Flood Protection and Drainage Bylaw 2020 Technical Report

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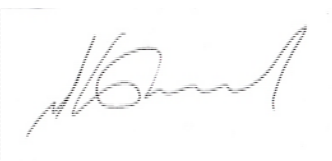

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Executive summary

Bylaw Applicable Areas (BAAs) - Inland

The periodic review of the Bay of Plenty Regional Council Floodway and Drainage Bylaw 2008 has led to the need for seepage modelling to provide supporting evidence to the Bylaw Applicable Areas (BAAs) on the 'inland' or landward side of stopbanks. The proposed changes to the width of the BAAs result from consideration of the outcomes of the modelling together with existing data and anecdotal evidence. The recommendations are;

- *the Rangitāiki River inland BAA increases to 200 m, an increase of 50 m,*

- *the Tarawera River inland BAA increases to 120 m, an increase of 60 m,*

- *the Kaituna River inland BAA increases to 140 m, an increase of 120 m,*

- *the Whakatāne/Tauranga inland BAA increases to 40 m, an increase of 20 m and*

- *the Waioeka/Otara inland BAA increases to 40 m, an increase of 20 m.*

Any water bodies that are continually (Ex., Wairere Stream to the Whakatāne River) or temporarily (Ex., The Rangitāiki Floodway to the Rangitāiki River) in direct connection to a scheme shall have the same BAA as that scheme.

For all other flood defences, including Drainage Scheme Flood Defences it is proposed:

- *If they feed to the Rangitāiki River this distances is 130 m;*

- *If the feed to the Tarawera or Kaituna this distance is 100m; and*

- *30 m otherwise.*

This assessment has provided an approach to quantify BAAs. Models were built using uniform ground and topographical conditions, to allow direct comparison between assessments. Modelling properties were then selected to represent the variable soil and hydraulic conditions that exist across the Bay of Plenty watersheds, including adjustments to the peak flood duration and selection of foundation soil permeability's. The selected inputs considered flooding characteristics drawn from previous data records and soil attributes that capture the complexity of the regions soils, including peat beds and volcanic ashes.

BAAs assist in preventing developments that could compromise the integrity of flood defences, while providing a means for proposed projects to comply with Bay of Plenty Regional Council bylaws. This allows a controlled approach to manage risk and asset protection.

Engineering judgement applies where-ever seepage is of concern.

Adaptability

In the modelling unique soil parameters were assigned to the stopbank fill soils, underlain foundation soils and to blanket soils (which act to confine pressures at ground surface due to their low contrasting permeability).

It is expected that site specific models will accompany bylaw applications or be required as part of a technical review. These assessments shall contain a higher level of detail, which may require allowance for geological layering at a site, tidal influences in the lower reaches, scientific projections relating to climate change or any other variables that are considered influential to the seepage regime.

An application for a FAD Bylaw Authority would typically be supported with site specific sub-surface investigation, analysis and recommended seepage control measures where necessary.

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Part 1: Introduction

The use of seepage modelling to inform the inland Bylaw Applicable Areas (BAAs) as measured from the landward toes of a stopbank.

There is a history of failures of stopbanks and other flood defences throughout the Bay of Plenty region. A significant proportion of these failures have initiated beyond the embankments themselves, on land not owned by the Bay of Plenty Regional Council. The Floodway and Drainage Bylaw was enacted to enable the Bay of Plenty Regional Council to control selected activities within potential failure zones. If unmanaged these activities can increase the risk of failures being initiated. Beyond these river margins, now referred to as BAAs it is considered that normal farming and building activities should have negligible influence of flood defence security.

In most day-to-day situations the sub-surface water flows toward the river, and contributes to normal flow conditions. The exceptions to this are when floods cause water levels to rise above the inland ground topography and when pumped drainage systems create sub-surface flows away from rivers. This report focusses on when flood conditions govern the sub-surface water regime.

Failures that originate inland of any stopbank or flood defence are due to a geohazard called **seepage**. This can be described as the underground migration of water through permeable soil layers. As water levels rise in drainage networks - which include rivers - the difference in water elevation to the inland ground surface causes a scenario that is alike to the formation of a small dam. As the difference in level increases with rising flood-waters, so does the pressure that drives the water to flow inland beneath the ground.

Seepage will increase the saturation of all soil within the path of a water plume migrating underneath or through, and ultimately beyond the flood defences. Water that daylights on the inland ground surface causes ponding. If this water flow is not managed it can erode soil particles or induce heave, both being pre-cursors to a possible breach scenario.

Seepage can develop to undesirable levels when there is enough energy to wash out soil particles. This could occur on the ground surface or where any weak anomalies exist below the ground. If the elevation of water level within a flood defence is sufficient to erode soils, the flow and velocity will increase as erosion occurs. The resulting void is known as a **pipe**, and for clarity it is a soil tunnel that self-forms; as opposed to a material conduit used for flow of a liquid. Often a less erodible material will exist above the pipe which forms a **roof**, allowing the pipe to remain open and to continue to enlarge until the moment when the stopbank could potentially collapse. Without an upper soil providing a roof - such as in a uniform soil - erosion will tend to cause collapse and blockage of the pipe, significantly slowing the failure process.

A problem with low permeability material is that it can cause water pressure beneath to build-up, to the extent that the effective soil stress becomes compromised. A dome-shaped formation can appear on the surface from the water trying lift the soil, or **heave**. Often it is only the rooting network of surface vegetation such as grass that prevents the area of heave from tearing and sands or other erodible particles becoming ejected at the ground surface.

During a flood event all the components of a stopbank will influence the seepage response, including the topography and the ground composition, together with the quality of earthworks and any protection features.

Typically the further the distance from the flood defence, the susceptibility to effects from seepage reduces, until a margin is reached where the hydraulic energy is insufficient to be hazardous.

When water is migrating beneath the ground it may encounter buried surfaces, such as trees, building foundations, posts and other structural penetrations. Any obstruction to the water flow can inhibit the wetting front and allow water pressure to concentrate. The water can then plume vertically and find pressure relief by daylighting on the ground surface, referred to as the development of a seepage face.

An interface between the ground and embedded objects can form a detachment, or 'gapping' which promotes the migration of seepage water. Dry ground, sensitive soils or cyclic loading on the super-structure are some examples that contribute to exacerbating this effect.

If the velocity of rising seepage water is sufficient to entrain and erode soil particles then piping is considered to have initiated. This situation can escalate such that piping failure may only be preventable using temporary remedial measures provided there is sufficient time to activate the seepage treatment.

Computer aided modelling that uses a theoretical design flood event can be used to simulate the seepage through soils. The model can allow seepage at the ground surface and facilitate the quantification of estimated parameters associated with the seepage. Of particular interest is the flux, velocity, flow rate, pore pressure and hydraulic gradient.

Together, these outputs can be used to estimate the distance from flood defences within which activities may affect seepage. When the impact from activities is undesirable a variety of seepage treatments can be adopted.

These activity margins define when land-owners and developers need to apply for a Floodway and Drainage Bylaw Authority from the Bay of Plenty Regional Council. This bylaw acts to capture proposed developments and identify seepage concerns at a particular site so the Bay of Plenty Regional Council can review applications and apply conditions to a proposal, such that every opportunity can be given to maintaining the protection of flood defences.

These set-back distances, or margins are referred to herein as landward or inland Bylaw Applicable Areas (BAAs).

Current and proposed Bylaw Applicable Areas

Bylaw Applicable Areas (BAAs) quantified in the Bay of Plenty Regional Council Floodway and Drainage Bylaw 2008, together with the proposed BAAs are listed in the following table:

SCHEME	***CURRENT*** *width measured from the landward stopbank toes* *(m)* ***NOTE: PREVIOUSLY REFERRED TO AS EXCLUSION WIDTHS.***	***PROPOSED*** *width measured from the landward stopbank toes* *(m)*
Rangitāiki	*150*	*200*
Tarawera	*60*	*120*
Kaituna	*20*	*140*
Whakatāne/ Tauranga	*20*	*40*
Waioeka/Otara	*20*	*40*
Drainage or other scheme flood defences	*20*	*• 130 m if connecting to the Rangitāiki scheme* *• 100 m if connecting to the Tarawera or Kaituna scheme* *• 30 m otherwise.*

Table 1: Current and proposed BAAs.

1.1 Approach to seepage modelling

The following sections describe how proposed BAAs were derived from seepage assessments.

The assessment of ground seepage during a flood is four dimensional due to the potential for soil profiles and ground levels to change in three dimensions and water pressures changing with time; therefore any analysis on a scheme should be given broad consideration to capture possible variables for any modelled cross-section.

1.1.1 Software

Seepage analyses were performed using the *SEEP/W* and heave assessment with *SIGMA/W* (Geo-slope, 2020) computer programme. This is a finite element programme which divides each soil layer into a mesh of small elements with user defined soil properties. Meshing was performed with 1 m quadrangles. As with meshing an anomaly can occur, with graphical results showing a distinct 'step' in the results. The figure that follows is taken from the Tarawera model and shows a discrepancy that occurs near 200 m chainage. In this case a triangular element was autonomously introduced to bind the quadrilaterals. Meshing can also produce irregular spikes in graphical outputs, particularly with total stress in *SIGMA/W* analysis, however the meshing was not adjusted to a finer net as the deviations in the results were considered non-influential to the outcomes.

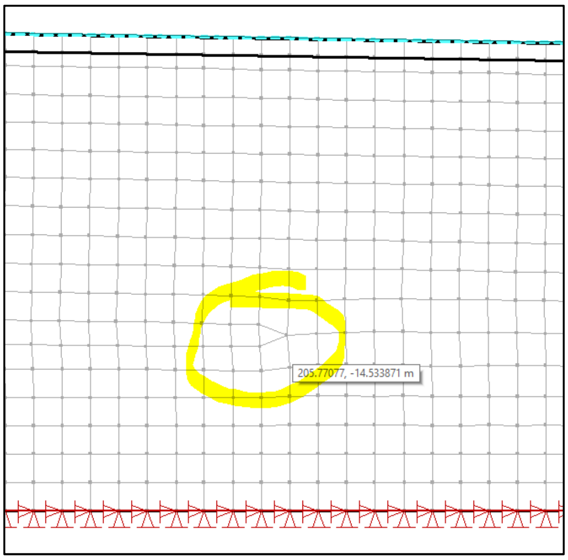

Figure 1: Meshing anomaly.

1.1.2 Boundary Conditions

Boundary conditions are used to define known water levels and surfaces where seepage can occur. Mathematical equations governing the flow of water through soil are then applied to each element to produce results in the form of water pressures, pressure gradients and water velocities. Broad soil models were used to prevent any numerical anomalies at the inland boundary influencing results in the area of interest.

The 2D models were assigned the origin co-ordinate [0,0 XY] at the inland toe and applied the following boundaries:

- Vertical Up = Ground Surface, assigned a seepage face review beyond the inland crest to the far-field boundary, assigned the flood attributes before the waterward crest to the near-field boundary. No boundary condition applied to the crest.

- Vertical Down = 40 m deep, considered to result in conditions that would be similar to an infinite depth effect. No boundary condition applied except fixed in the X-Y for SIGMA/W assessments.

- Horizontal Left Hand Side = Referred to as the near field boundary is set-back 40 m from the inland toe. This margin provides for the stopbank footprint and the bed of the water source. Generally no boundary conditions applied except during the initial parent setup runs.

  Given the Tarawera stopbank was of lesser width a check was performed on the sensitivity of the bed length. This was modelled extending back to 100 m for Simulation K with flat ground. Results showed the wetting front propagated to the same margin and heave was predicted at the same distance. A second check was performed with Simulation C on sloping ground and this did show that the backing up effect from the far-field boundary occurred quicker. The Tarawera Model was re-run setting the bed of the water source at 19 m to be consistent with the other schemes.

- Horizontal Right Hand Side = Referred to as the far field boundary set at 500 m distance from the inland toe. This edge was given the boundary condition with ground-water at 1.0 m depth. As this distance is well over double the current longest margin [>2 x 150 m] and based on the results it is considered to be set-back an appropriate distance.

1.1.3 **Schemes assessed**

Quantitative analysis refers to an assessment where numerical answers are used to categorize outputs. In contrast, qualitative analysis refers to assessment of the systems attributes that cannot be given numerical values, such as visual inspection, past performance and local experience.

Quantitative seepage analysis was performed for the river schemes; whereas qualitative assessment was predominant for other schemes.

The six [6] assessed scenarios correspond to the:

- Rangitāiki River (Rangitāiki-Tarawera Rivers Scheme);
- Tarawera River (Rangitāiki-Tarawera Rivers Scheme);
- Kaituna River (Kaituna Catchment Control Scheme);
- Whakatāne and Tauranga rivers (Whakatāne-Tauranga Rivers Scheme);
- Waioeka and Otara rivers (Waioeka-Otara Rivers Scheme); and
- Drainage Scheme Flood Defences and other protected networks such as the upper Kaituna Catchment.

1.1.4 **Modelling sequence**

The assessments begins with steady-state conditions to develop the ground water profile under normal inland and river conditions. Static ground water levels were selected based on a 1.0 m depth to ground water. Shallow ground-water is common in coastal areas of the Bay of Plenty, and future site-specific assessments may encounter shallower levels than that modelled, notably with predicted sea level rise from climate change. The sensitivity of GWT is partly explored with a select simulation being re-run with the initial water table set at 2.0 m depth. From this single assessment it can be deducted that a shallower water table produces results with larger water migrations, while a deeper water table is favourable for restricting/reducing effects of seepage.

The next step in the assessment is to perform a steady-state flood simulation with the water level set near the stopbank crest to simulate a design event. During site specific design this is referred to as the Design Water Surface Elevation (DWSE) and does not include freeboard.

During a flood there is a peak in water levels which subsequently recedes; therefore some soils do not become completely saturated and transient conditions occur. Therefore, following the steady state analysis a transient analysis was assessed. For this reason the transient conditions values are the cases that are used in determining the BAA's.

Transient assessment begins with normal flow conditions that rise to a theoretical flood peak then eventually return to normal levels. The plot of river level versus time is called a hydrograph. The hydrographs were designed to represent the water level and duration of floods that have been historically recorded for each of the river networks and are characteristic of the catchments. The hydrograph attributes for each river system are presented and discussed in each of the respective sections.

Design of a hydrograph requires a return period. This approach works on the theory that larger floods should occur less frequently that smaller floods. Scheme design standards, also known as technical levels of service vary depending on the scheme with most river schemes nominated at 100 years whilst other schemes are mostly 5-10 years. Scheme design standards are detailed in the Rivers and Drainage Asset Management Plan (Bay of Plenty Regional Council, 2018).

The freeboard height also varies and is influenced in part by the return period. Urban areas of higher risk have between 500 - 800 mm freeboard applied, conversely in rural areas this height ranges between zero and 450 mm.

To finish the assessments they were tied to a SIGMA/W analysis in which the data could be extracted for computation of safety factors relating to heave.

1.1.5 **Simulations**

Simulations have been assigned alphabetically, A through to X; each letter corresponding to a simulation.

For each of the [6] assessed scenarios, three [3] models were developed. These included situations with landward topography being:

- flat;
- sloping at 1°; and
- sloping then eventually flattening at a set distance, referred to as transitional models.

The degree of slope and distances were arbitrarily selected with the initial results considered for relevance. This initial data seemed usable and was adopted as the control parameters. Using GIS and a digital elevation model the grade adjacent to schemes was screened. The inferred slope angle and distance to flat ground were compared to the parameters above. Gentler falling topography and shorter sloping distances were considered to relate to better conditions than the models. Steeper falling topography and longer sloping distances were considered to relate to worse conditions comparable to the model.

In nature, ground slope and elevations continually vary along river reaches, and impractically, infinite models would be required to reflect this. The above conditions were therefore set to constrain the scope of modelling. Analysis also considered a 'hole' scenario where a seepage face was extended to the base of the blanket soil layer to represent a ground crack or gapping around a buried object.

The Tarawera scheme model contains all of the simulations; assigned alphabetically A through to X. Governing cases were then identified to focus assessments for other schemes.

Hydraulic properties assigned to the stop-bank soils reflect the earth-fill used to construct the flood defences. The foundation soil represents the ground that has high permeability, which promotes the migration of seepage. The blanket soils tend to constrain or slow the seepage, being of lower permeability.

Each letter corresponds to a simulation as defined in the following table. Every second simulation varies only from the previous (B&A, D&C, E&F etc.,) by difference of assigned permeability values, and attempt to match the colour used in the models. This provides sensitivity control. The darker orange backing represents the higher permeability parameters, these models result in further seepage migrations.

Other visual identifiers used for the result cells are:

Red	Green	Blue	Lighter	Darker	Yellow
			Lighter	Darker	
			Lighter	Darker	
40 m foundation thickness	2.0 m foundation thickness	5.0 m foundation thickness	Thinner blanket soil	Thicker blanket soil	GWT sensitivity check using an initial 2.0 m deep water table.
Considered to represent unlimited thickness	Considered to represent limited thicknesses		Blanket soil thickness		

Table 2: Colour representation.

Simulation		Stop-bank permeability [homogenous] (k)	Foundation soil of higher permeability* [homogenous] (k)	Foundation soil thickness (m)	Blanket soil of lower permeability [homogenous] (k)	Blanket soil thickness (m)
A		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**Not limited**	**5×10^{-7} m/s**	**Nil**
B		1×10^{-10} m/s	1×10^{-4} m/s	Not limited	5×10^{-7} m/s	Nil
C		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**Not limited**	**5×10^{-7} m/s**	**0.5 m**
D		1×10^{-10} m/s	1×10^{-4} m/s	Not limited	5×10^{-7} m/s	0.5 m
E		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**Not limited**	**5×10^{-7} m/s**	**1.0 m**
F		1×10^{-10} m/s	1×10^{-4} m/s	Not limited	5×10^{-7} m/s	1.0 m
G		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**Not limited**	**5×10^{-7} m/s**	**2.0 m**
H		1×10^{-10} m/s	1×10^{-4} m/s	Not limited	5×10^{-7} m/s	2.0 m
I		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**2.0 m**	**5×10^{-7} m/s**	**Nil**
J		1×10^{-10} m/s	1×10^{-4} m/s	2.0 m	5×10^{-7} m/s	Nil
K		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**2.0 m**	**5×10^{-7} m/s**	**0.5 m**
L		1×10^{-10} m/s	1×10^{-4} m/s	2.0 m	5×10^{-7} m/s	0.5 m
M		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**2.0 m**	**5×10^{-7} m/s**	**1.0 m**
N		1×10^{-10} m/s	1×10^{-4} m/s	2.0 m	5×10^{-7} m/s	1.0 m
O **		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**2.0 m**	**5×10^{-7} m/s**	**2.0 m**

P **		1×10^{-10} m/s	1×10^{-4} m/s	2.0 m	5×10^{-7} m/s	2.0 m
Q		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**5.0 m**	**5×10^{-7} m/s**	**Nil**
R		1×10^{-10} m/s	1×10^{-4} m/s	5.0 m	5×10^{-7} m/s	Nil
S		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**5.0 m**	**5×10^{-7} m/s**	**0.5 m**
T		1×10^{-10} m/s	1×10^{-4} m/s	5.0 m	5×10^{-7} m/s	0.5 m
U		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**5.0 m**	**5×10^{-7} m/s**	**1.0 m**
V		1×10^{-10} m/s	1×10^{-4} m/s	5.0 m	5×10^{-7} m/s	1.0 m
W		**1×10^{-10} m/s**	**1×10^{-3} m/s**	**5.0 m**	**5×10^{-7} m/s**	**2.0 m**
X		1×10^{-10} m/s	1×10^{-4} m/s	5.0 m	5×10^{-7} m/s	2.0 m

Table 3: Description of simulations

* The permeability's used vary with the type of soil predominant within the catchment. For the Whakatāne, Tauranga, Waioeka and Otara rivers the permeability's were reduced from those of the other rivers by a magnitude of ten [10] to be 1×10^{-4} and 1×10^{-5} m/s. This reflects the reduced presence of pumiceous soils.

** The thickness of the blanket soil extends the full depth of the foundation soil therefore no aquifer exists in the model. The results indicate the effect of seepage migrating only through the blanket region and are included for interest only.

