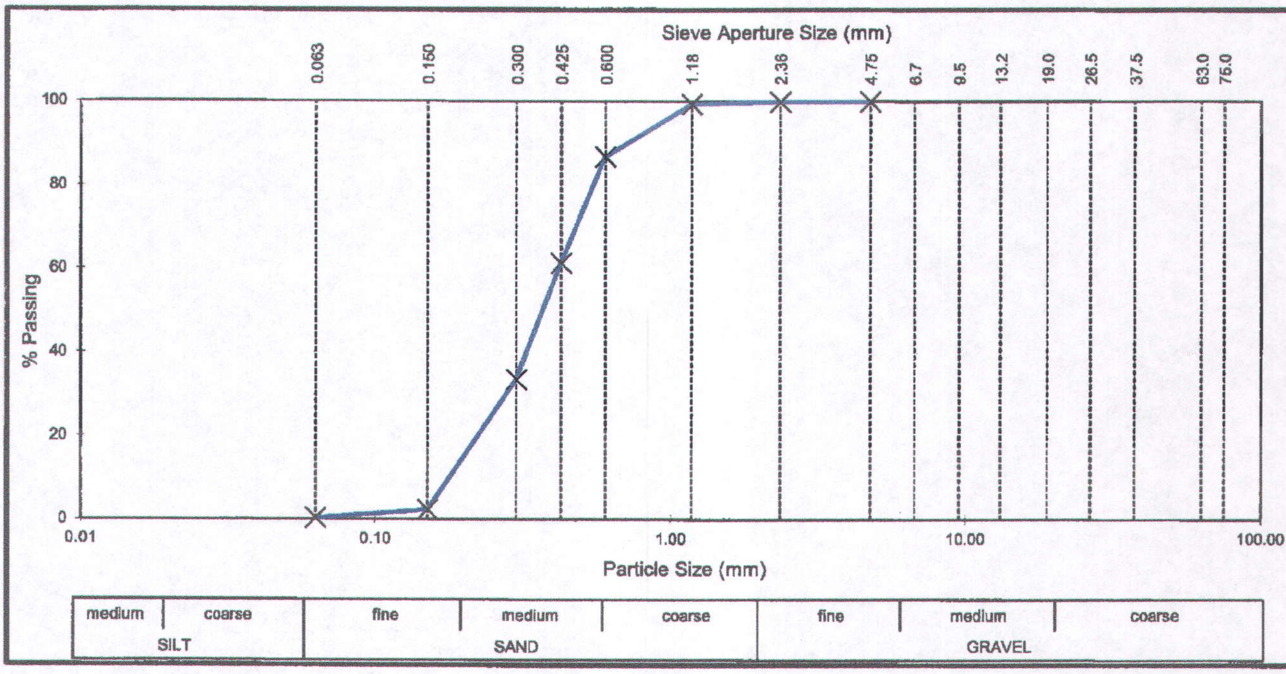
OPUS

| | |
|---|---|
| Project : | **Reids Canal Stage 3** |
| Location : | **Thornton** |
| Client : | **Ice Geo & Civil** |
| Contractor : | **Unknown** |
| Sampled by : | **Marriane O'Halloran** |
| Date sampled : | **April 2013** |
| Sampling method : | **N/A** |
| Sample description : | **Fine - coarse SAND** |
| Sample condition | **Natural State (as received)** |
| Bore hole no : | **8** |
| Depth : | **5.5 Metres** |

| | |
|---|---|
| **Project No :** | **255549.00/0TL** |
| **Lab Ref No :** | **13/306D** |
| **Client Ref No :** | **--** |

**Sieve Analysis**

| Size (mm) | % Passing | Size (mm) | % Passing | Size (mm) | % Passing | Size (mm) | % Passing |
|---|---|---|---|---|---|---|---|
| 75.00 | - | 19.00 | - | 4.75 | **100** | 0.425 | **61** |
| 63.00 | - | 13.20 | - | 2.36 | **100** | 0.300 | **34** |
| 37.50 | - | 9.50 | - | 1.18 | **99** | 0.150 | **2** |
| 26.50 | - | 6.70 | - | 0.600 | **87** | 0.063 | **0** |




| Test Method | Notes |
|---|---|
| NZS 4402:1986 : Test 2.8.1 | Percentage passing the finest seive was obtained by difference.<br>This report may only be reproduced in full. |