Anisotropy of the earthen embankment due to compaction in layers has been accounted for by assigning an anisotropic ratio of 0.33 to the embankment soil. This means the horizontal permeability is three times the vertical due to the compaction processes during construction.

A generic model representation is shown in the following figure. Geometries used in analysis are discussed in the geometry section. Green layers represent blanket soil, yellow layers represent embankment soil and orange represents permeable foundation soils.

The thickness of the green layers can be adjusted to represent the blanketing. Darker orange represents a higher permeable soil as opposed to the light orange which represents the lower permeable soil. The orange layers can be toggled to control a confining bottom layer.

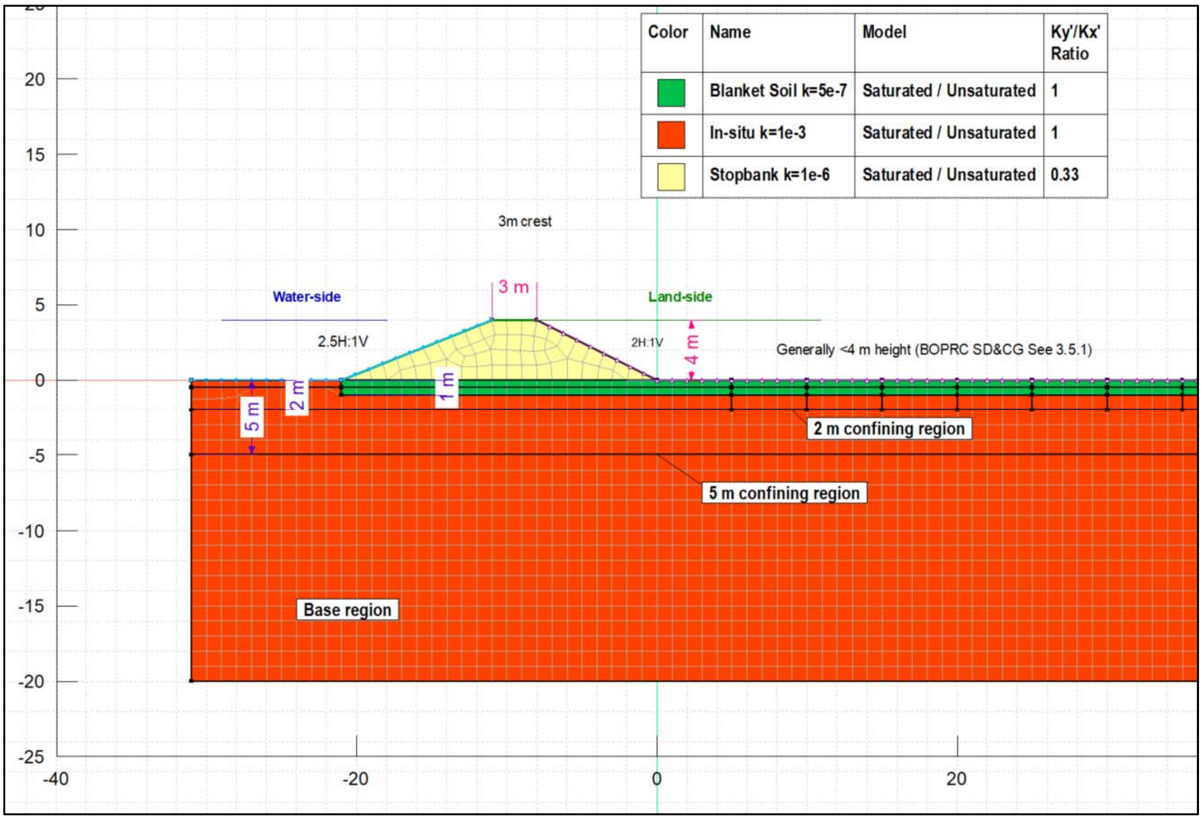

Figure 2: Example seepage model. In this conceptual illustration there is 1.0 m of blanket soil (green) and no thickness limit for the in-situ foundation soils (orange). Stopbank soil (light yellow) is modelled as a trapezoid shape to account for the batters and crest.

1.1.6 Hydraulic Parameters

Soils were assigned the parameters shown in the following table:

Scheme	High Permeability	Low Permeability	Steady state stage
Tarawera	**$1x10^{-3}$ m/s**	**$1x10^{-4}$ m/s**	**2.2 m**
Rangitāiki	**$1x10^{-3}$ m/s**	**$1x10^{-4}$ m/s**	**3.7 m**
Kaituna	**$1x10^{-3}$ m/s**	**$1x10^{-4}$ m/s**	**3.7 m**
Whakatāne/Tauranga & Waioeka/Otara	**$1x10^{-4}$ m/s**	**$1x10^{-5}$ m/s**	**3.7 m**

Table 4: Hydraulic Parameters

In all cases the stopbank material was given a permeability of 1×10^{-10} m/s which is considered to be a very low permeability medium. This was to reduce interaction of the water table within the stop-bank as this study focusses on the propagation of the seepage plume within the foundation soils beneath the stop-bank.

1.1.7 Surface seepage

The surface seepage conditions govern the volume of water that can reach the ground surface on the inside of a stopbank and the potential for soil particles to be washed out. To assess the potential for seepage to develop at an inland ground surface the distance from the stopbank toe to where pore pressure at the surface tended to zero was assessed. To estimate where soil particles could be washed out the distance to where horizontal gradients reduced to a value of 0.4 was measured. Based on the Bay of Plenty Regional Council Stopbank Design and Construction Guidelines, for exiting gradients a critical hydraulic gradient of 0.4 is commonly used for some pumiceous soils within the Bay of Plenty. Detailed assessments of distances associated with critical gradients are required to support a bylaw application. It should be clear what safety factors were used in assessment together with sound reasoning.

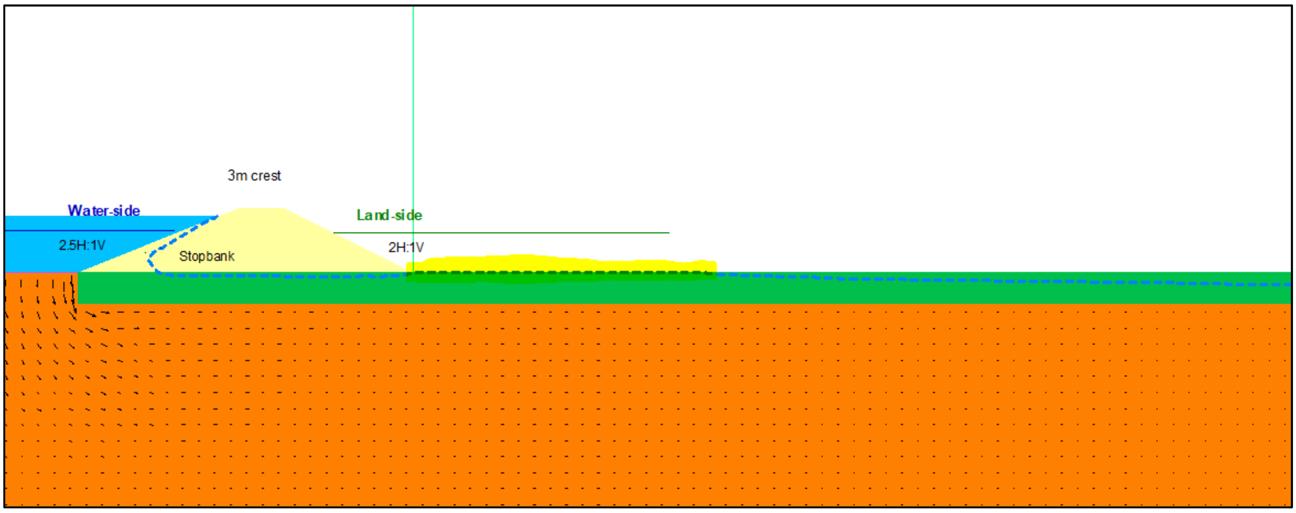

Figure 3: Example of a seepage model with the developed seepage face highlighted in yellow.

1.1.8 **Heave**

When soils loses particle to particle contact - also known as effective strength - it can heave. Water pressure is required to exceed the total stress of the soil. Confining soils such as soil blankets inhibit the release of water pressure such that pressure will increase in the underlain soil aquifers proportionate to the pressure head. The downward/resisting force provided by the soil weight is dependent on the soil density and thickness of the deposit. To assess heave the total stress was divided by the upward water pressure in order to calculate a factor of safety. In each case a *SIGMA/W* analysis - which calculates stresses - was tied to the parent seepage analysis associated with the time interval representing the most severe progression of pore water pressures. Data was then exported to *EXCEL* (Microsoft) so safety factors could be tabulated.

When the calculated safety factor is below one [1] heave is anticipated. As values increase above one [1] the theoretical risk of heave reduces. A safety factor of both 1.0 and 1.2 were analysed for the assessment of heave.

Figure 2 shows the two data sets used in the calculation:

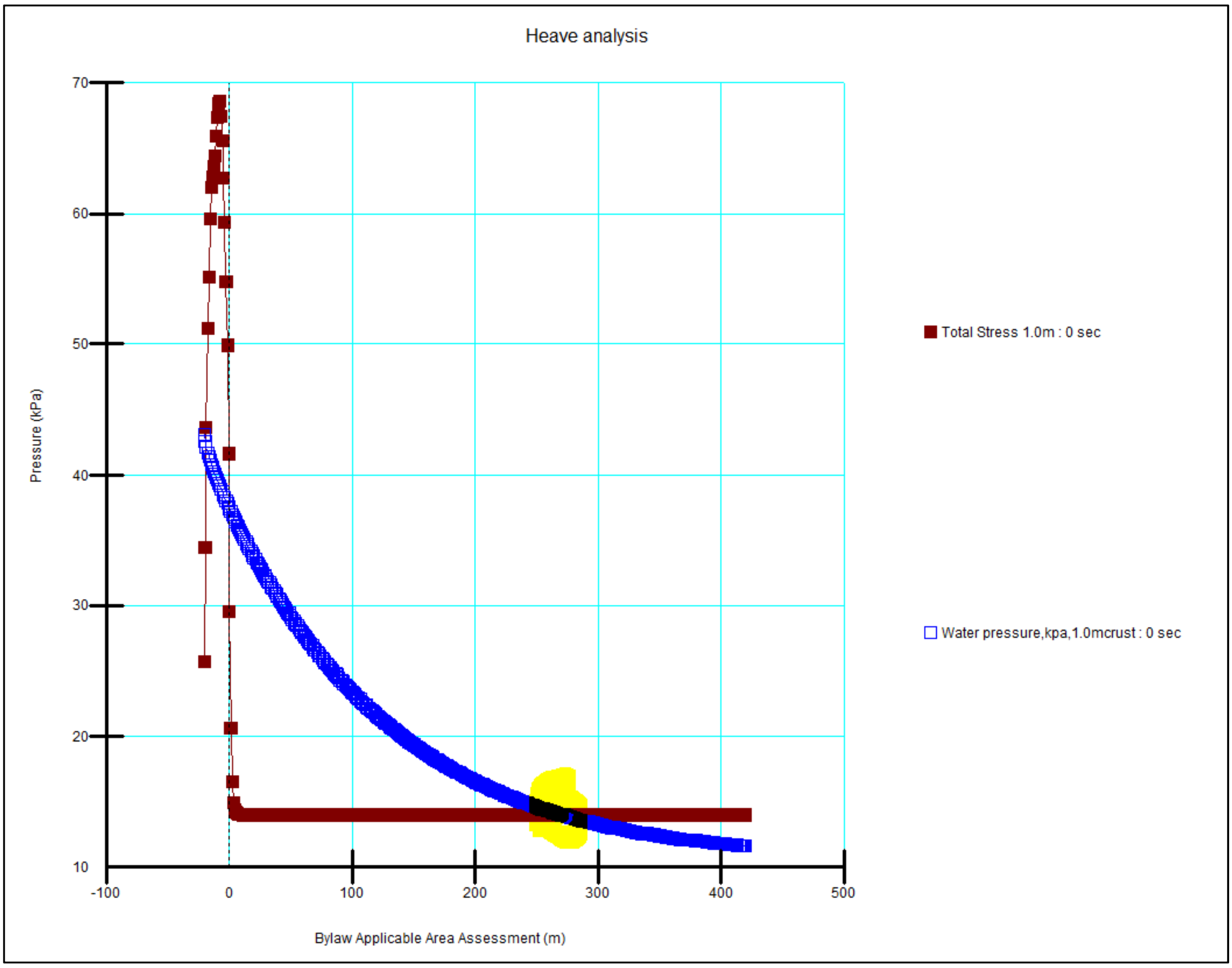

Figure 4: Method of heave evaluation. The highlighted region represents a factor of safety = 1, to the left of the intersecting lines - around 270 m - the ground is considered susceptible to heave.

1.1.9 Cracks/penetrations/buried objects - "Holes"

Where there is a connection between the ground surface and the seepage water below, short circuiting of ground water flow can occur. This connection may be in the result of a ground crack, around the surface of a buried object or up the side of a penetration. Tree topple, anchor/foundation pull-out, ground movement or gapping are examples that could cause a short circuit. Pressure relief in the form of filter collars which let out water without eroding soil particles may be required. These distances should be verified with site specific models; the 'hole scenario' section of this document provides some guidance on the distances that may need to be considered.

Horizontal hydraulic gradients were assessed by limiting exiting values to 0.4 and 0.1 depending on the pumiceous nature of the catchment. Distances were then recorded from the inland stopbank toe. These gradients are considered to horizontal exit gradients to an unconfined-space such as the base of a penetration, a crack or a hole including the radial effect of pressure surrounding a point.

When the blanket soil is 2.0 m thick and the initial water table is set at 1.0 m depth there is instantaneous gradients from the start of the simulation, so the nearest horizontal node to the water source was selected for observation. Note that negative values represent movement to the right, positive values represent movement leftward; this is how the software presents result. In a similar manor, negative can represent upward or out of the system, while positive can be downward.

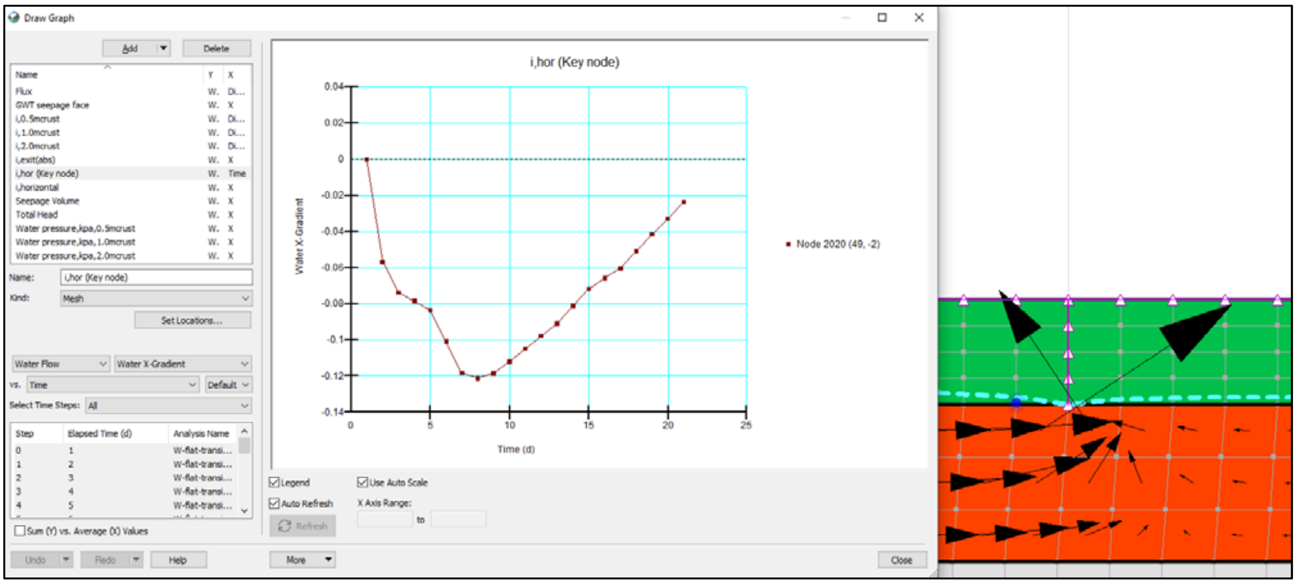

Figure 5: Illustration of node selection shown by the blue dot and a resulting graph where gradients were measured near 0.12 around 8 days.

1.1.10 Soil Unit Weight

The assumed soil weights are given in Table 5.

Soil layer	Unit weight (γ)
Embankment	16 kN/m^3
Blanket Soil	15 kN/m^3

Table 5: Assigned unit weight for soil layers used in heave analysis.

1.1.11 Geometry

Flood defences were modelled as stopbanks with a universal cross-section that was developed following the Bay of Plenty Regional Council Stopbank Design and Construction Guidelines (SD & CG). This geometry is conservative in terms of the present analyses as most stopbanks have been constructed with 3H:1V batters or flatter for stability and maintenance reasons resulting in a wider footprint than produced by the Table 6 geometry. Future review of the SD & CG together with current best practice may further increase the conservatism of geometry regularly used for stop-bank design.

Stopbank height*	Water side batter slope	Land side batter slope	Crest width
4 m**	**2.5H:1V**	**2H:1V**	**3 m**

Table 6: Adopted stop-bank geometries.

* Mentioned in the SD&CG as *generally* less than this height.

** Tarawera stopbank heights were reduced to reflect their actual condition as discussed in Part 2.

1.1.12 Hydrographs

It is worth noting that all modelling has assumed an arbitrary datum, and is referred to in terms of stage and not reduced level. There may be reaches along schemes that are designed to withstand a greater pressure head than that used in modelling.

As all river schemes are designed for some freeboard allowance the peak of the hydrographs in modelling were set to at least 0.3 m below crest level. In some reaches freeboard may be up to 0.8 m, and occasionally the actual crest height will exceed the design height plus the added freeboard allowance. No modelling was completed with the freeboard added, nor for the Hydraulic Top Of Levee (HTOL) case which is also referred to as 'bank-full conditions'. This is in-line with the International Levee standard.

1.2 Modelling objective

Sequential modelling of the stopbanks on each river scheme was completed to quantify theoretical bylaw applicable areas, measured inland from the landward toes of any stopbank or flood defence.

To some degree the models act as a 'blind study' to compare directly with exclusions widths defined in the 2008 and previous versions of the Floodway and Drainage Bylaw. Known numerical analysis had begun in this area prior to 2005, so during the previous review there was some numerical data available to accompany anecdotal observations.

Generic inputs and model surfaces were used where possible in order to highlight the influence of the selected variables on model response.

1.1.13 Marker Cells

In each seepage face assessment the Simulation W for flat ground was highlighted in green as the extent to which hydraulic gradients up to 0.4 could propagate under transient conditions. This model has 5.0 m of foundation soils of the higher permeability range with 2.0 m blanket soil. This case was selected to be relevant for comparison between schemes as the results were generally well quantified and this ground profile is considered to exist at all sites.

Similarly for the heave assessments, Simulation U [flat ground] was highlighted in magenta. These cells are considered relevant to the Tarawera model and the soil conditions within that catchment so were carried through to the other heave assessments to provide another means to compare the data sets. The 5.0 m foundation soil with 1.0 m blanketing is also considered to be very likely to exist in all catchments.

Yellow cells refers to other simulations that were considered in assessing the quantitative data. These values are generally near or in agreement with the green and magenta cells. The commentary section of each scheme assessment will usually mention these cells.

Green or magenta cells take preference over yellow cells.

These *marker* cells provides useful comparison between assessments.

Models were designed so they could be readily accessed to aid site specific studies or be re-calibrated on demand.

It was necessary to keep the soil models simple for this bylaw review. Anomalies such as old river meanders and faults crossing rivers have therefore not been taken into account. It is considered however that there are sufficient conservatisms in the soil models and the soil and flood parameters used to provide adequate BAAs for the majority of the known issues relating to flood defence security.

Part 2: Tarawera Assessment

Seepage Parameters

Foundation soils were assessed using permeability values of $k=1\times10^{-3}$ m/s (high k) and $k=1\times10^{-4}$ m/s (low k). This provides representation of the pumiceous sands and gravels found in the Rangitāiki Plains.

Geometric Model

The Tarawera cross-section is shown below:

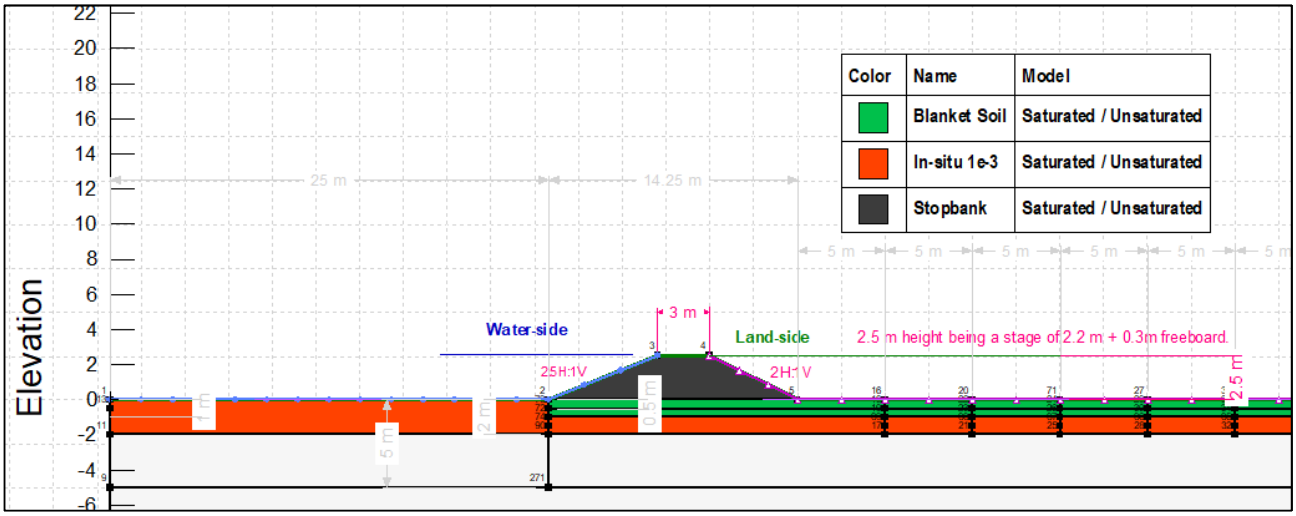

Figure 6: A Tarawera seepage model with sloping ground inland. Batter gradients are shown accommodating a 2.5 m crest height with 3.0 m crest width. This particular simulation shows the setup with 1.0no blanket soil and the higher permeability (darker orange) foundation soil of 2,0 m limited thickness, Simulation K.

Topography Screening

The sloping to flat model was set at 60 m. The following images presented in-line show LiDAR at a relevant section where a 60 m distance has a change in elevation of 1.5 m, relating to a 1.43° slope.

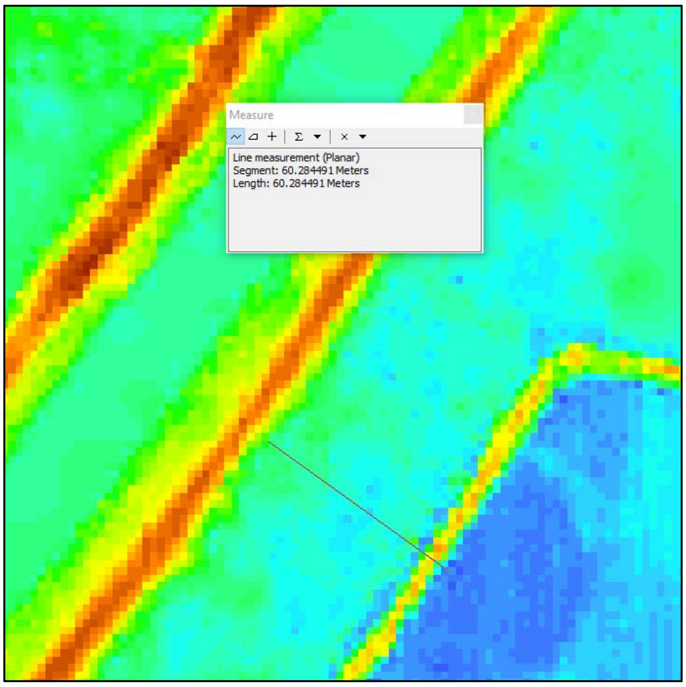

Figure 7: Measured section

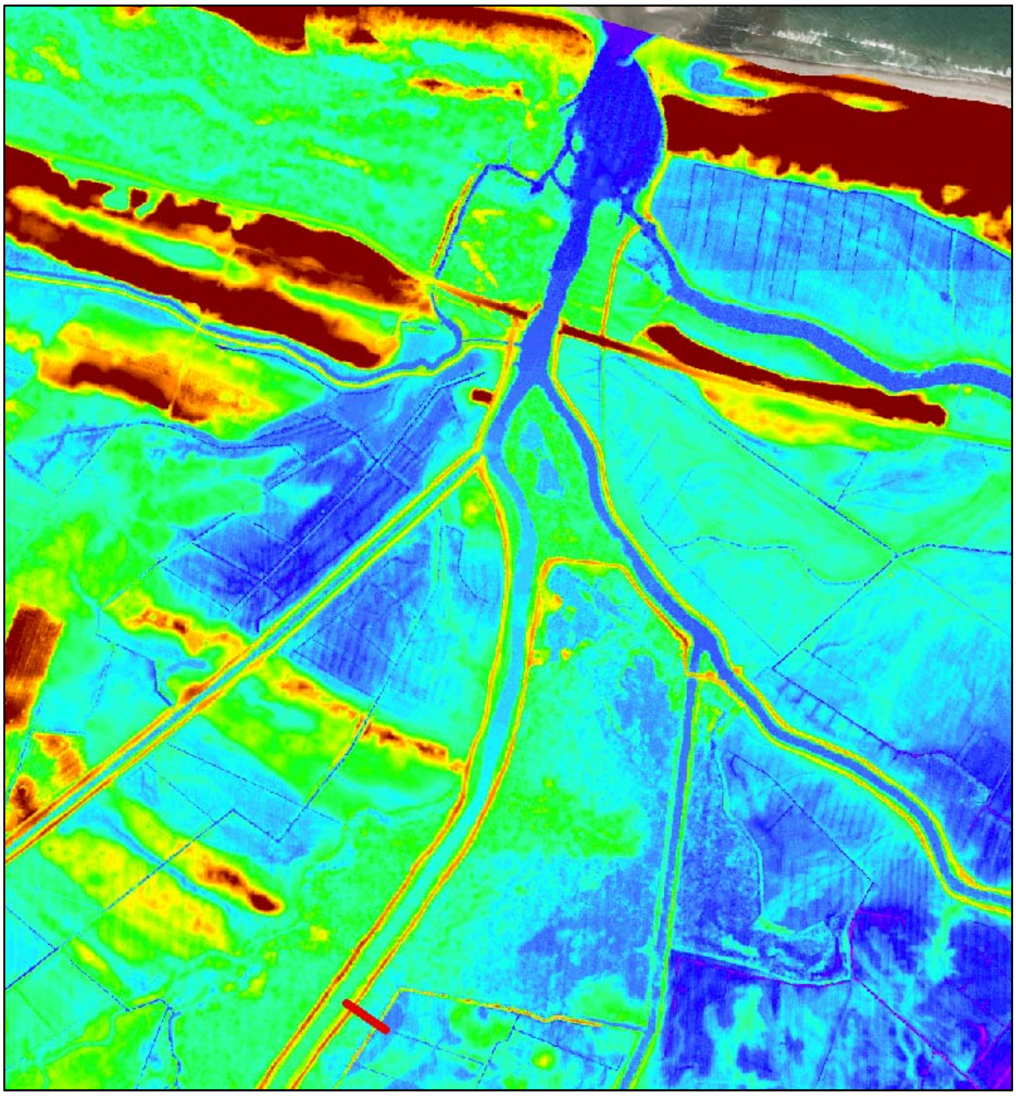

Figure 8: Tarawera LiDAR with red line showing location of section.

Design Hydrograph

The hydrograph used for modelling relates only to this bylaw review. Due to varying flood heights and ground levels along a scheme a generic hydrograph has been adopted for modelling. For site-specific assessment hydrographs calibrated to the flood and stretch of flood defence should be used.

The BOPRC Flood Warning Manual (Bay of Plenty Regional Council, 2018) details a mean flow of 30.2 cumecs in the Tarawera River at the Awakaponga recorder. In the same manual the rating table has this discharge corresponding to a stage of approximately 0.90 m. The peak 100 year stage height is 3.20 m, being 2.30 m above average stage. Freeboard above the estimated peak flood level is provided in stopbank design to take into account inaccuracies in the water level models, waves, the effects of bends, etc. The freeboard allowance for the Tarawera River is about 0.30 m for the scheme, therefore the rise from average water level to the crest of a stopbank would equal the 100 year stage with the freeboard added to give 2.60 m.

This is comparatively lesser than other rivers, so for modelling the Tarawera scheme the geometry was reduced to give a crest height of 2.5 m with a theoretical DWSE pressure head of 2.2 m. This geometry was shown previously in Figure 6. For the other schemes a crest height of 4.0 m and DWSE pressure head of 3.7 m was applied, this geometry is presented in Figure 13. The Tarawera rating table is copied from its original documentation and included below:

11.11 **Tarawera at Awakaponga rating table**

STATION NUMBER JM102399
Tarawera at Awakaponga

LATITUDE 37.9414100646973
LONGITUDE 176.766693115234
Rating for Discharge (m^3/s)

Data correct as at May 2018
The latest rating curves are available at: https://envdata.boprc.govt.nz/

Stage (m)	Discharge (m^3/s)	Reference	Stage (m)	Discharge (m^3/s)	Reference
0.1	15		1.7	51	
0.2	17		1.8	53	
0.3	19		1.9	56	
0.4	21		**2**	**59**	**River rising**
0.5	23		**2.1**	**62**	**5 year flood**
0.6	25		2.2	64	
0.7	27		2.3	68	
0.8	29		**2.4**	**71**	**Inspection level**
0.9	31		2.5	74	
1	**34**		**2.6**	**77**	**20 year flood**
1.1	36		2.7	81	
1.2	38		2.8	84	
1.3	41		2.9	88	
1.4	43		**3**	**91**	**50 year flood**
1.5	46		3.1	95	
1.6	48		**3.2**		**100 year flood**

* Equation points

Figure 9: Tarawera at Awakaponga rating table from the BOPRC Flood Warning Manual

A hydrograph was produced to simulate a Tarawera duration flood, with data from the Hydraulic Design of the Awarua Drain (Environment Bay of Plenty, 2007). This hydrograph is copied from its original documentation and included below:

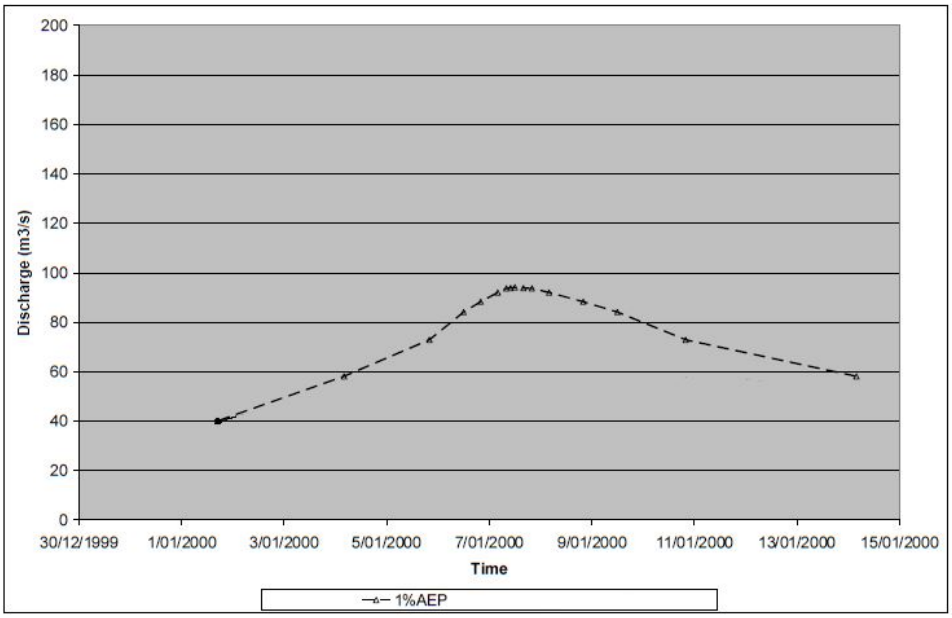

Figure 10: Design Hydrograph for the Tarawera River shown in the black dashed line.

Using the above references a hydrograph for modelling was developed. The duration of the peak is approximately of 2 days, before the water level drops down to non-flood conditions over the following 6 days.

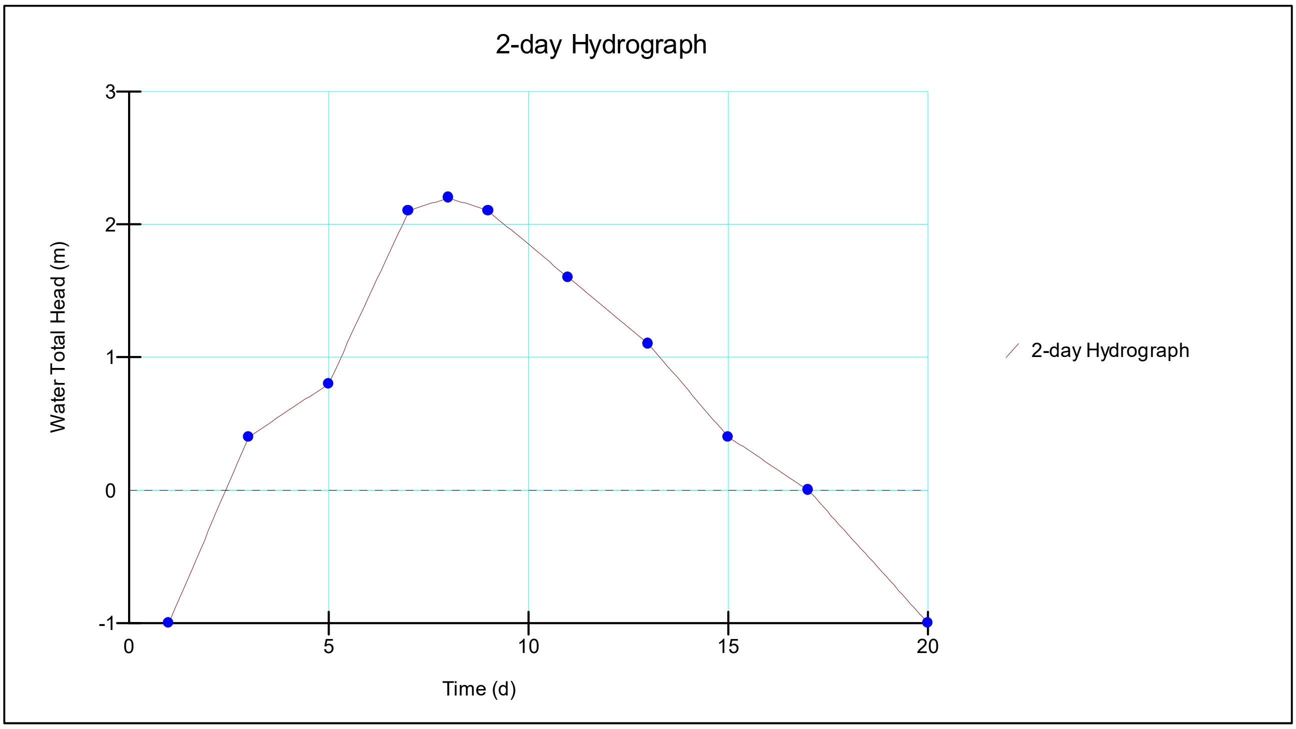

Figure 11: Tarawera Flood hydrograph used for bylaw modelling.

2.1 Seepage face review

The distance from the stopbank toe to which a seepage face can develop is summarised for each simulation in Table 5 below:

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground				Sloping ground				Sloping for 60 m then transitioning to flat ground			
	Measured distance to where a seepage face develops (m)		Measured distance to an exit gradient of 0.4		Measured distance to a seepage face develops (m)		Measured distance to an exit gradient of 0.4		Measured distance to a seepage face develops (m)		Measured distance to an exit gradient of 0.4	
	Transient	Steady State	Transient	Steady state	Transient	Steady State	Transient	Steady State	Transient	Steady State	Transient	Steady State
A (U/0)	**65**	**71**	**<1**	**D/O**	**106**	**115**	**<1**	**D/O 0.34 at toe**	**99**	**101**	**<1**	**D/O 0.35 at toe**
B (U/0)	33	Same as A	<1	D/O	15	Same as A	<1	Same as A	82	Same as A	<1	Same as A
C (U/½)	**281**	**285**	**239**	**241**	**310**	**315**	**253**	**256**	**326**	**327**	**278**	**279**
D (U/½)	96	174	72	111	69	215	100	104	201	215	136	141
E (U/1)	**303**	**304**	**226**	**226**	**327**	**328**	**226**	**227**	**340**	**340**	**264**	**265**
F (U/1)	193	209	109	102	210	241	71	80	235	243	133	137
G (U/2)	**312**	**315**	**170**	**171**	**331**	**337**	**139**	**140**	**349**	**350**	**213**	**221**
H (U/2)	218	242	75	79	230	270	23	27	263	274	113	115
I (2/0)	**4**	**120**	**<1**	**D/O**	**3**	**328**	**<1**	**D/O 0.25 at toe**	**3 R/S 58-62**	**117**	**<1**	**<1**
J (2/0)	1	165	<1	D/O	<1	328	<1	Same as J	2 Doesn't RS	3 R/S 58-157	<1	<1
K (2/½)	**65**	**135**	**49**	**79**	**57**	**153**	**36**	**74**	**149**	**169**	**98**	**102**
L (2/½)	14	54	9	20	4	67	2	16	69	91	10	14
M (2/1)	**107**	**146**	**57**	**63**	**94**	**152**	**43**	**53**	**149**	**175**	**81**	**84**
N (2/1)	27	60	12	14	9	67	2	11	68	93	10	11
O (2/2)	**D/O**	**199**	**D/O**	**D/O**	**D/O**	**303**	**D/O**	**D/O 0.25 at toe**	**D/O**	**4 R/S 58-211**	**D/O**	**D/O 0.26 at toe**
P (2/2)	D/O	201	D/O	D/O	D/O	Same as O	D/O	Same as O	D/O	Same as O	D/O	Same as O
Q (5/0)	**10**	**16**	**<1**	**D/O**	**7**	**39**	**<1**	**D/O 0.32 at toe**	**7 R/S 54-64**	**7 R/S 54-67**	**<1**	**D/O 0.32 at toe**
R (5/0)	6	17	<1	D/O	5	Same as Q	<1	Sane as R	4	7 R/S 54-68	<1	Same as Q

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground				Sloping ground				Sloping for 60 m then transitioning to flat ground			
	Measured distance to where a seepage face develops (m)		Measured distance to an exit gradient of 0.4		Measured distance to a seepage face develops (m)		Measured distance to an exit gradient of 0.4		Measured distance to a seepage face develops (m)		Measured distance to an exit gradient of 0.4	
	Transient	Steady State	Transient	Steady state	Transient	Steady State	Transient	Steady State	Transient	Steady State	Transient	Steady State
S (5/½)	**120**	**190**	**96**	**133**	**115**	**194**	**82**	**127**	**216**	**228**	**157**	**161**
S (5/½) GWT 2.0 m deep	**66**	**-**	**54**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
T (5/½)	29	84	22	39	19	95	11	33	93	116	38	44 R/S 53-63
U (5/1)	**205**	**220**	**123**	**138**	**187**	**210**	**102**	**111**	**245**	**252**	**152**	**154**
V (5/1)	63	104	31	35	44	107	19	27	100	130	30	32 Nearly R/S at hip
W (5/2)	**215**	**242**	**85**	**90**	**183**	**223**	**58**	**65**	**256**	**269**	**118**	**120**
X (5/2)	63	121	18	21	44	116	9	14	101	143	12	14

All values in metres

D/O = Doesn't Occur

R/S = Re-surfaces; The seepage surfacing at ground level does not continue and so this phreatic surface is below ground, however due to boundary conditions of the modelling the ground-water reaches the end of the model and 'backs up' causing it to re-surface. The distance in which the subject isoline re-surfaces follows the plus '+' symbol.