Date tested : 24 April 2013
Date reported : 2 May 2013

**IANZ Approved Signatory**

All tests reported herein have been performed in accordance with the laboratory's scope of accreditation

Designation : *Laboratory Manager*
Date : 2 May 2013




Opus International Consultants Ltd
Tauranga Laboratory
Quality Management Systems Certified to ISO 9001

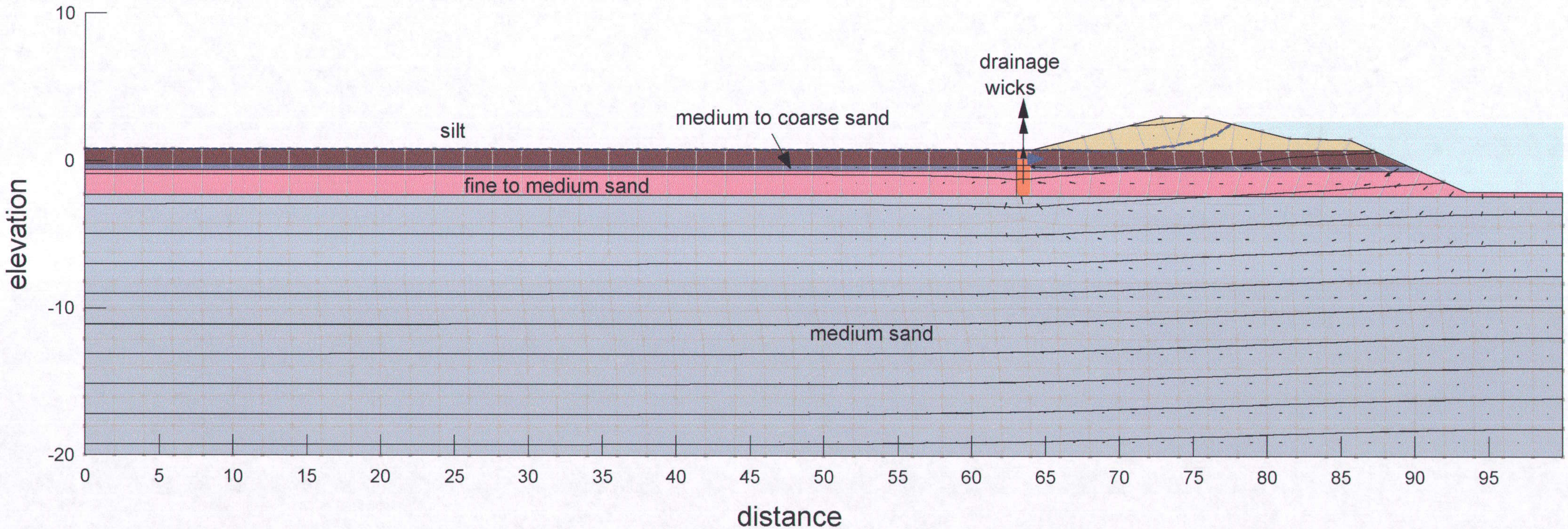
278 Chadwick Road, Greerton
PO Box 9057, Tauranga 3142, New Zealand