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note 2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 7: Results of Tarawera assessment for development of a 'seepage face'

2.1.1 Commentary

There are two [2] boreholes registered on the New Zealand Geotechnical Database near the subject scheme. On the right bank near the river mouth the borehole is predominately coarse sand being homogenous. 1.4 km upstream about 362 m east of the right bank the log indicated variable, layered soil conditions. These results are not complimentary and therefore foundations soils greater than the 5 m thickness could exist at particular reaches.

Based on the unlimited foundation thicknesses, hydraulic gradients were 278 and 136 m respectively for high and low permeability simulations. The other values for high permeability were a similar order of magnitude, these values seem unrealistic for this river scheme. It could then be deducted that 136 is an upper bound.

Knowing that 5.0 m thicknesses of highly permeable soils exist – if only at least near the river mouth - this data set was given more consideration than the 2.0 m data set. For flat ground a seepage face was predicted between 120-215 m under transient conditions, with the hydraulic gradients not exceeding 0.4 between 85 – 123 m. Similarly for sloping ground values ranged between 216-256 m for a seepage face, and 118-157 for hydraulic gradients not exceeding 0.4.

When the ground water was initially set at 2.0 m depth as opposed to 1.0 m depth the results were reduced by about half.

Noteworthy is the seepage face distances for simulations U and W, which both have a seepage face developing at a similar distance, but have different distances for the propagation of hydraulic gradients of 0.4. The blanket soil didn't influence the seepage face, but thicker blanketing results in a hydraulic gradient of 0.4 propagating a shorter distance.

As the ratio of foundation soil to blanketing thickness increases, the transient and steady-state values tend to converge. For Simulation C, E and G particularly illustrate this, as opposed to Simulation K where the transient values for flat and sloping runs were about half the steady-state value. Interestingly, for the transitional model the transient value was within 20% of the steady state value. This identifies that sloping ground which flattens could represent regions of greater seepage hazard provided the wetting front reaches the transition.

2.1.2 Conclusions

Deep foundation sands thicknesses can exist within this scheme. Slopes can exceed 1° over a 60 m distance but tend to flatten thereafter.

From the unlimited soil thickness models with lower permeability, flat ground conditions and limited hydraulic gradients to 0.4 the data set is:

{72, 75, 109}

From the 5.0 foundation soil models with higher permeability and limiting hydraulic gradients to 0.4 under transient conditions, the following data set is:

{58, 82, 85, 96, 102, 118, 123, 152, 157}

Ten of the twelve identified data values are within 125 m. As the purpose of this assessment is to define an applicable distance for bylaw application and the above analysis is designed to cover extremes, it is proposed to select a distance that encompasses the majority of the analysed results and is within the determined upper band of 134 m.

<u>120 m is selected for the distance relating to hydraulic gradients related to seepage for the Tarawera catchment.</u>

2.1.3 List of appended graphs/figures.

Some illustrations or graphical outputs are included in the appendices. This are all based on the Tarawera scheme and are intended to illustrate the approach to modelling and interpretation. Although they weren't reproduced for all schemes, they convey transferable concepts. The list includes:

- Simulation A/SS exiting hydraulic gradients.
- Simulation A/SS overlain graphs of pore-water-pressure at surface with exiting hydraulic gradients on day 6.
- Simulation B/TR showing exiting hydraulic gradient overlain where pore-water-pressure reaches the ground surface.
- Simulation C/TR showing overlain graphs of pore-water-pressure at surface with exiting hydraulic gradients. When the seepage face rises to the value of zero, this is simulating the seepage surfacing. Over any distance where this occurs it is valid that the exit gradient shall be checked.
- Simulation C/TR showing heave occurring the full extent to the far-field boundary, referred to as 'FF' in the results.

2.2 Heave analysis

For all simulations the length to which heave is anticipated is summarised in the following table. Where alphabetic entries are not listed this is due to no blanket soil allowing water pressure confinement in those particular simulations, or the simulation is not considered to govern or to add significant benefit to the data set. For sloping models often far-field boundary conditions caused a backing up effect. Where possible this effect was ignored if not considered to be influencing the wetting front.

SIMULATION (Foundation thickness /Blanket Thickness)	FLAT GROUND				SLOPING GROUND				60 m of SLOPING GROUND THEN FLAT GROUND			
	Measured distance to FoS=1.0		Measured distance to FoS=1.2		Measured distance to FoS=1.0		Measured distance to FoS=1.2		Measured distance to FoS=1.0		Measured distance to FoS=1.2	
	Transient	Steady State	Transient	Steady state	Transient	Steady State	Transient	Steady State	Transient	Steady State	Transient	Steady State
A (U/0)	-	-	-	-	-	-	-	-	-	-	-	-
B (U/0)	-	-	-	-	-	-	-	-	-	-		
C (U/½)	**227**	**233**	**254**	**260**	**244**	**252**	**281**	**287**	**276**	**308**		
D (U/½)	66	99	80	131	36	96	51	151	134	140		
E (U/1)	**178**	**206**	**231**	**254**	**136**	**151**	**221**	**231**	**213**	**219**		
F (U/1)	82	87	128	135	17	23	69	81	90	93		
G (U/2)	**64**	**104**	**162**	**194**	**34**	**68**	**211**	**223**	**183**	**190**		
H (U/2)	25	31	87	95	D/H	D/H	76	95	83	89		
I (2/0)	-	-	-	-	-	-	-	-	-	-		
J (2/0)	-	-	-	-	-	-	-	-	-	-		
K (2/½)	**48**	**72**	**56**	**96**	**40**	**75**	**49**	**111**	**99**	**103**		
L (2/½)	8	17	11	25	D/H	16	2	28	10	14		
M (2/1)	**43**	**53**	**68**	**82**	**23**	**28**	**45**	**56**	**37 FOS~1.02 near hip**	**59**		
N (2/1)	7	10	15	20	D/H	5	D/H FoS,min=1.31	11	4	6		
O (2/2)	**D/H**	**D/H FoS=1.66**	**D/H-**	**D/H**	**D/H**	**D/H**	**D/H**	**D/H**	**D/H**	**D/H FoS~1.55**		
P (2/2)	D/H	Same as O	D/H	D/H	D/H	D/H	D/H	D/H	D/H	D/H		
Q (5/0)	-	-	-	-	-	-	-	-	-	-		
R (5/0)	-	-	-	-	-	-	-	-	-	-		

S (5/½)	**92**	**125**	**105**	**155**	**82**	**125**	**98**	**161**	**157**	**163**		
S (5/½) GWT 2.0 m bgl	**52**	**Same**	**58**	**Same**	**-**	**-**	**-**	**-**	**-**	**-**		
T (5/½)	20	34	25	48	9	33	12	54	D/H FoS~1.3 near hip	62		
U (5/1)	**94**	**100**	**140**	**155**	**59**	**66**	**105**	**114**	**111**	**115**		
V (5/1)	25	28	40	47	9	13	20	28	12	14		
W (5/2)	**30**	**49**	**87**	**107**	**33**	**41**	**97**	**113**	**95**	**99**		
X (5/2)	D/H	8	22	27	D/H	D/H	18	28	D/H FoS~1.01	7		

All values in metres

- = not assessed

D/H = Doesn't Heave

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note 2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 8: Results of Tarawera assessment for development of 'heave'.

2.2.1 Commentary

Day 8 was the critical epoch for assessment of heave. This was deducted by checking a random scattering of nodes to see the time epoch that registered the highest pore-water pressure development. To validate the results a stress analysis that can compare pore-water pressure to total stress was checked for the critical epoch and 1 day either side. For Tarawera the indicator nodes and results are shown in the figure below. It can be seen on the eighth day the greatest pressures developed.

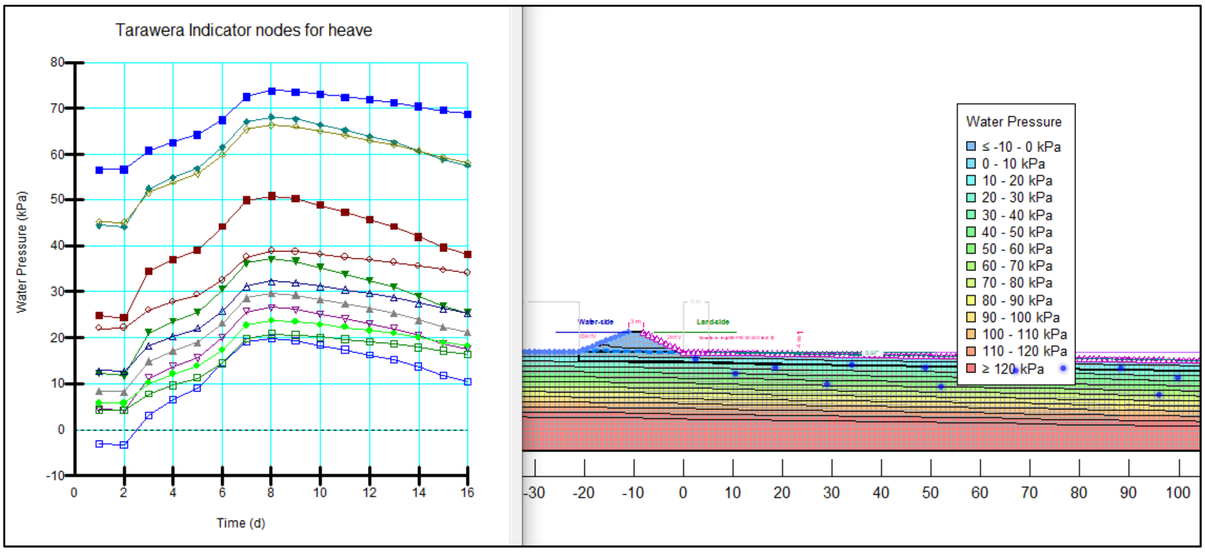

Figure 12: Day 8 was the critical time epoch for heave with the adjoining days, 7 and 9 checked for verification. Indicator nodes are demarcated by blue dots on the model.

For all models the factor of safety increases with thicker blanket soil.

For 1.0 m blanket soil simulations the transient values were nearest to the steady-state, as the initial ground-water was set at 1.0 m depth which coincided with the interface between blanket and foundation soils. For the 0.5 m blanket soil simulation there was initially 0.5 m to the water table which needed to become saturated under the transient load before heave would be expected. This caused the transient and steady state values to have a larger difference. The exception being Simulation C where the ratio of foundation soil to blanket soil became small enough that very little difference occurs.

Simulation K showed that heave was predicted further for flat ground than sloping ground under transient conditions, these values measuring 40 and 48 m. When the transitioning ground was assessed the distance more than doubled to 99 m. This infers that heave is more sensitive to the soil permeability and ratio of blanket to foundation soil, than ground slope. Under steady state conditions the order reversed, however the transition ground was still larger than the other topography conditions. This shows that heave has an increased risk where topography flattens.

As LiDAR demonstrates the transition model is applicable to the Tarawera catchment, the unlimited soil thickness with high permeability soil gives an indication of the upper bound, these values for varying blanket thickness were 276, 213 and 183 m.

Comparing the high permeability transitional model results to the 5.0 and 2.0 m foundation thicknesses results give 37, 99, 157, 111 and 95 m. The low permeability results values did not exceed 12 m.

The low permeability results for flat ground exceed the sloping and transitional ground results for transient conditions. For limited foundation soils these values were 8, 7, 20 and 25 m.

When considering a safety factor (FOS) it is seen that for thin blanket cover there is less separation between the values corresponding to safety factors of 1 and 1.2. As the blanket soil increases, the margin between the values also increase. Most distances doubling in magnitude with 2.0 m blanket thickness. This indicates that heave will likely occur close to the toe when there is thin soil blanketing.

It is noted that when the ground water was initially at 2.0 m, as opposed to being at 1.0 m, the heave distance reduced to just above half the value. Risk of heave increases when ground water becomes shallower.

2.2.2 Conclusions

Based on the commentary it was decided relevant models included limited foundation soil thickness, high permeability and at least 1.0 m of blanket soil. Based on transient conditions, cells that met this criteria are highlighted in yellow. The average of the values is 62.5 m. Values are:

{ 23, 30, 33, 37, 40, 43, 48, 52, 59, 82, 92, 94, 95, 99, 111, 157}

Modelling suggests that when ground conditions represent the modelling then heave could occur beyond 100 m. This is considered a conservative figure. The modelling set is designed to look for extremes. This means the highest value is not necessarily the applicable one as it contains a lot of conservatism. Given fourteen of the sixteen values are less than this 100m, it is proposed:

<u>100 m be selected for the distance relating to heave for the Tarawera catchment.</u>

2.3 Hole scenario

The following table gives the distance to which a critical hydraulic gradients of 0.1 could be exceeded at a hole for each simulation.

Results in the table are based on checks completed at 5 m increments. Increments were built into the models to 150 m, where gradients exceeded this distance the results was displayed as '>150 m' with the gradient value bracketed below the resulting distance.

Note: Simulations that do not possess blanket soil were not checked for a 'hole scenario' as pore water pressure becomes relieved through the unconfined permeable soils near the inland toe and the propagation of hydraulic gradients was not considered to benefit this study. This applies to all schemes assessed for the hole scenario.

SIMULATION (Foundation thickness /Blanket Thickness)	Measured distance to x-grad <0.1 for transient conditions (m)		
	Flat Ground	**Sloping Ground**	**Transition 60**
C (U/½)	140	>150 (0.16)	>150 (0.15)
D (U/½)	70	65	135
E (U/1)	>150 (0.15)	>150 (0.19)	>150 (0.17)
F (U/1)	~150 (0.102)	>150 (0.14)	>150 (0.13)
G (U/2)	>150 (0.185)	>150 (0.25)	>150 (0.22)
H (U/2)	>150 (0.181)	>150 (0.21)	>150 (0.22)
K (2/½)	20	15	20
L (2/½)	15	5	5-10
M (2/1)	25	20	20

SIMULATION (Foundation thickness /Blanket Thickness)	Measured distance to x-grad <0.1 for transient conditions (m)		
	Flat Ground	**Sloping Ground**	**Transition 60**
N (2/1)	15-20	10	10
O (2/2)	No foundation soil	-	-
P (2/2)	" "	-	-
S (5/½)	40	45	70
T (5/½)	30	15	50
U (5/1)	55	65	75
V (5/1)	45	40	65
W (5/2)	65	75*	80
X (5/2)	60	65*	85

* There was a distinguishable decrease for Simulation W and X for sloping ground between the recorded distance and 5.0 m less. Gradients at the described distances had horizontal gradients near 0.05, not 0.10.

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note 2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading of the respective colours.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 9: Results of Tarawera assessment for development of a 'hole scenario'.

2.3.1 Commentary

Only a single simulation with unlimited thickness and high permeability resulted in a distance less than 150 m. This was for flat ground and measured between 135-140 m. Simulation D for low permeability soil produced distances of 70, 65 and 135 for flat, sloping and the transitional model.

These results identify the unlimited soil model as to be an unlikely representation for this scheme when it comes to assessing holes. All results were excluded from the data set.

The 2.0 m foundation soil models all measured less than 25 m. Consequently, the data set was taken from all results relating to the 5.0 m foundation soil simulations, being:

{15, 30, 2 × 40, 2 × 45, 50, 55, 60, 4 × 65, 70, 2 × 75, 80, 85}

Simulation T for sloping ground is the most interesting value. The model was re-checked, and then noted it had the same distance as the matching model with 2.0 m foundation soil. This result is considered an anomaly and may have converged within a very sensitive domain, as seen with two other entries(*). Slight adjustments to the slope, permeability, hydrograph or other inputs may have resulted in a value that better aligned with neighbouring values.

2.3.2 Conclusions

<u>It is considered that the data set that gives the best representation is the 5.0 m of foundation soil thickness. Stratum thicker than 5.0 m may exist but it is more likely that uniform seepage would be somewhat controlled by heterogeneity of the soils or effects of layering. Lighter particles tend to be</u>

buoyed up during loss of effective strength more than denser particles during liquefaction, and heavier lapilli fall from the sky before finer particles during an eruption. Both liquefaction and falling ash are considered relevant reasons, together with alluvion processes.

The consistency of the results for the 5.0m of foundation soil thickness indicate that the upper value of 85 m be selected for the distance relating to a hole scenario for the Tarawera catchment.

2.4 Tarawera Summary

Key results are shown in the summary table that follows:

SEEPAGE MECHANISM	DISTANCE
Seepage propagation	120 m
Heave	100 m
Hole scenario	85 m
BAA Recommendation	**120 m**

Table 10: Tarawera Results Summary Table

Part 3: Rangitāiki Assessment

Governing cases

Following the detailed assessment of the Tarawera River all simulations were completed for the Rangitāiki however only a specific set of simulations were selected for assessment.

Models with no blanket soil were removed for assessment as they illustrate that pressure relief is occurring near to the inland toe such that confined seepage pressures do not occur. They were also of no benefit for the analysis of heave.

The higher permeability models with unlimited foundation thickness were excluded as the distances would be greater than the Tarawera which produced results over 300 m. The lower permeability models were retained.

For the limited foundation soil models only the high permeability simulations were assessed, as it is considered that 5.0 m aquifers with permeability’s of 1×10-3 m/s are very likely to exist on this scheme. Geotechnical investigations and laboratory testing support this. The low permeability models were therefore excluded for limited soil thickness simulations.

During the Tarawera modelling for heave it was observed that a safety factor of 1.2 could result in double the distances, particularly when blanket soil thickens. Given that the Rangitāiki will have thick blanketing in areas, the results are predicted to result in excessive distances and only results relating to a safety factor of one were assessed.

It can be seen that simulations O & P do not include any foundation soil thickness. They were removed from all future assessment on the basis that permeable soils in the order of magnitude of interest to this research underlain the study areas in all locations to some effect.

Parameters

Foundation soils were assessed using permeability values of k=1×10-3 m/s (high k) and k=1×10-4m/s (low k). This provides representation of the pumiceous sands and gravels in the Rangitāiki Plains.

Geometric Model

The Rangitāiki cross-section is shown in the figure that follows. This same geometry is also used for the Kaituna, Whakatāne-Tauranga and Waioeka-Otara assessments.

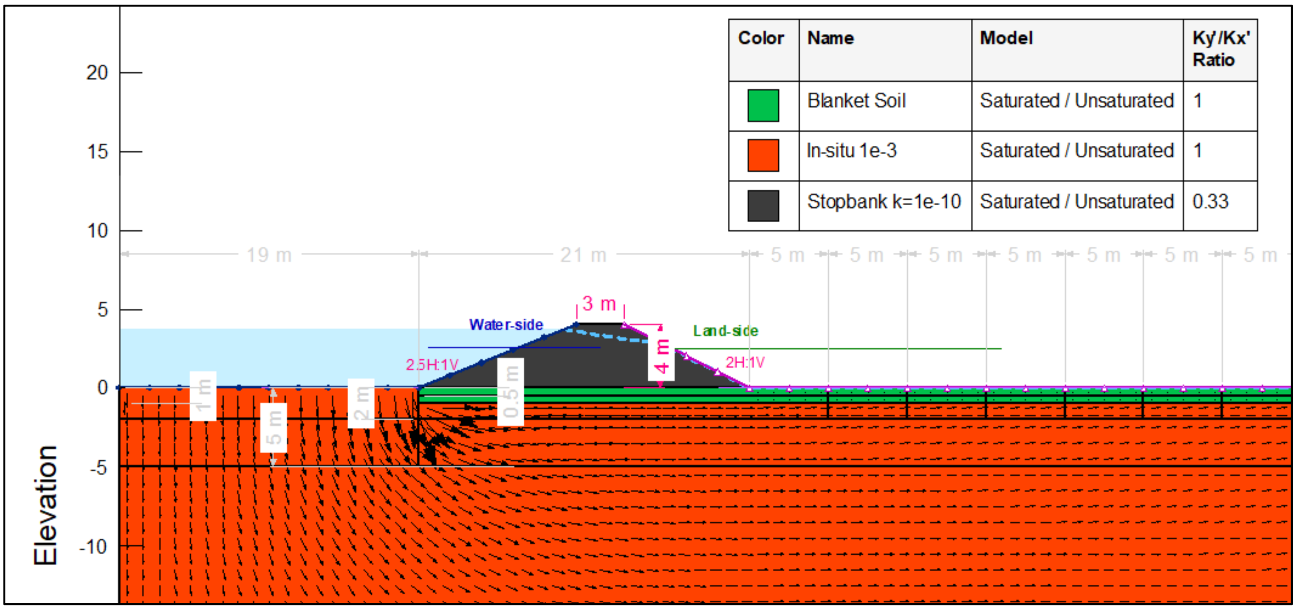

Figure 13: A Rangitāiki seepage model with flat ground inland. Batter gradient are shown accommodating a crest 4.0 m high and 3.0 m wide that retains 3.7 m of flood head with 0.3 m of freeboard. This particular simulation shows the effect of 1.0 m blanket soil with the higher permeability foundation soil of unlimited thickness, Simulation E.

Topography Screening

The transitional model that slopes for 60 m then flattens was retained because this geometry was available from the Tarawera analysis and could be readily assessed. A second transitional model was produced with the ground sloping for 150 m before flattening. This distance was selected as it reflects a cross-section that was identified during the topography screening. The LiDAR presented in the next figure shows this margin can remain fairly consistent along this river.

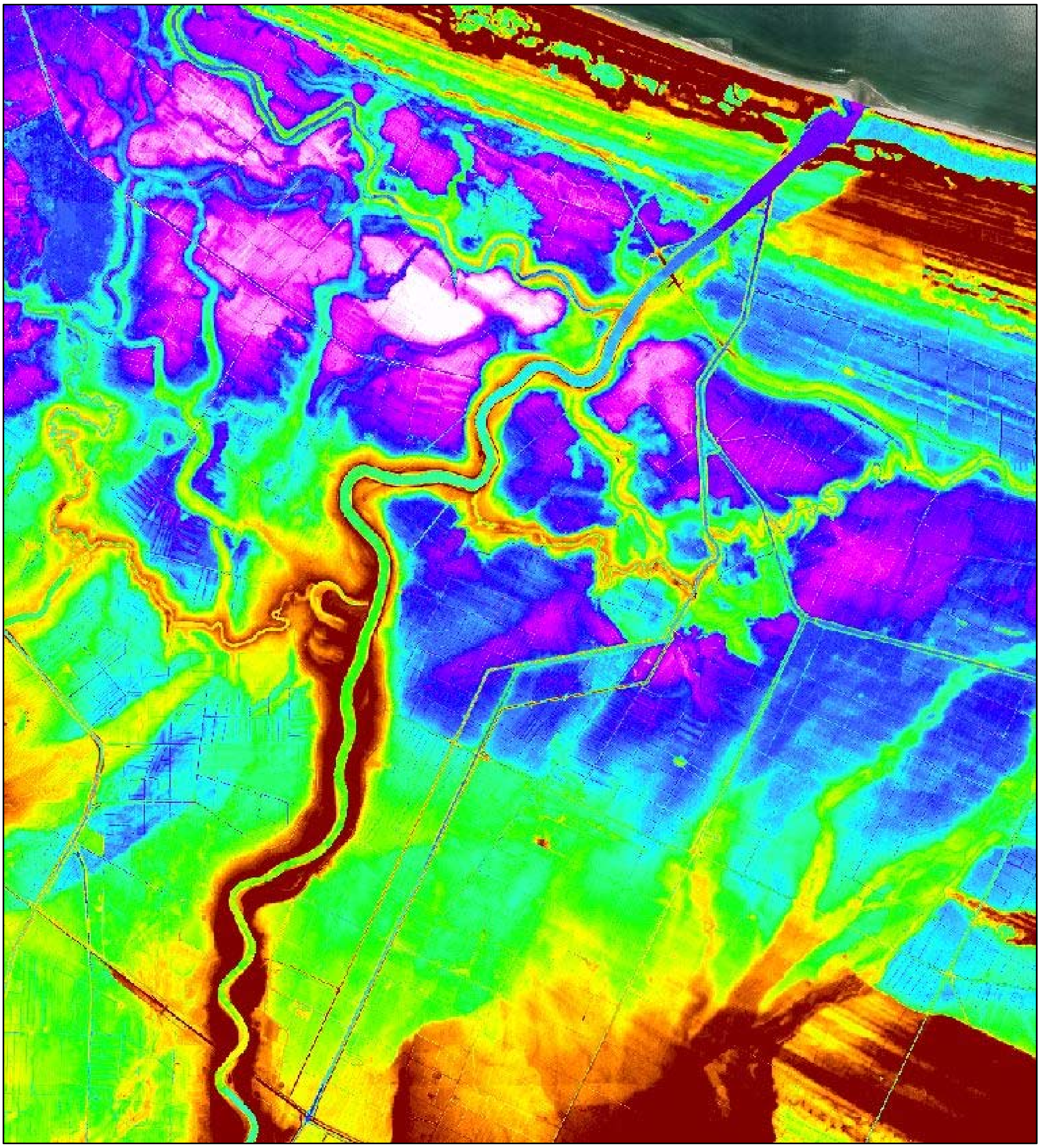

Figure 14: Rangitāiki LiDAR overview with focus on the reddish brown margin beside the river which reflects the natural levee deposition.

The grade of the levee silt was assessed to be less than 1°, adding further validation to the use of this grade for any models with sloping ground regions.

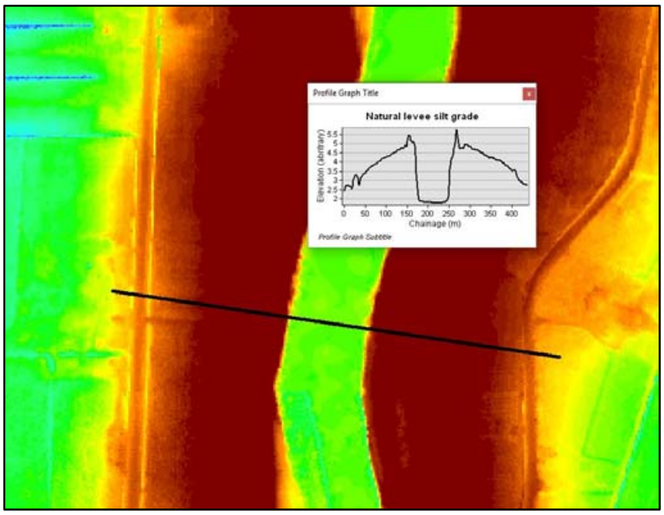

Figure 15: Cross-section on Rangitāiki River used to measure grade of natural levee deposition.

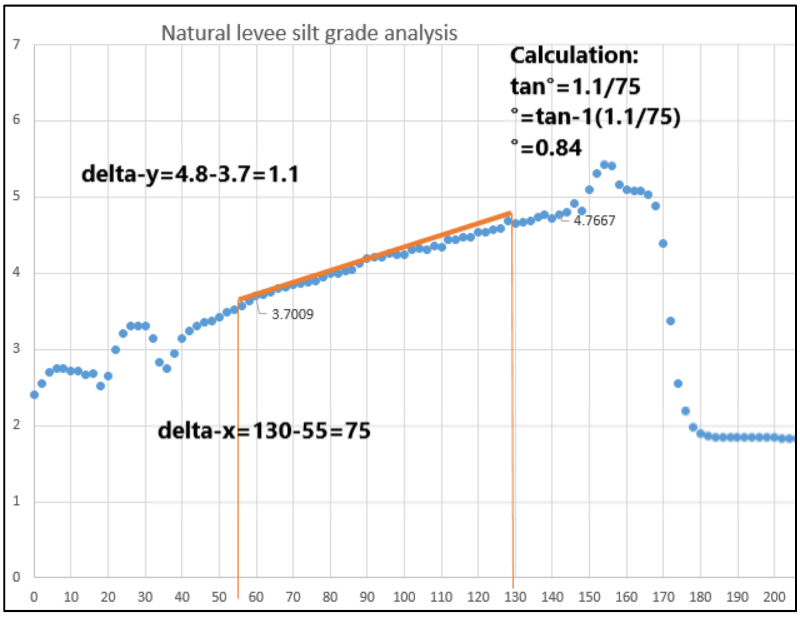

Figure 16: Calculation showing the slope of the natural levee deposits to be less than 1 degree.

The following images presented in-line show LiDAR at a relevant section where a 168 m distance has a change in elevation of 3.2 m, relating to a 1.09° slope. The angle of 1° was therefore retained in the models as the grade for sloping ground and models with sloping ground to 150 m were added to the sequence of simulations.

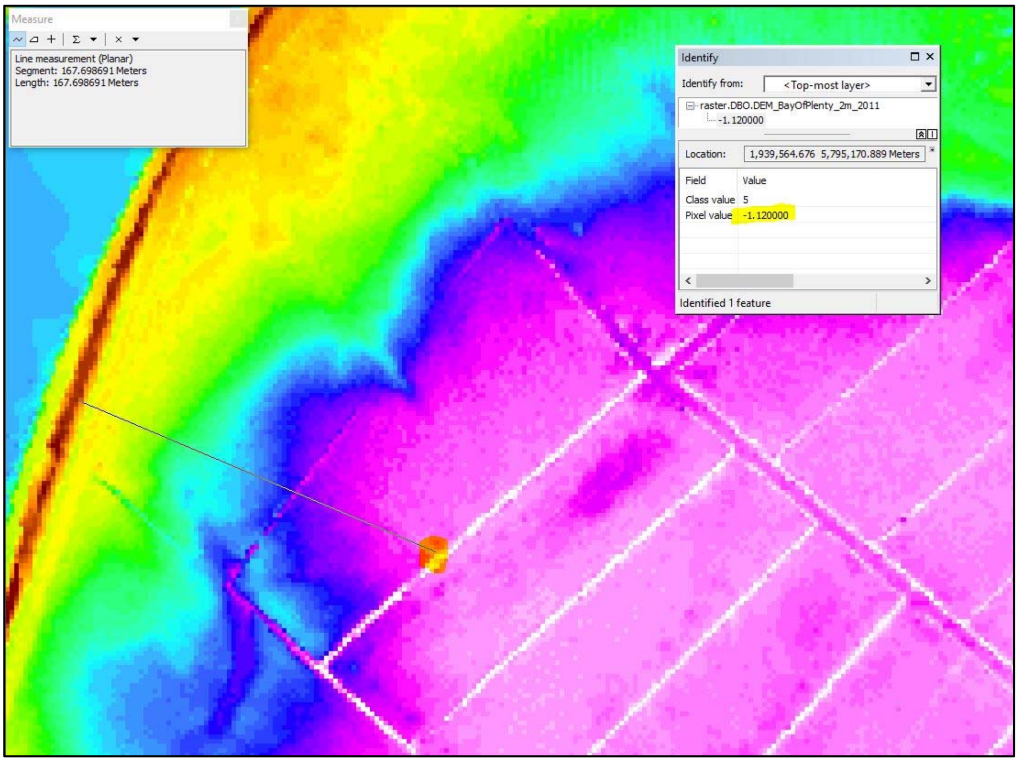

Figure 17: Rangitāiki Measured section showing ~1° grade.

A screening for steeper sections using the LiDAR data was completed. A 2.35° slope was detected.

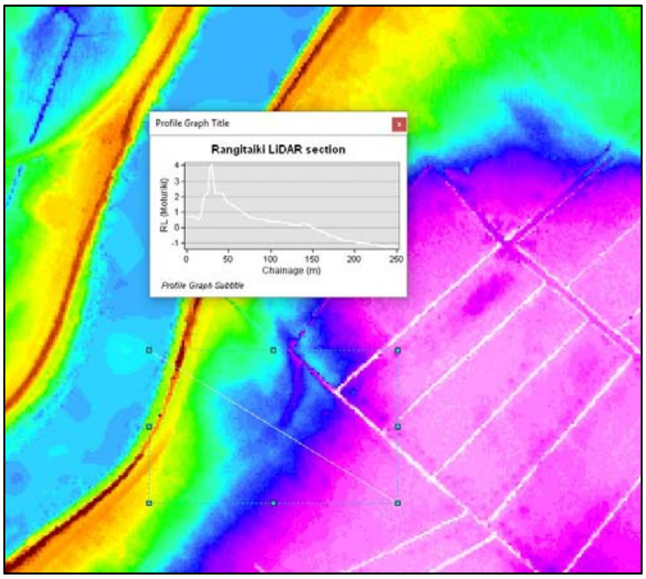

Figure 18: Steep section between ~50 - 70 m chainage. Note the elevation of the bed is just below 1.0 m, and this elevation doesn't occur until about 70 m chainage, being the end of the steeper portion.

On further analysis it becomes apparent that the inland sloping ground is elevated in comparison to the projected inland surface of the sloping model, and is still elevated in comparison to the 150 m transitional model. Models representing ground sloping steeper than 1° were therefore not considered for inclusion to the assessment. The next figure shows the measured ground surface at this section using LiDAR with two lines illustrating how flat and sloping conditions were projected during modelling.

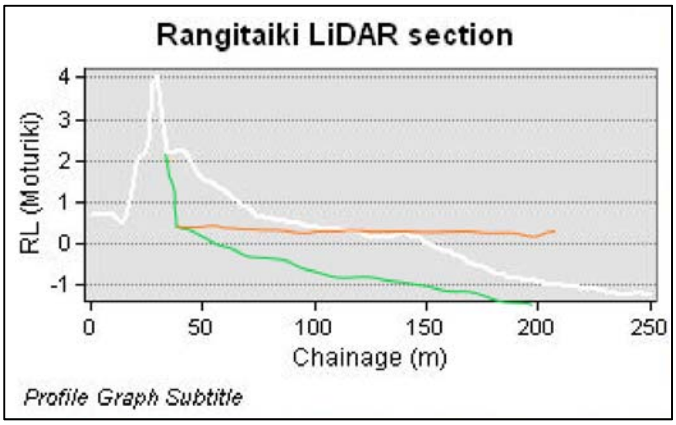

Figure 19: White line is measured ground level using LiDAR at the steeper section. The orange line resembles how flat ground conditions were projected during modelling and similarly the green line with sloping ground conditions.

Design Hydrograph

The hydrograph used for modelling relates only to this bylaw review. Due to varying flood heights and ground levels along a scheme a generic hydrograph has been adopted for modelling. For site-specific assessment hydrographs calibrated to the flood and stretch of flood defence can be used.

The following 100-yr hydrographs are examples of site specific data that have been used in previous assessment reports.

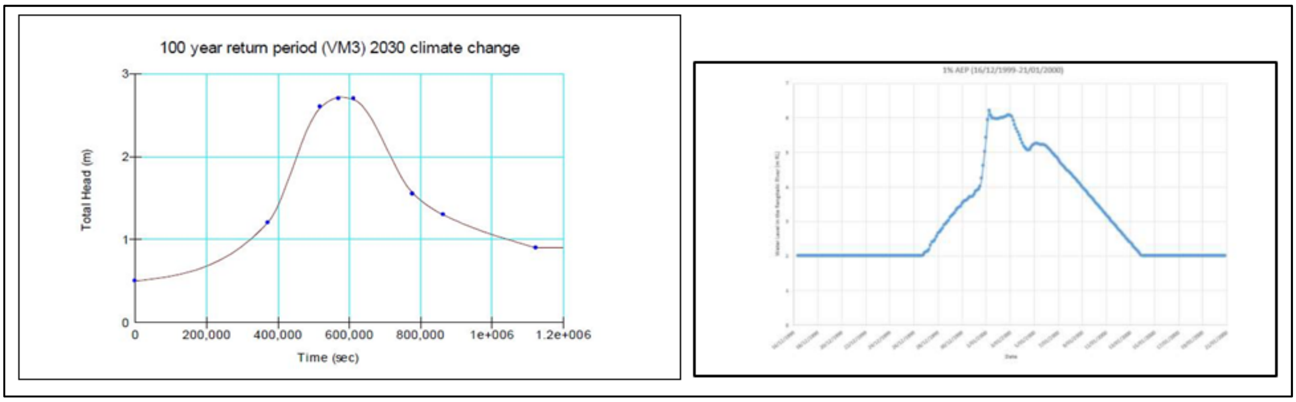

Figure 20: Example of a recent hydrographs used by BOPRC consultants.

These hydrographs are in terms of total head, while the hydrograph used in the modelling is in terms of pressure head.

Two curves (purple lines) to represent the hydrograph signature have been overlain against several total head hydrographs. This shows how the modelling has attempted to capture the range of patterns associated with the hydrographs of this river. The two curves represented by the purple lines in figure 19 have thus been carried forward to simulate the hydrographs for subsequent geotechnical modelling.

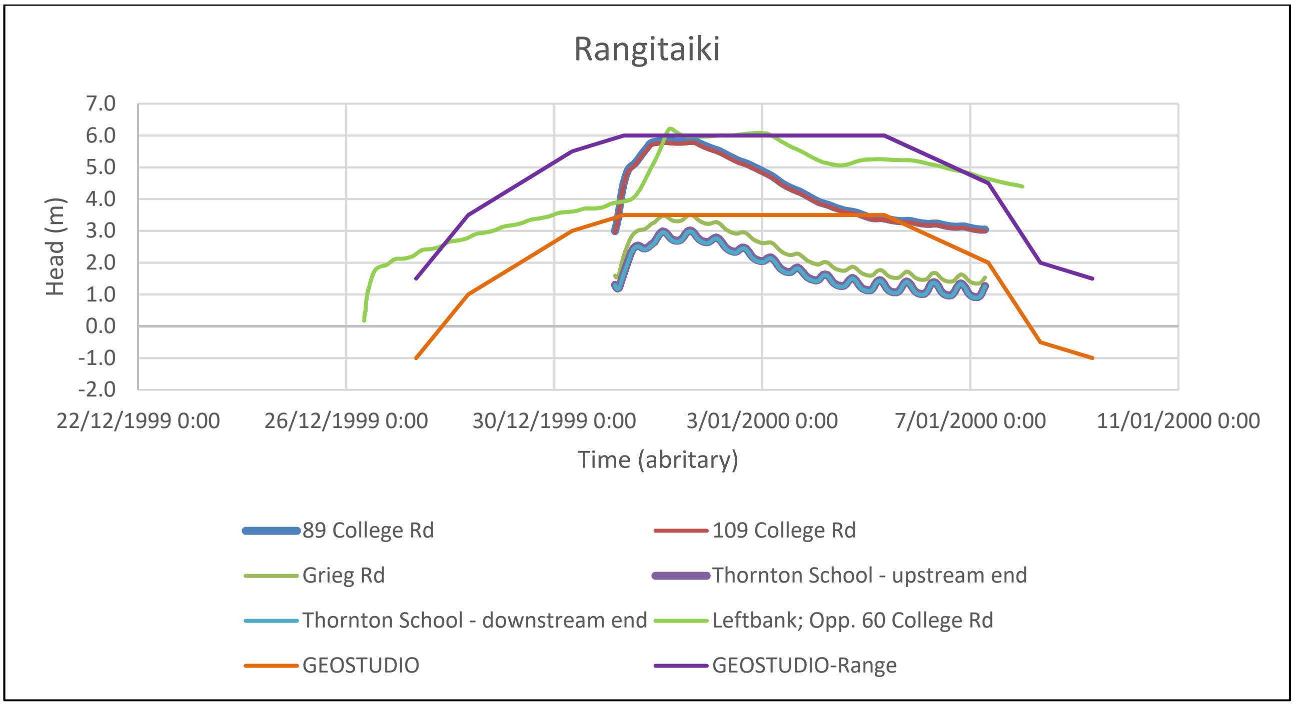

Figure 21: River hydrographs overlain with hydrograph used in bylaw modelling.

The water level in the 100 year return period flood hydrograph for the Rangitāiki River rises quickly over a day, remains high for five days then drops over a further six days to the original water level. This 12 day long hydrograph is due to this river scheme having the largest catchment in the region and the hydro-electric network situated along the river, notably Matahina and Aniwhenua dams. While the dams offer some attenuation of the flood peak this adversely affects seepage as the flood waters are elevated for a longer duration, causing the wetting front to propagate further inland and increasing the build up of pore-water pressures in the ground.. This is reflected in the design hydrograph below.