Telephone +64 7 578 5425
Facsimile +64 7 578 3382
Website www.opus.co.nz

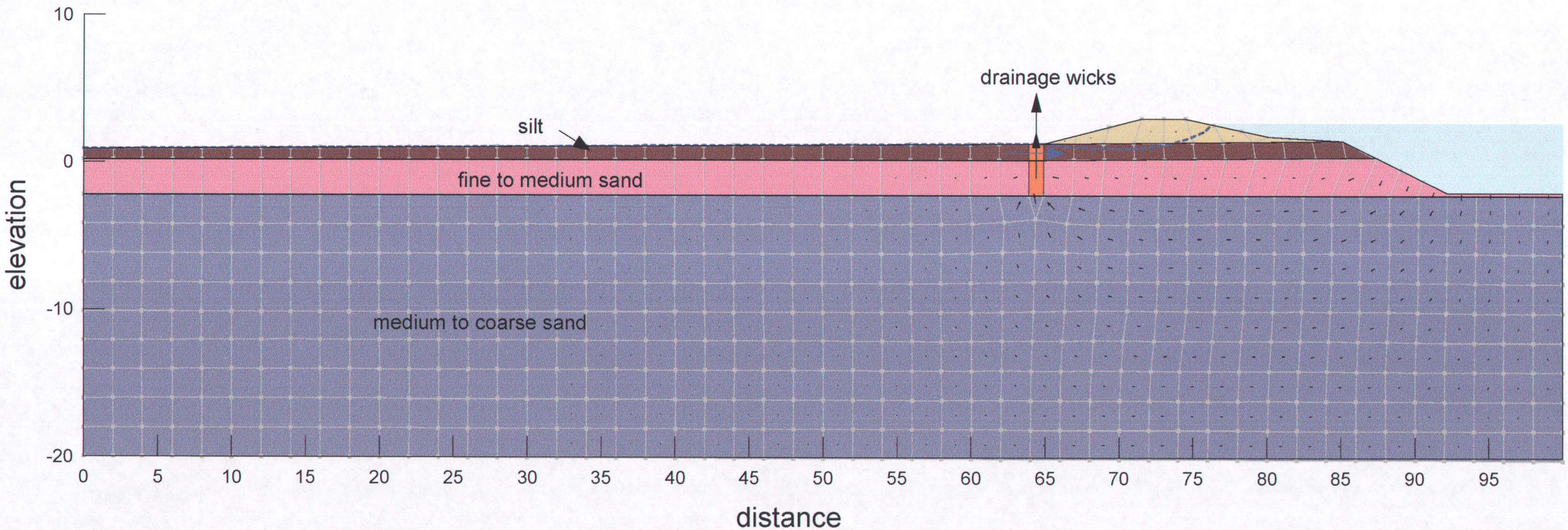
# Appendix C

# Soil Seepage Models

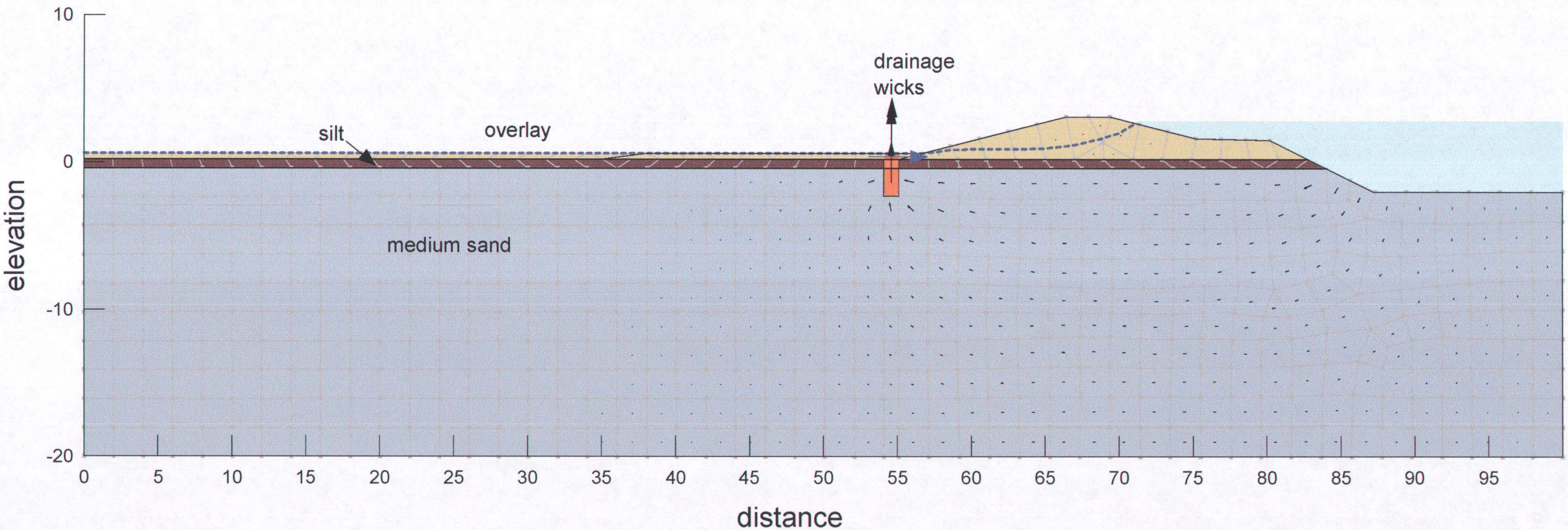
File Name: Cross Section LB50 stopbank trans.gsz
Date: 17/06/2013 Time: 9:19:09 p.m.