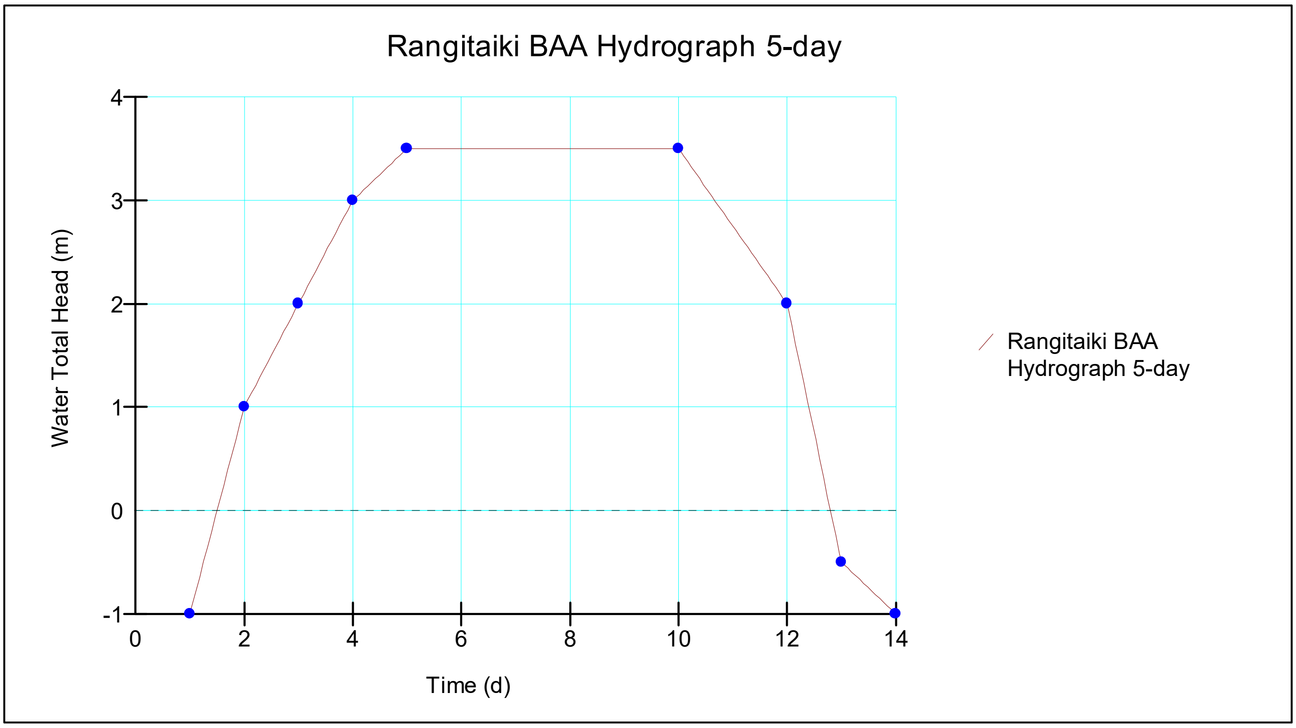

Figure 22: Rangitāiki Flood hydrograph used for bylaw modelling.

3.1 Seepage face review

The table that follows summarises the length to which a seepage face can develop for the simulations: As stated earlier the high permeability simulations were only checked where permeable foundation soils where 2.0 and 5.0 m thick.

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground				Sloping ground				Transitional ground			
	Measured distance to where a seepage face develops (m)		Measured distance to an exit gradient of 0.4 (m)		Measured distance to where a seepage face develops (m)		Measured distance to an exit gradient of 0.4 (m)		Flattens after 60 m Measured distance to an exit gradient of 0.4 (m)		Flattens after 150 m Measured distance to an exit gradient of 0.4 (m)	
	Transient	Steady-State	Transient	Steady-state	Transient	Steady-State	Transient	Steady-State	Transient	Steady-State	Transient	Steady-State
D (U/½)	137	200	110	140	131	240	99	145	159	164	214	216
F (U/1)	235	241	142	147	264	272	135	142	164	169	219	221
H (U/2)	273	281	128	135	297	306	109	119	152	158	211	214
K (2/½)	87	149	71	94	83	169	65	96	110	114	171	172
M (2/1)	20	57	13	23	123	170	68	76	94	97	154	155
S (5/½)	160	214	133	161	162	222	130	160	171	176	212	213
S (5/½) GWT 2.0 m bgl	100	(214)	89	(161)	-	-	-	-	-	-	-	-
U (5/1)	246	251	160	165	237	245	148	154	170	174	230	233
W (5/2)	268	277	132	139	249	262	114	121	141	145	202	205

- = Not assessed.

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note 2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 11: Results of Rangitāiki assessment for development of a 'seepage face'.

3.1.1 Commentary

The unlimited soil thickness data set (A-H) is from the lower permeability soil. These results may be under conservative, however given the over conservatism in the hydrograph and the modelled thickness of 40 m which is also likely to be an upper bound, the values have been deemed a good quantitative data set.

Comparison between steady-state and transient conditions show that for transitional models the results are similar, generally within 5%. This trend is evident in the sloping and flat models where the blanket thickness is greater than 1.0 m, it is noted that these models begin with full saturation of the foundation soils. It is only in the models D,K and S with 0.5 m of blanket soil that lag -time offset of the seepage migrating inland - between steady state and transient conditions was apparent. These were the only models with an unsaturated column of foundation soil.

When the ground-water was set to 2.0 m depth lag increases, being about 60-70% the distance of the models where the initial water table was at 1.0 m depth. This is because the foundation soils have greater storativity due to the lower water table occupying less void spaces. The propagation of seepage is slowed because it takes time for the water pressure to expel the air from the voids so it can occupy the space. Until the air is displaced it also causes a reduced flow area.

The interesting relationship from this data set was for simulation M. Propagation of hydraulic gradients of 0.4 increased with slope, and more so for transitional topography. Distances went from 13 m for flat ground, to 154 for the transitional model with a change in slope at 150 m. This should also be of interest to any sites of this nature in which ploughing or similar agricultural activities are performed or planned as a topography transition of this nature acts like a bottleneck attracting a localised concentration of pore water pressure.

The respective data sets for the distance in which a hydraulic exit gradient of 0.4 occurred for flat, sloping and the transitional models of 60 then 150 m are highlighted in yellow in Table 11 and are:

{13, 71, 89, 110, 128, 132, 133, 142, 160} – Flat ground, transient flow

{65, 68, 99, 109, 114, 130,135, 148} - Sloping ground, transient flow

{94, 110, 141, 152, 159, 164, 170, 171} - Transitional ground flattening after 60m, transient flow

{154, 171, 202, 211, 212, 214, 219, 230} - Transitional ground flattening after 150m, transient flow

While 6 of these 33 entries exceed 200 m they all relate to the transitional 150 m model. With no values greater than 150 m for the sloping ground conditions. It can be concluded that a change in slope adversely causes further seepage migrations. The topography screening detected a slope 168 m long, which was located nearest the 'Thornton School –downstream end'. The modelling uses a hydrograph that peaks for several days and is considered to have over-represented the flood at this site. The first topography screening also shows a slope near 150 m long but with slope angle of 0.84°. While this would still attract concentrated seepage energies it would not be expected to propagate to the same extent beyond the change in slope. This coloration of this LiDAR feature is also present in the Edgecumbe Township. The 'Left bank – opposite 60 College Rd' was checked and shows the hydrograph peak dropped about 2 days earlier by 1.0 m of head than what was modelled.

3.1.2 Conclusions

Thin, highly permeable aquifers with ground conditions that slope then flatten are highlighted in this data set as having an elevated susceptibility to seepage hazard.

The flat and sloping ground results are considered more applicable, whereas for the transitional ground conditions results, there is combined conservatism between the slope angle and hydrograph.

Consequently, allowing for the conservatism in the transitional ground results, 200 m is selected for the distance relating to hydraulic gradients for the Rangitāiki catchment.

3.2 Heave analysis

The length to which heave is anticipated is summarised in the following table.

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground		Sloping ground		Sloping ground that flattens at 60 m		Sloping ground that flattens at 150 m	
	Measured distance to FoS=1.0		Measured distance to FoS=1.0		Measured distance to FoS=1.0		Measured distance to FoS=1.0	
	Transient	Steady-State	Transient	Steady-State	Transient	Steady-State	Transient	Steady-State
D (U/½)	103	128	96	138	157	163	210	211
F (U/1)	123	128	80	88	122	126	179	181
H (U/2)	82	89	219	233	133	138	181	184
K (2/½)	68	87	65	95	110	115	170	170
M (2/1)	67	71	46	51	72	74	52	55
S (5/½)	128	153	85	99	173	177	228	230
S (5/½) GWT 2.0 m bgl	86	(153)	-	-	-	-	-	-
U (5/1)	143	149	109	115	143	146	200	202
W (5/2)	93	99	91	99	92	96	175	178

All values in metres

- = not assessed

Note1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 12: Results of Rangitāiki assessment for development of a 'heave'

3.2.1 Commentary

Day 10 was the critical epoch for assessment of heave. This was deducted by checking a random scattering of nodes to see the time epoch that registered the highest pore-water pressure development. To validate the results a stress analysis that can compare pore-water pressure to total stress was checked for the critical epoch and 1 day either side. For Rangitāiki the indicator nodes and results are shown in the figure below. It can be seen on the tenth day the greatest pressures developed.

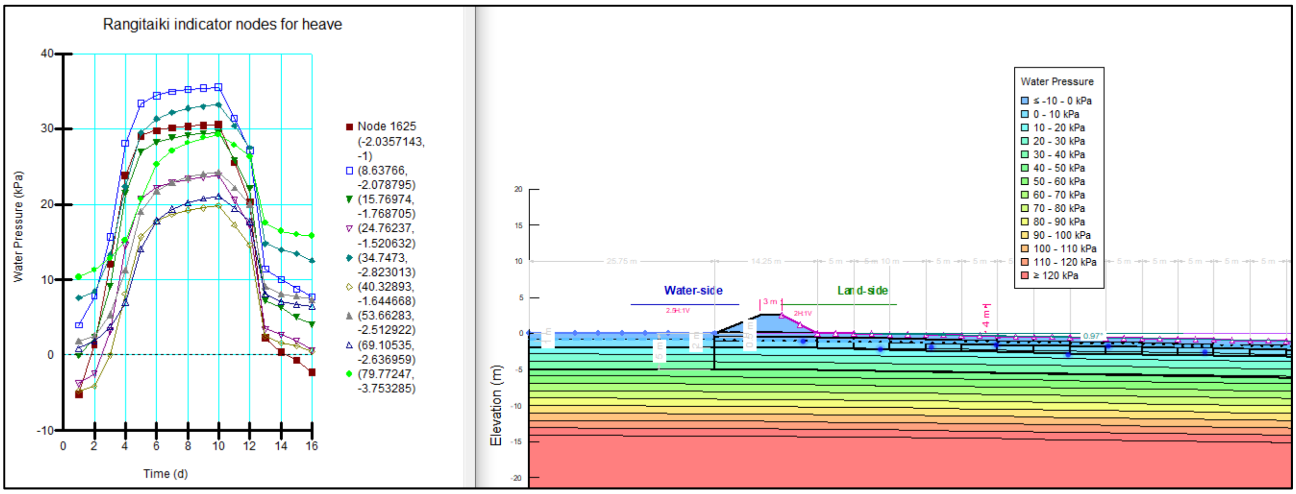

Figure 23: Day 10 was the critical time epoch for heave with the adjoining days, 9 and 11 checked for verification. Indicator nodes are demarcated by blue dots on the model.

Comparison of transient to steady-state shows that only for the thinnest blanket soil was lag apparent, and only for the flat and sloping cases.

The transitional model results produced the greatest distances and the combined transient data from both sets is:

{52, 72, 92, 110, 157, 122, 133, 143, 170, 173, 175, 179, 181, 200, 210, 228}

In terms of transient results the transitional models at 150 m for Simulation D and S were 210 and 228 m, being the highest respective distances of the unlimited and limited soil foundation thicknesses of this data set. The remaining values did not exceed 200 m, with thirteen of the sixteen entries less than 185m.

The longest sloping ground distance was Simulation H being 219 m. The actual thickness of the unlimited model is 40 m, which may be conservative. All other results were less than 150 m.

3.2.2 Conclusions

Heave is anticipated to occur beyond 100 m regardless of aquifer thickness should soil that reflect the high permeability used in model exist. In some instances heave over 200 m could arise. However, the ground would have to match the conservative modelled profile and not be influenced by lateral variation which could occur due to fault lines, relic meander alignments, peat deposits or debris flow margins. Given the majority of transient results from the greater data set were less than 200 m it seems relevant that a value or this magnitude be appropriate.

<u>200 m be selected for the distance relating to heave for the Rangitāiki catchment.</u>

3.3 Hole scenario

Results in the table are based on checks completed at 5 m increments. Increments were built into the models to 150 m, where gradients exceeded this distance the results was displayed as '>150 m' with the gradient value bracketed below the resulting distance. For Rangitāiki only, an additional region was formed in the model to allow a check to made at 200 and 250 m.

Only transient cases were assessed as these were considered a sufficient sample to provide relevant data. 2.0 m foundation soils were run but not summarised due to the results being comparatively short in distance compared to other values.

Modelling starting with the 5.0 m foundation soil model and when it was apparent the 1.0 m blanket soil was governing the longest distances the corresponding simulations from the unlimited soil model for flat ground and transitional ground at 150 m were added.

The distances to which critical hydraulic gradients could be exceeded at a hole for various simulations are given in the following table with 0.1 selected as the critical gradient due to the pumiceous nature of the catchment.

SIMULATION **(Foundation thickness /Blanket Thickness)**	**Transient**			
	Measured distance to x-grad <0.1			
	Flat ground	**Sloping ground**	**Transitional 60**	**Transitional 150**
E **(U/½)**				>200 (0.23)
F **(U/½)**	>150 (0.21) >200 (0.15) >250 (0.11)			>200 (0.18) >250 (0.16)
S **(5/½)**	55	85	95	110
T (5/½)	35	40	70	50
U **(5/1)**	80	95	100	125
V (5/1)	55	70	80	80
W **(5/2)**	85	105	115	120
X (5/2)	80	100	115	115

All values in metres

Note1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 13: Results of Rangitāiki assessment for development of a 'hole scenario'

3.3.1 Commentary

Simulation X for the transitional models produced interesting results. Unlike any other simulations this attracted a very large gradient at a much earlier epoch and kept stable around this value. The time steps were adjusted to 0.1 of a day. In the following image there is a cluster of data points between day 1 and day 2 that reflects this, as day 1 was the starting epoch. This effect occurred without hydraulic load from a flood hydrograph, and is attributed to the fact the seepage face that simulated a hole was set beneath the initial water table. A final check on the convergence at each time did not highlight any issue with the model, and it was concluded the results during the critical epoch were valid for interpretation.

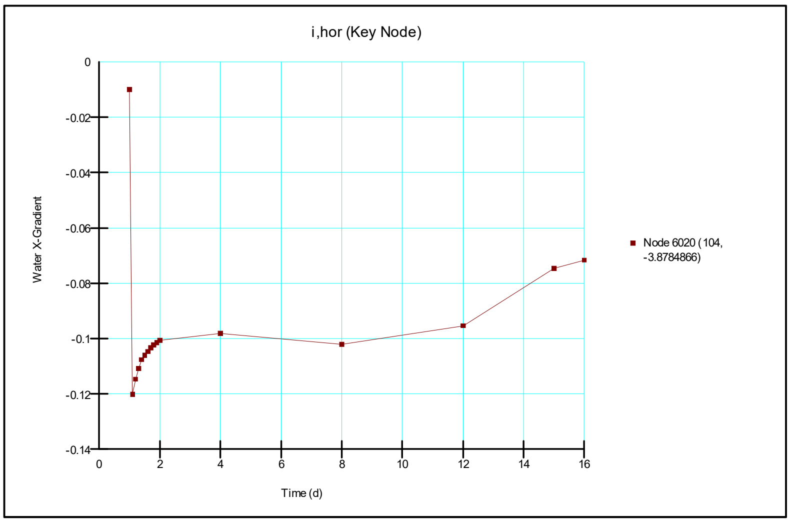

Figure 24: Effect of instantaneous draw-down on horizontal gradients 'i,hor' with the seepage face condition being set below the initial water table.

This effect should be detectable regardless of hydraulic conductivity, so a high permeability simulation had the time steps adjusted and the same effect occurred.

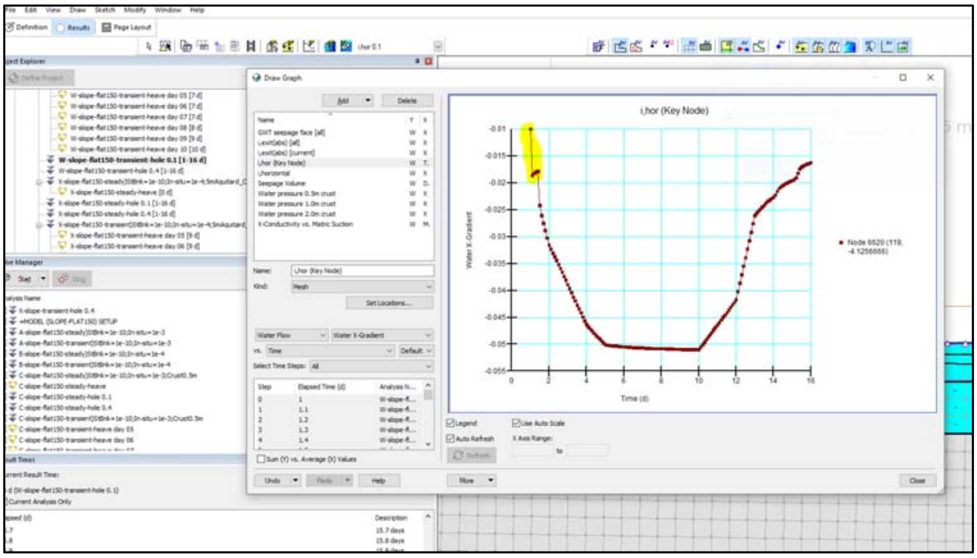

Figure 25: Check on a high permeability simulation identified the same occurrence.

Simulation X also resulted in the same distance as Simulation W which was the high permeability equivalent. It is concluded that the ratio of foundation soil to blanket soil has caused the difference in distance to go undetected for the 5 m block increments that were built into the model.

Simulation F was extended to include assessment to 250 m. This is a low permeability model and for flat ground the gradient of 0.11 was still greater than the targeted search for 0.10. A uniform layer to 40 m that extended near horizontal to 250 m is therefore considered too thick or it is possible a horizontal discontinuity would exist alongside this scheme. Such a discontinuity could come from a fault line which are frequent in this catchment, or from the natural meander of the river complex. Horizontally it is a given that some layering will exist, unless a debris flow of this thickness with clean particles occurred, or some other unique event.

The data set listed is considered to be on the low side of distance due to underlain layers more than 5.0 m expected in this catchment.

{95, 100, 110, 115, 120, 125}

3.3.2 Conclusions

The distance was selected based on the data set which considers that foundation soil thickness exceeding 5.0 m is likely, but that 40.0 m which represents the unlimited model is too conservative, due to geomorphic processes as discussed in the Tarawera section. The highest value in the 5.0 m data set was chosen.

125 m be selected for the distance relating to a hole scenario for the Rangitāiki catchment.

3.4 Rangitāiki Summary

Key results are shown in the summary table that follows:

SEEPAGE MECHANISM	DISTANCE
Seepage propagation	200 m
Heave	200 m
Hole scenario	125 m
BAA Recommendation	**200 m**

Figure 26: Rangitāiki Results Summary Table

Part 4: Kaituna

Governing cases

The Kaituna has many relic oxbow bends and this suggests a dynamic and more layered ground model. Unlimited foundation soils models were not assessed.

The inland topography is considered to have less fall in comparison to the Rangitāiki, therefore a 1° slope is considered conservative to the transitional models and sloping models were not assessed. The transitional models are expected to be an upper bound with relevant data for assessment being less than these measured distances.