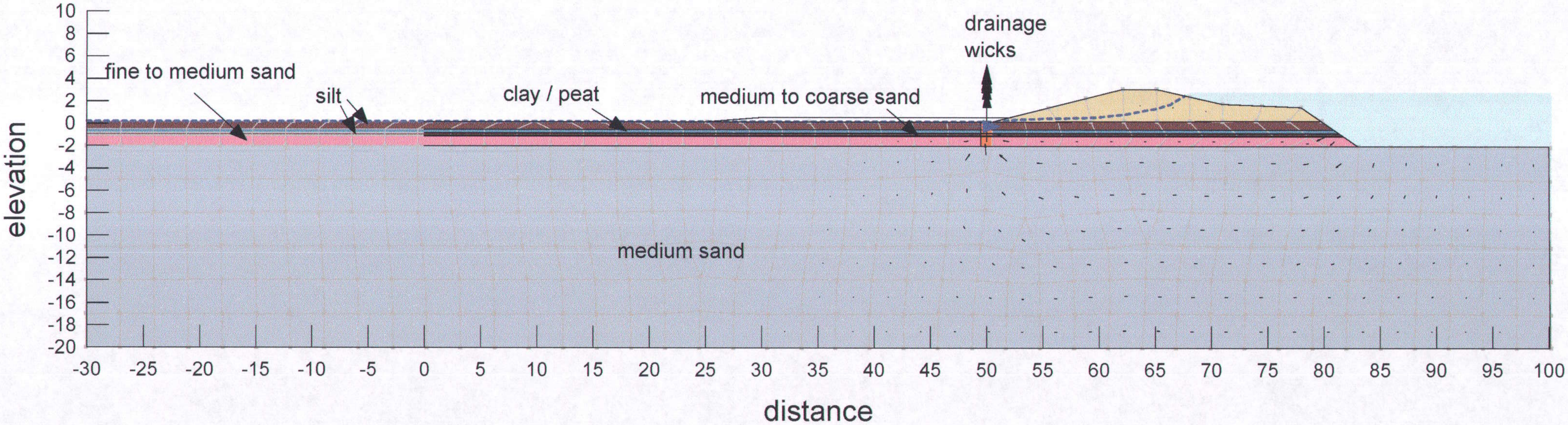
File Name: Cross Section LB250 stopbank trans.gsz
Date: 17/06/2013 Time: 9:32:34 p.m.



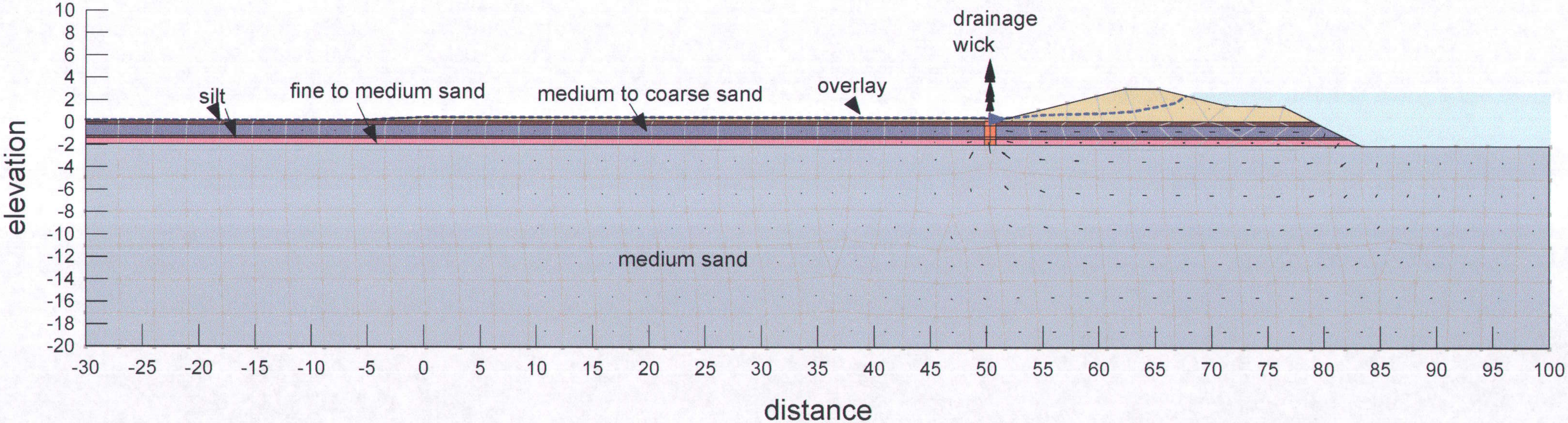
File Name: Cross Section LB500 stopbank trans overlay.gsz
Date: 17/06/2013 Time: 9:38:14 p.m.