Models with no blanket soil were again removed from assessment as they illustrate that pressure relief is occurring near to the inland toe such that confined seepage pressures do not occur. They were also of no benefit for the analysis of heave.

Soils in the lower reaches near the mouth of the scheme are likely to have permeability in the higher range. Only a few of the low permeability simulations were included and their selection was based on the models that produced the highest distances for the high permeability simulations.

Simulations O & P no longer are being assessed as they do not include any foundation soil thickness which is assumed to exist to some extent everywhere within the areas being researched.

Parameters

Foundation soils were assessed using permeability values of $k=1\times10^{-3}$ m/s (high k) and $k=1\times10^{-4}$ m/s (low k). This provides representation of the pumiceous sands and gravels found along this river.

Topography Screening

Five [5] sections were screened using GIS. Screening 5 shown in the white line gives a good illustration of the inland topography near the bed of the water source, which is symbolic of the modelling whereas screening 1 shows the inland level to be slightly depressed which is possible to do with diversion works or sediment aggradation. These are shown in the following image:

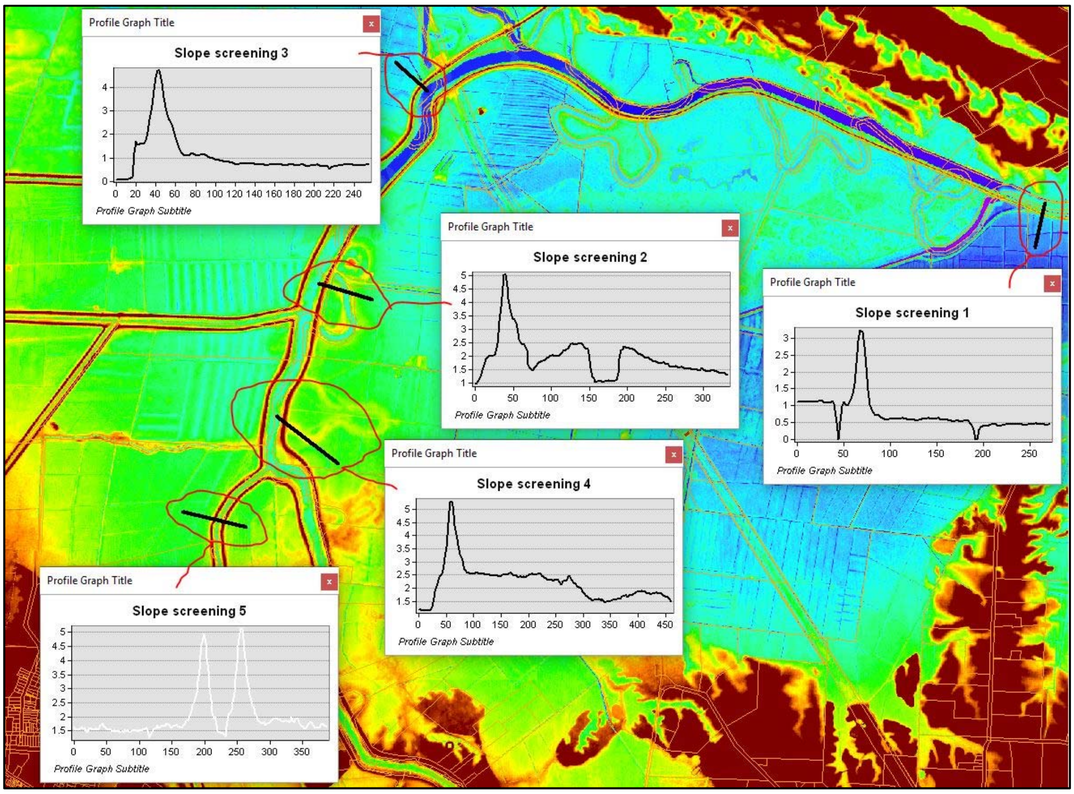

Figure 27: LiDAR screening profiles for the Kaituna catchment.

This confirmed inland slopes are expected to be less than 1° with the steepest section measured just below 0.6°. Key plots of grade follow:

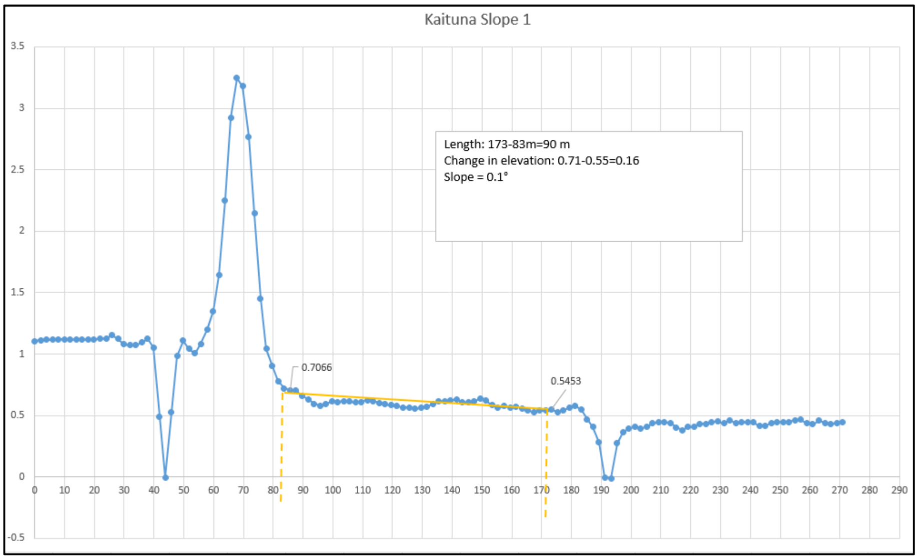

Figure 28: Kaituna grade assessment 1

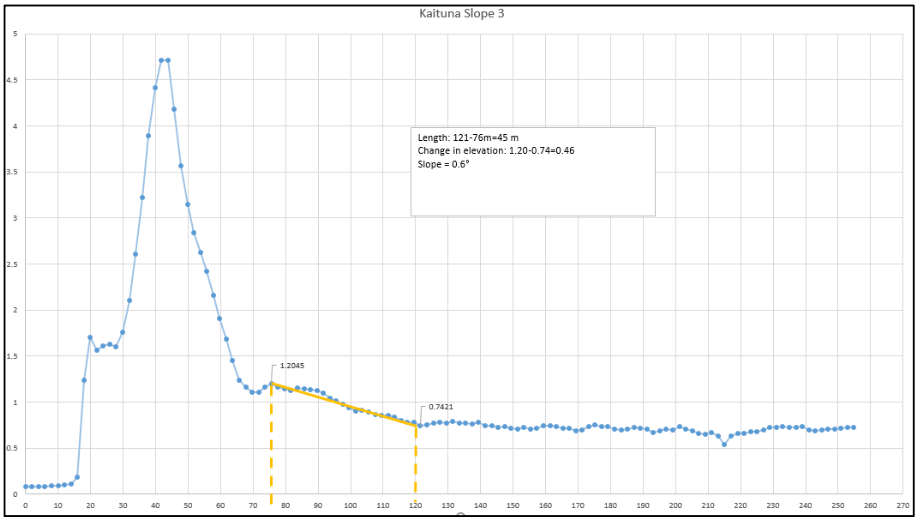

Figure 29: Kaituna grade assessment 2

Design Hydrograph

The hydrograph used for modelling relates only to this bylaw review. Due to varying flood heights and ground levels along a scheme a generic hydrograph is adopted for modelling. For site-specific assessment hydrographs calibrated to the flood and stretch of flood defence should be used.

For this assessment a hydrograph was created so a three day long peak following a one day rise occurs. The river level recedes 1 m over 1 day, then recedes a further 1 m over two days before ramping down to non-flood conditions where the river level is typically 1m below the adjacent ground level.

The hydrograph used in modelling is overlain against a recent 100 year hydrograph for a cross-section on the Kaituna River at 4.7 km chainage, and two further hydrographs upstream near the Waitangi township. The following two figures illustrate this process:

Figure 30: Recent 100-yr hydrograph used for assessment on the Kaituna River with the hydrograph used for assessment overlain.

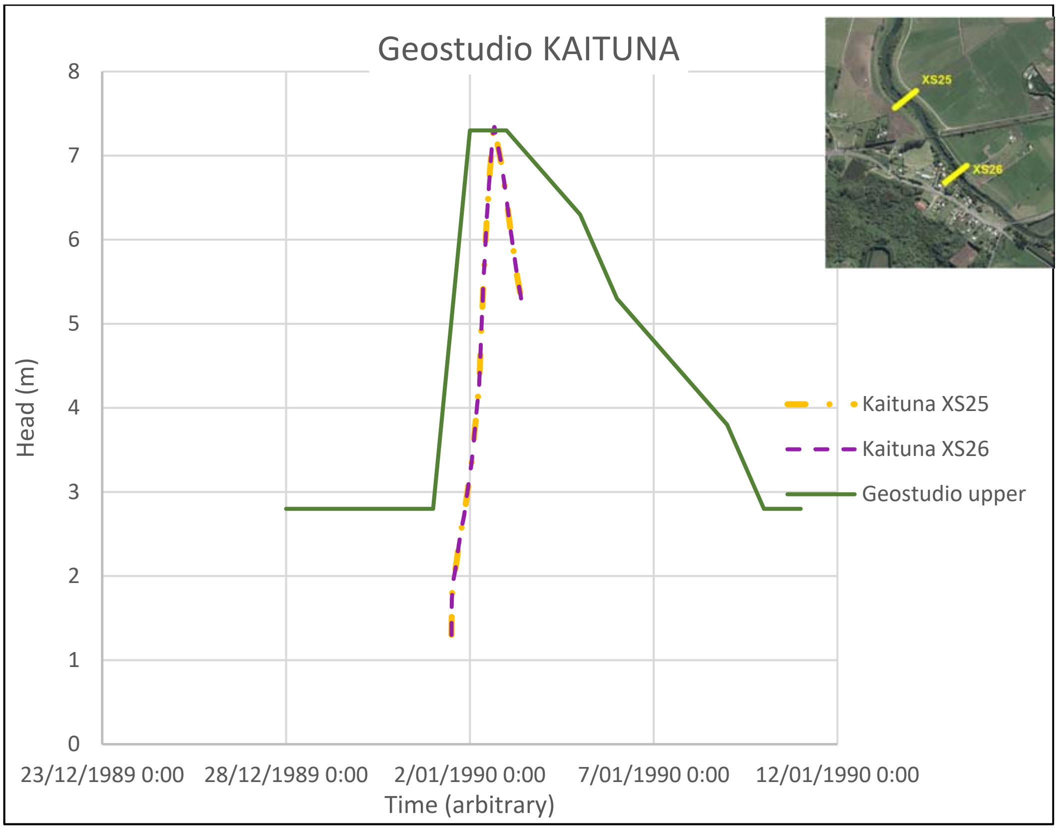

Figure 31: Hydrographs (in yellow dash and purple dash) near the Waitangi Township used for assessment on the Kaituna River with the hydrograph used for assessment overlain (in green).

The hydrograph used for the bylaw modelling follows:

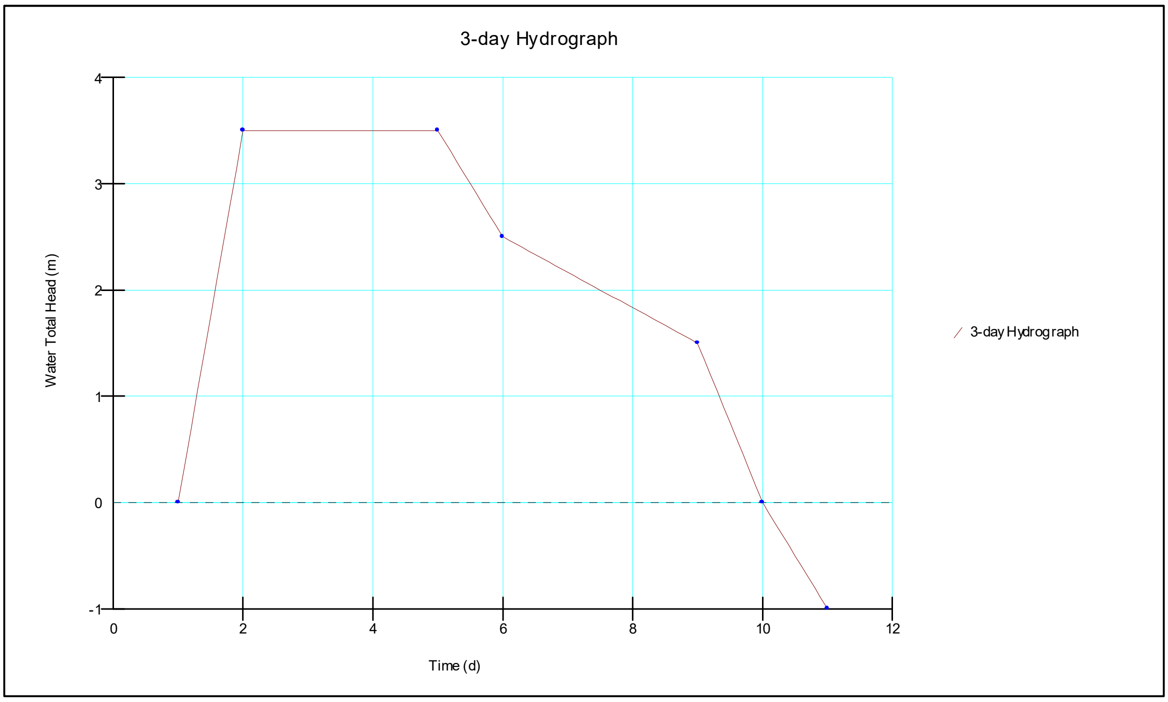

Figure 32: Kaituna Flood hydrograph used for bylaw modelling.

It can be seen that near Waitangi Township the hydrographs rise from ~1.3 m to ~7.3 m, being a pressure head change of approximately 6.0 m. The design hydrograph rises approximately 4.5 m which is about 1.5 m of pressure head short than the hydrographs as these cross-sections.

A further LiDAR assessment shows that in this region the river is incised and inland topography is elevated. Contours show the waterward berm to be near RL2.0 m and the inland surface approximately RL3.0 m with the stopbank crest contour RL6.0 m in places. Therefore the inland batter drops around 3.0 m in elevation. The simulations model a head differential across the stopbanks of 3.7 m, therefore near Waitangi township the head differential between the river at the crest level and the inland ground surface would be about 3.0 m. Separate simulations to reflect this were not completed as additional confining soil inland is considered beneficial to a seepage regime, in this case it could be considered similar to a 0.7 m overlay.

The hydrographs near Waitangi Township therefore do not represent the typical situation and due to the incised channel and elevated ground inland the model is considered to be conservative at this section, but not adverse.

4.1 Seepage face review

For the simulations the length to which a seepage face can develop is summarised in the table that follows:

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground				Transitional ground			
	Measured distance to where a seepage face develops (m)		Measured distance to an exit gradient of 0.4		Flattens after 60 m Measured distance to an exit gradient of 0.4		Flattens after 150 m Measured distance to an exit gradient of 0.4	
	Transient	Steady-State	Transient	Steady-state	Transient	Steady-State	Transient	Steady-State
K (2/½)	**60**	**149**	**49**	**94**	**102**	**114**	**170**	**172**
M (2/1)	**101**	**163**	**64**	**81**	**87**	**97**	**152**	**155**
N (2/1)	24	63	12	18	**10**	**14**	**8**	**16**
S (5/½)	113	214	94	161	**161**	**176**	**228**	**232**
S (5/½) GWT 2.0 m deep	57	-	50	-	**-**	**-**	**-**	**-**
U (5/1)	210	251	142	165	**161**	**174**	**228**	**233**
V (5/1)	58	114	34	46	44	61	**35**	**41**
W (5/2)	213	277	116	139	**133**	**145**	**199**	**206**
X (5/2)	57	133	25	35	**27**	**34**	**20**	**29**

All values in metres

- = Not assessed.

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note 2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 14: Results of Kaituna assessment for development of a 'seepage face'.

4.1.1 Commentary

For steady-state conditions the results equal the results from the Rangitāiki assessment. This is because with soil parameters and topography kept constant the only variable comes from the hydrograph, which will only vary for transient conditions.

Simulation V is of interest as the change in grade at 60 m tended to attract higher hydraulic gradients which reduced seemingly quickly reducing to 0.3 at just 68 m. Another example of this is Simulation M, in which the gradient of 0.5 occurred at 72 m, 0.4 at 155 m but after only 12 m more had dropped to 0.3. This effect is shown in the following image.

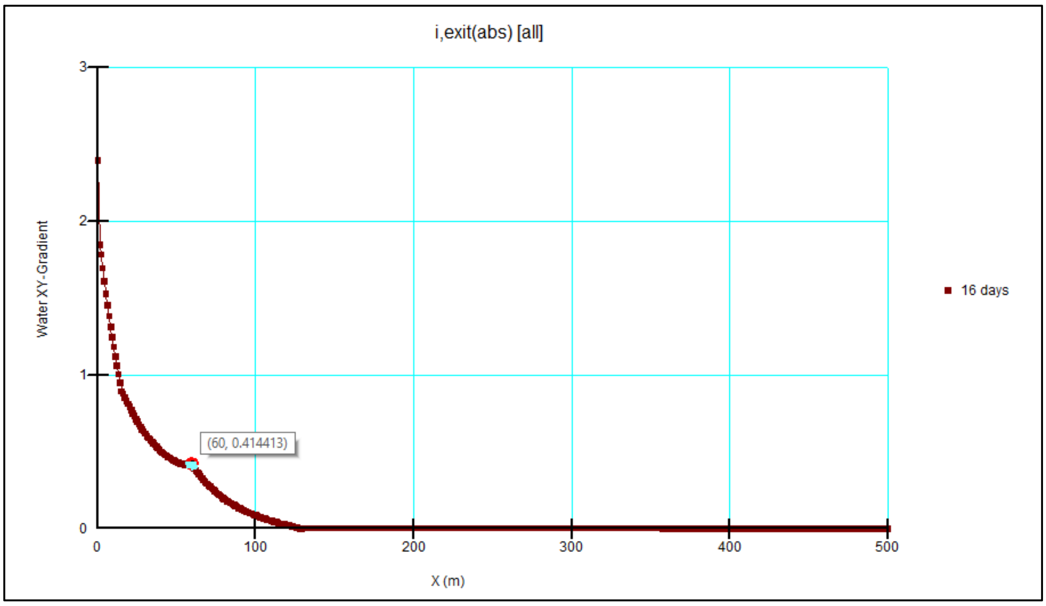

Figure 33: The transition to flat ground at 60 m caused the rate of decrease in hydraulic gradient to slow, but beyond 60 m the rate of decrease had the opposite effect by increasing.

It is noticed that the lower permeability simulations caused the hydraulic gradient of 0.4 to propagate further for the 60 m than the 150 m transitional models. The opposite of this occurred for the high permeability soils. It is concluded that when the wetting front and a change in slope coincide there is an elevated effect of the seepage regime.

Flat ground results for Simulation U and W show there is a protective effect from thicker blanket soil, as Simulation W had a longer seepage face distance but shorter distance for a hydraulic gradient of 0.4. It would require further research but the matric suction of the blanket soil may be the cause of the longer seepage face, and if so is not worthy of expenditure to assess in detail as the distance was only 3 m extra for the transient condition.

Values from the two transitional models are thought to be conservative as generally the inland slope is less than 1°.

4.1.2 Conclusions

The largest measured distances were all from the 150 m transitional model. Topography screening identified a slope of about 0.6° over 50-60 m, so only the flat and 60 m transitional model results contribute to the assessed data set.

Based on all transient results for the selected models, the data set is:

{10, 12, 25, 27, 34, 3, 44, 49, 50, 64, 87, 94, 102, 116, 133, 142, 161, 161}

The flat ground with higher permeability soil was measured at 142 m, so this value is irrespective of transitional ground influences. Similarly, Simulation S and W were measured respectively at 94 and 116 m. Considering all the data entries a distance was deducted that captures the majority of these results.

140 m is selected for the distance relating to hydraulic gradients for the Kaituna catchment.