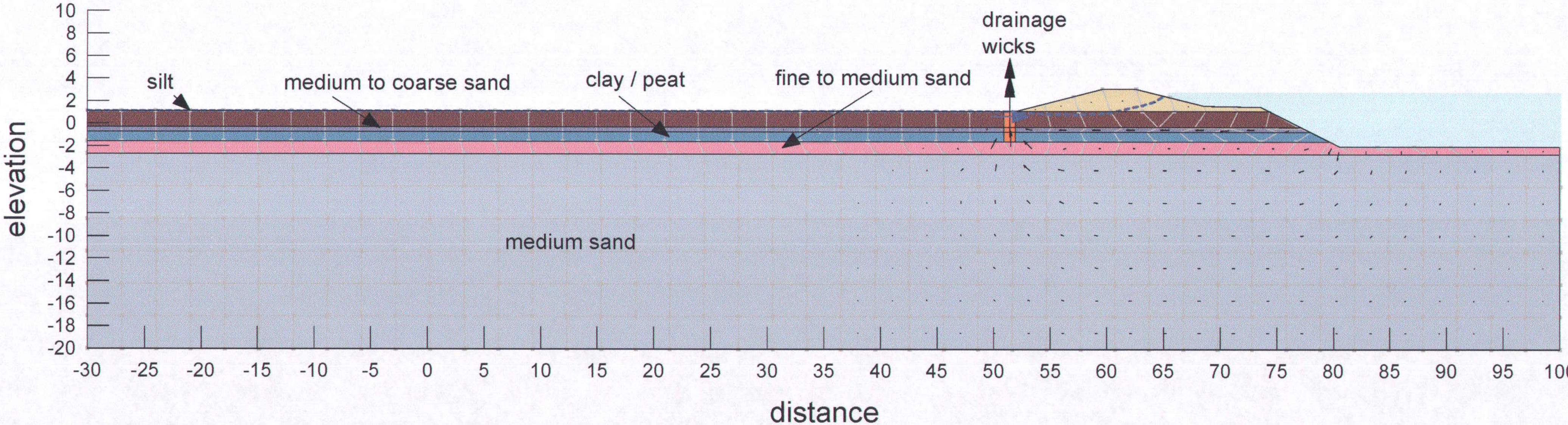
File Name: Cross Section LB650 stopbank trans.gsz
Date: 16/06/2013 Time: 3:54:45 p.m.



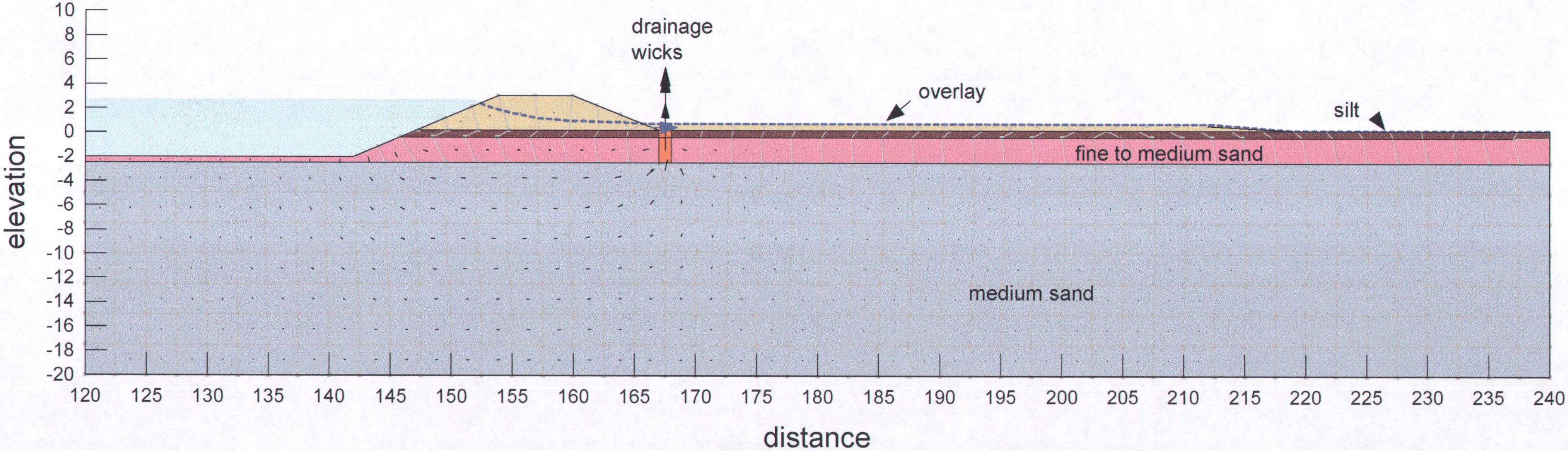
File Name: Cross Section LB750 stopbank trans overlay.gsz
Date: 17/06/2013 Time: 10:09:14 p.m.



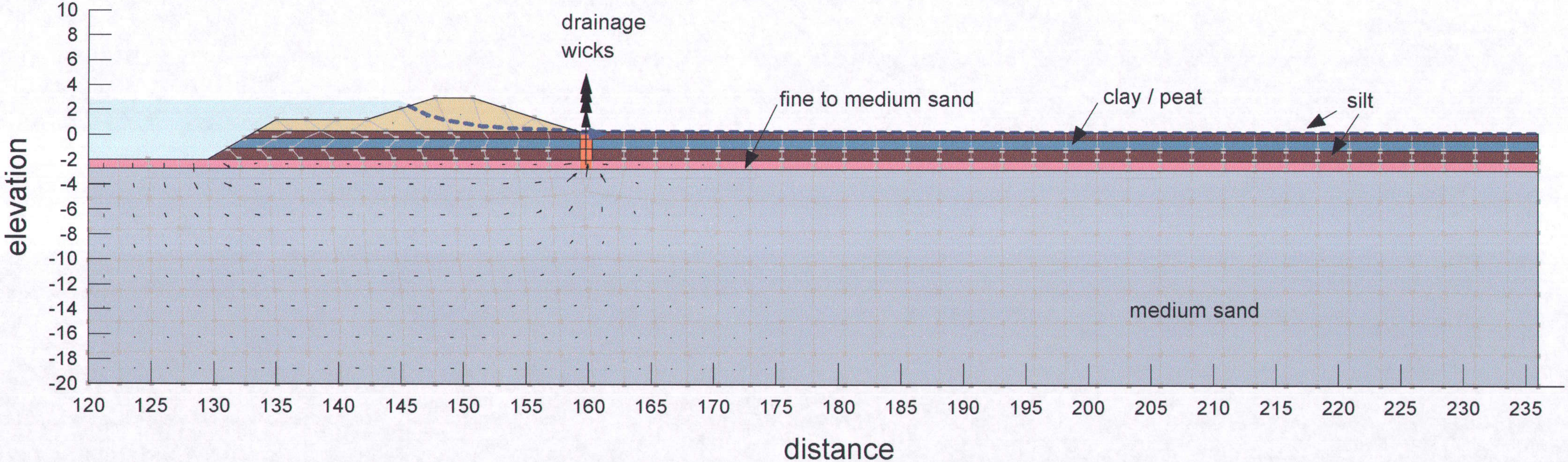
File Name: Cross Section LB850 stopbank trans.gsz
Date: 13/06/2013 Time: 6:21:56 p.m.



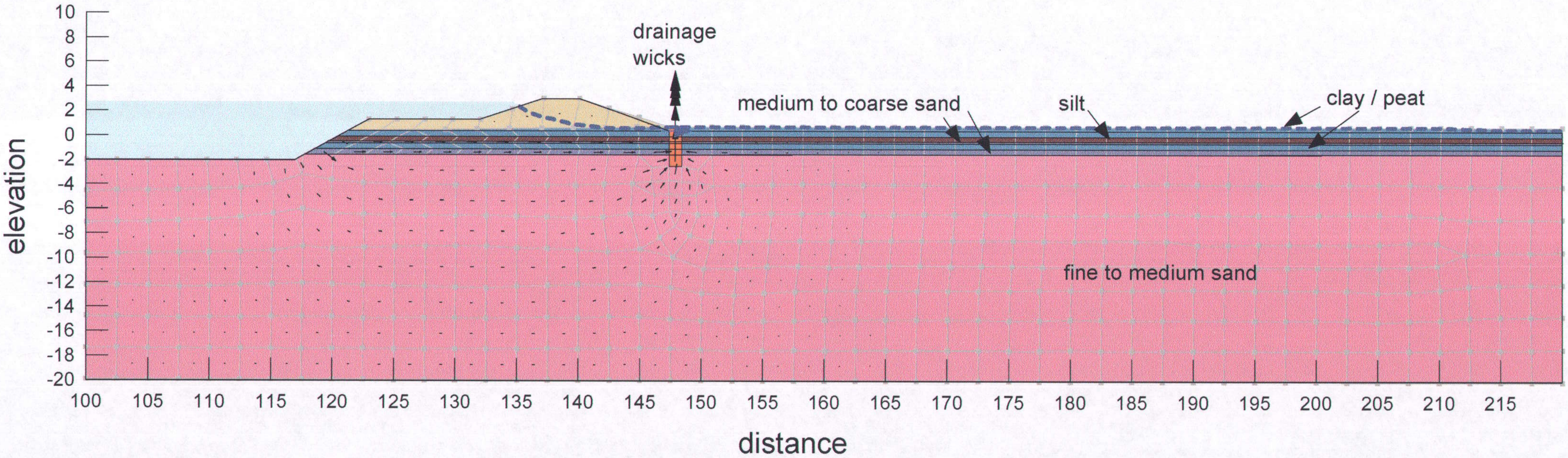
File Name: Cross Section RB-40 stopbank trans overlay.gsz
Date: 14/06/2013 Time: 9:02:52 a.m.



File Name: Cross Section RB450 stopbank trans.gsz
Date: 16/06/2013 Time: 8:45:21 p.m.



File Name: Cross Section RB820 stopbank trans 07.gsz
Date: 17/06/2013 Time: 10:17:24 p.m.



## Appendix D

## Drainage Wick Model

## Reids Canal Stage 3 Seepage Analysis

## Wick drain modelling

Wick drain type    Ceteau

width    $w := 100$ mm

thickness    $t := 3$    mm

discharge capacity at 300kPa ground pressure with 0.1 pressure gradient and kink in drain    $q_w := 60 \cdot 10^{-6}$    $\frac{m^3}{s}$

$i_w := 0.1$

effective permeability    $k_w := \frac{q_w}{w \cdot 10^{-3} \cdot t \cdot 10^{-3} \cdot i_w}$

$k_w = 2.00 \times 10^0$    $\frac{m}{s}$

assuming wick drain has a free outlet    $i := 1.0$

assume two rows of wicks 0.65m apart with wicks at 0.75m spacings in 1m wide element

$sp := 0.75$    m

$w_e := 1.0$    m

effective area per wick    $a_w := \frac{sp}{2} \cdot w_e$

$a_w = 3.75E\text{-}001$    $m^2$

assuming no vertical permeability in soil

vertical wick permeability for 1m wide element in model

$k_e := k_w \cdot w \cdot 10^{-3} \cdot t \cdot \frac{10^{-3}}{a_w}$

$k_e = 1.6E\text{-}003 \quad \frac{m}{s}$

**horizontal permeability in element**

assume wicks are draining sand with $k_s := 5 \cdot 10^{-5} \quad \frac{m}{s}$

assume 3mm width of smeared clay/peat on surface of geotextile

$d_{sm} := 0.003 \quad m$

permeability of smeared zone $k_{sm} := 5 \cdot 10^{-8} \quad \frac{m}{s}$

distance from edge of element to centre of wick drains $d_w := \frac{w_e}{2}$

$d_w = 5E\text{-}001$

$$k_{heq} := \frac{d_w}{\left[\left(\frac{d_{sm}}{k_{sm}}\right) + \frac{(d_w - d_{sm})}{k_s}\right]}$$

$k_{heq} = 7.149E\text{-}006$

$$k_{ratio} := \frac{k_e}{k_{heq}}$$

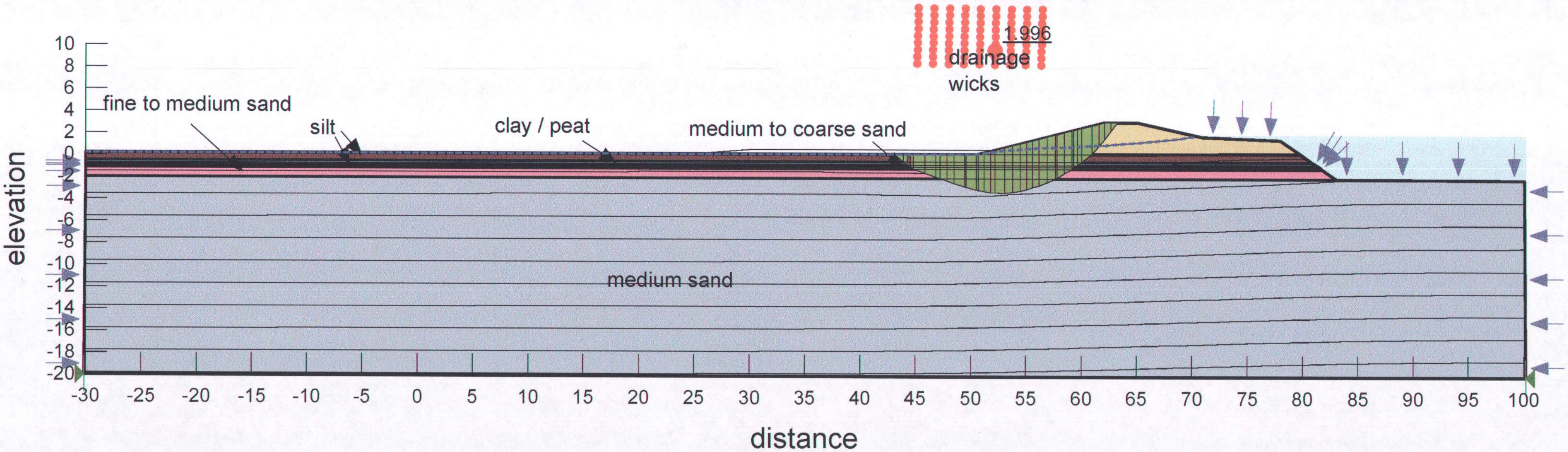
$k_{ratio} = 223.8$

## Appendix E

## Slope Stability Models

Name: Material 1 fill Unit Weight: 17 kN/m³ Cohesion': 2 kPa Phi': 33 °
Name: Material 2 silt Unit Weight: 15 kN/m³ Cohesion': 2 kPa Phi': 24 °
Name: Material 3 fine to medium sand Unit Weight: 13 kN/m³ Cohesion': 0 kPa Phi': 35 °
Name: Material 4 medium to coarse sand Unit Weight: 13 kN/m³ Cohesion': 0 kPa Phi': 35 °
Name: Material 5 medium sand Unit Weight: 13 kN/m³ Cohesion': 0 kPa Phi': 35 °
Name: Material 6 clay / peat Unit Weight: 10.5 kN/m³ Cohesion': 30 kPa
Name: Material 8 wick drains Unit Weight: 13 kN/m³ Cohesion': 0 kPa Phi': 35 °

File Name: Cross Section LB650 stopbank trans.gsz
Date: 16/06/2013 Time: 4:37:25 p.m.



Name: Material 1 fill Unit Weight: 17 kN/m³ Cohesion': 2 kPa Phi': 33 °

Name: Material 2 silt Unit Weight: 15 kN/m³ Cohesion': 2 kPa Phi': 24 °

Name: Material 3 fine to medium sand Unit Weight: 13 kN/m³ Cohesion': 0 kPa Phi': 35 °

Name: Material 4 medium to coarse sand Unit Weight: 13 kN/m³ Cohesion': 0 kPa Phi': 35 °

Name: Material 6 clay / peat Unit Weight: 10.5 kN/m³ Cohesion': 30 kPa

Name: Material 8 wick drains Unit Weight: 13 kN/m³ Cohesion': 0 kPa Phi': 35 °

File Name: Cross Section RB450 stopbank trans.gsz

Date: 16/06/2013 Time: 5:11:12 p.m.