4.2 Heave analysis

The trend from the Tarawera and Rangitāiki schemes is for the 0.5 and 1.0 m blanket soil simulations to be governing heave assessment. The 2.0 m blanket simulation with 5.0 m foundation soil was included to validate this.

For the simulations the length to which heave is anticipated is summarised in the following table.

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground		Transitional ground that flattens at 60 m	
	Measured distance to FoS=1.0		Measured distance to FoS=1.0	
	Transient	Steady-State	Transient	Steady-State
D (U/½)	66	128	147	163
K (2/½)	46	87	103	115
M (2/1)	55	71	68	74-
S (5/½)	89	152	161	177
U (5/1)	124	148	137	146
W (5/2)	72	99	121	131

All values in metres

- = not assessed

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note 2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 15: Results of Kaituna assessment for development of a 'heave'

4.2.1 Commentary

Day 7 was the critical epoch for assessment of heave. This was deducted by checking a random scattering of nodes to see the time epoch that registered the highest pore-water pressure development. To validate the results a stress analysis that can compare pore-water pressure to total stress was checked for the critical epoch and 1 day either side. For Kaituna the indicator nodes and results are shown in the figure below. It can be seen on the seventh day the greatest pressures developed.

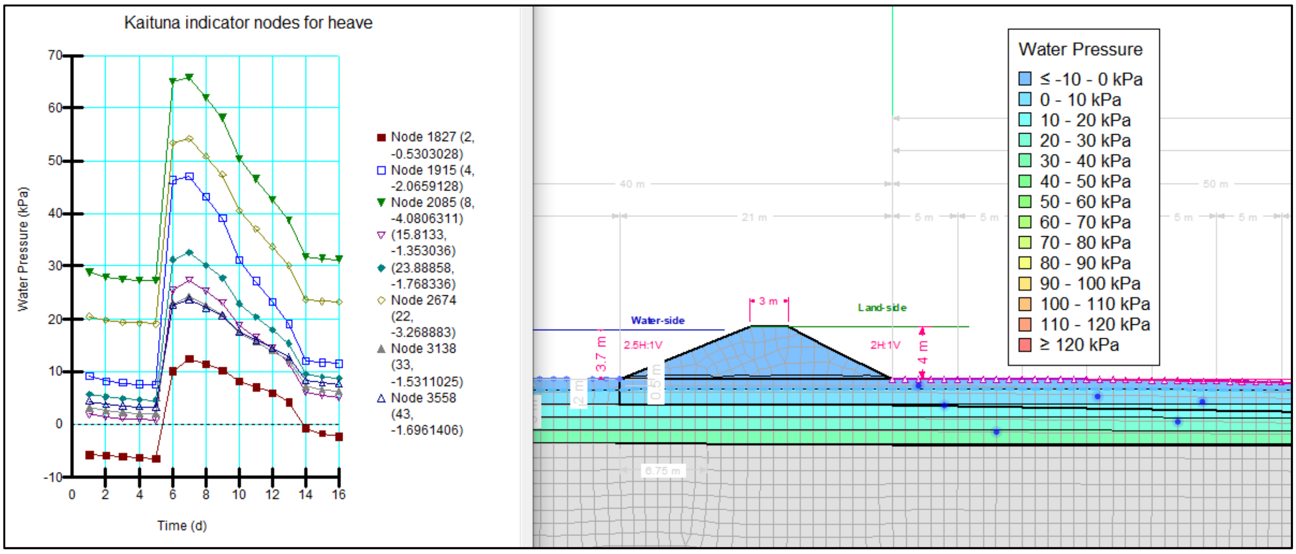

Figure 34: Day 7 was the critical time epoch for heave with the adjoining days, 6 and 8 checked for verification. Indicator nodes are demarcated by blue dots on the model.

While sands can be deep in the lower Kaituna, they tend to have some interbedded layering, which in effect would reduce the long distances predicted from modelling heave. Another effect is that closer to the ocean margin there could be a reduction in permeability either to less pumice content as the larger flows and tidal cycles carry in suspension a larger proportion seaward. This higher energy environment can also result in a denser structure with less void space making the soil less permeable. The low permeability soil simulation with unlimited foundation soil thickness predicts heave near 150 m. Out of interest the high permeable simulation was checked and the distance for the same simulation was greater than 300 m.

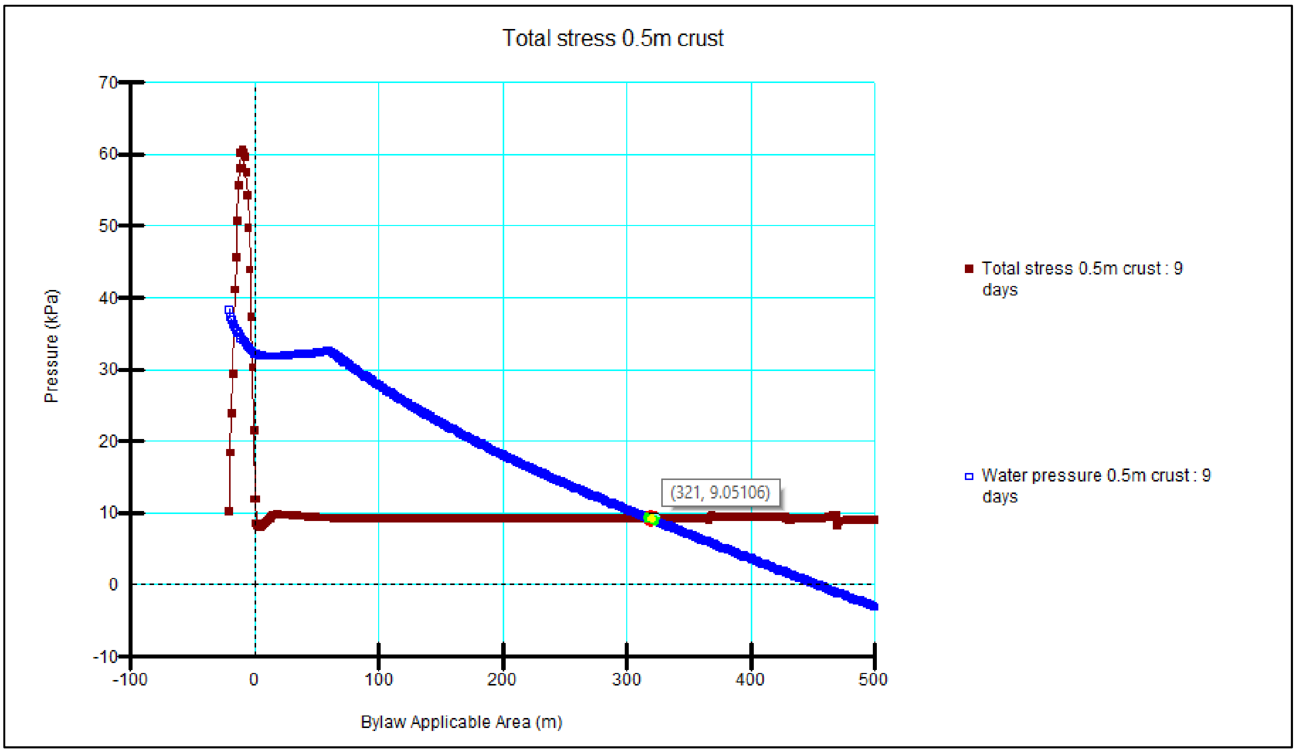

Figure 35: Heave was further checked for a high permeability with unlimited soil thickness.

It may be that soils have a lesser permeability than 1×10^{-4} m/s in the lower Kaituna and this simulation is still too conservative. Most likely the permeability varies with depth and is higher nearer the surface where the limited foundation soil thickness results are better suited.

Keeping in mind that a 1° slope was considered greater than expected for this scheme, the results from the heave assessment under transient conditions for transitional ground simulations were:

{68, 103, 121, 137, 161}

As expected the thickest blanket soil results did not govern. The two longest distances from the flat simulations with 5.0 m foundation soils were:

{89, 124}

4.2.2 Conclusions

The transitional data set is considered to be conservative. The focus is on the flat ground model results and how they compare with transitional results. The value of 124 m would rank 4th in terms of longest distances if included in the transitional data set.

125 m be selected for the distance relating to heave for the Kaituna catchment.

4.3 Hole Scenario

The distances to which hydraulic gradients could be exceeded at a hole for selected simulations were studied. For these pumiceous soils the gradient of 0.1 was considered critical.

Results in the table are based on checks completed at 5 m increments. Increments were built into the models to 150 m, where gradients exceeded this distance the results were displayed as '>150 m' with the gradient value bracketed below the resulting distance.

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground	Transitional ground flattening at 60 m
	Measured distance to x-grad <0.1	Measured distance to x-grad <0.1
	Transient	Transient
C (U/½)	-	>150 (0.26)
D (U/½)	90	>150 (0.17)
E (U/1)	>150 (0.26)	>150 (0.31)
F (U/1)	>150 (0.19)	
G (U/2)	>150 (0.34)	>150 (0.42)
H (U/2)	>150 (0.30)	>150 (0.19)
K (2/½)	-	<50
M (2/1)	-	<50
S (5/½)	40	80
U (5/1)	55	75
W (5/2)	70	90

All values in metres

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note 2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 16: Results of Kaituna assessment for development of a 'hole scenario'

4.3.1 Commentary

Initially the high permeability soils were assessed with checks beginning arbitrarily at 50 m. When results did not exceed this distance the entry of '< 50 m' was used. This prevented having to undertake excess simulations that required adjusting the boundary condition to lesser distances, as this was also not considered of benefit to the data set.

Models assessed with unlimited soil thickness all exceeded 150 m regardless of high or low foundation soil permeability except Simulation S which was measured near 90 m.

It is also apparent the transition model results produce larger distances than flat models, and often these distances exceed the 150 m margin, sometimes with gradients exceeding 0.4. While 0.1 has been used previously for assessments on this scheme, the results of this modelling indicate that 0.1 could be too low, otherwise it is inferred that this is further validation that unlimited soil simulations are not valid on this scheme.

The data set for assessment of a hole scenario is taken from the 5.0 m foundation soil simulations and is:

{40, 55, 70, 75, 80, 90}

These values are highlighted in yellow in the table.

4.3.2 Conclusions

Results are consistent, within a data range of 50 m. The maximum length was chosen.

90 m be selected for the distance relating to a hole scenario for the Kaituna catchment.

4.4 Kaituna Summary

Key results are shown in the summary table that follows:

SEEPAGE MECHANISM	DISTANCE
Seepage propagation	140 m
Heave	125 m
Hole scenario	90 m
BAA Recommendation	**140 m**

Figure 36: Kaituna Results Summary Table

Part 5: Whakatāne/Tauranga Assessment

Governing cases

Within the Rangitāiki Plains the Whakatāne River is the only river that does not outlet to the ocean via a diversion channel. The catchment still contains pumice deposits but as the geography moves eastward in the upper catchment the Taupō Volcanic Zone boundary merges with the North Island Shear Belt fault system which exposes jurassic greywacke. This parent rock supplies gravel to clay particles into the Whakatāne/Tauranga river network which have a heavier specific gravity.

Thick sand volumes are known to exist with minimal blanket cover in the tidal regions of the lower catchment. The unlimited foundation soil models are therefore relevant, and were assessed against the 5.0 m thick soil models. The 2.0 m models were not selected for this assessment except for Simulations K and L which were retained to provide some control to the data set.

The inland topography is flatter, with four slope sections all measured less than 1°. The flat and transitional model for 60 m were selected for assessment.

Parameters

Foundation soils were assessed using permeability values of $k=1\times10^{-4}$ m/s (high k) and $k=1\times10^{-5}$ m/s (low k). These values reflect the influence of greywacke derived material as opposed to the highly vesicular and angular nature of pumice that promotes high permeability soil.

Topography screening

Downstream of where the Whakatāne River flows from the Taneatua Valley several ground profiles were analysed. Yellow highlighted sections were checked for slope grade which varied between 0.2 and 0.7°.

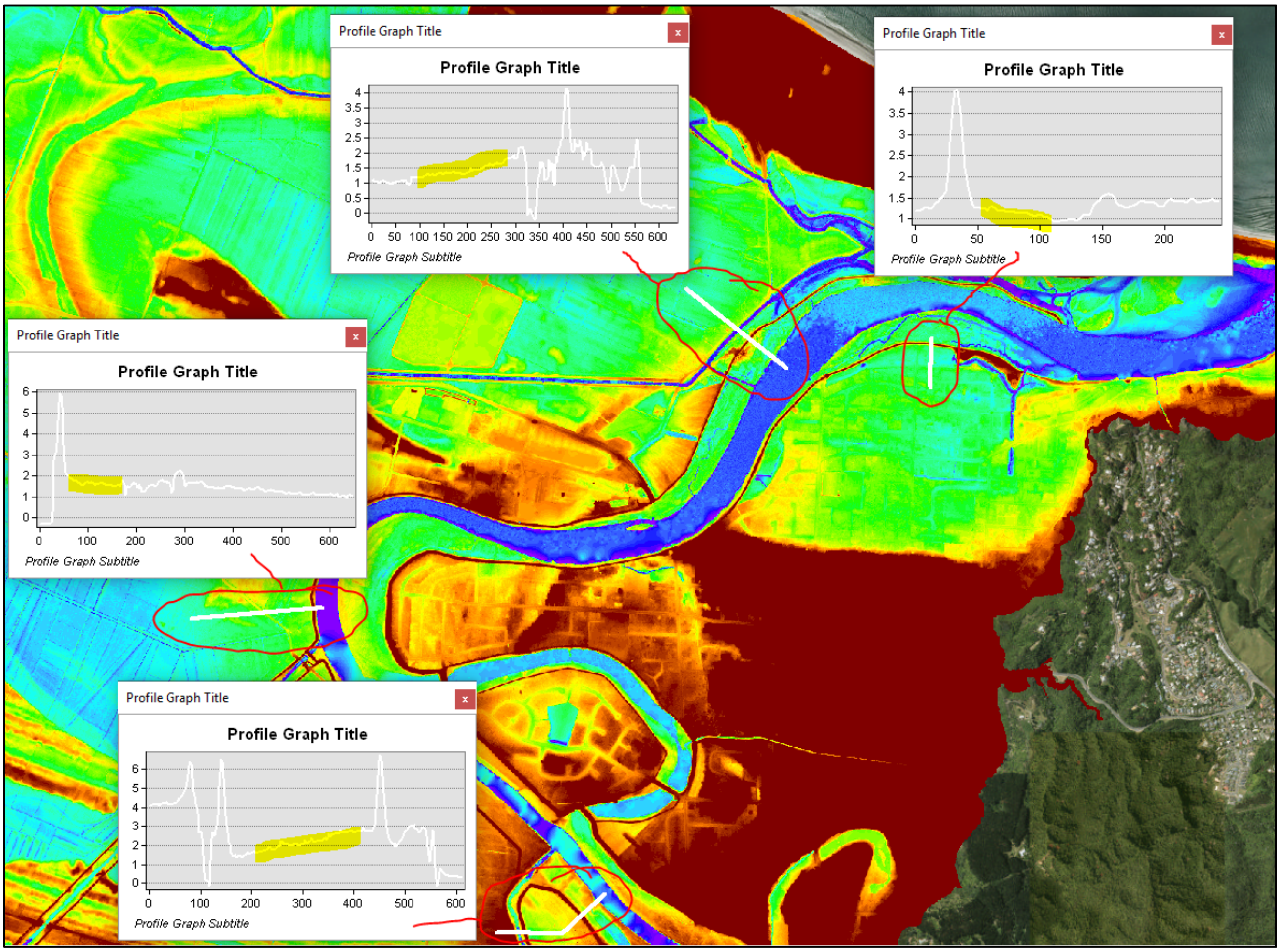

Figure 37: Sections where the inland slope grade was analysed.

Design Hydrograph

The hydrograph used for modelling relates only to this bylaw review. Due to varying flood heights and ground levels along the river scheme a generic hydrograph is adopted for modelling. For site-specific assessment hydrographs calibrated to the flood and stretch of flood defence should be used.

Based on historic flood events the peak duration of river levels was assigned as 3 days. Flood waters rise within 1 day. Flood waters recede 1 m over 1 day, then recede a further 1 m over two days before ramping down to non-flood conditions with a ground water table 1.0 m below ground. This hydrograph is the same as used for the Kaituna model. The below images compares the Whakatāne River hydrograph at a specific cross section which is calibrated to the Moturiki Datum, against the hydrograph used for this modelling which is in terms of total head.

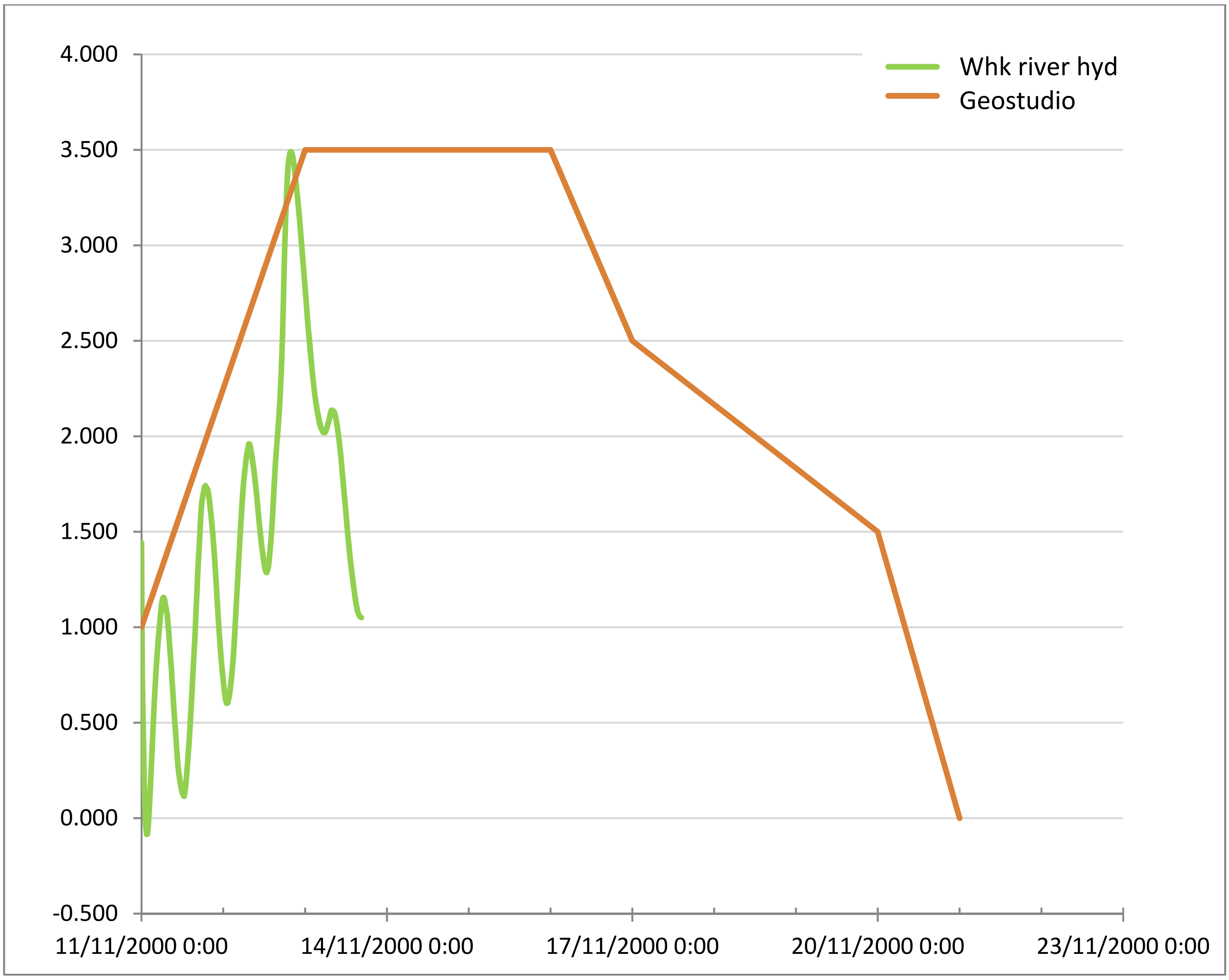

Figure 38: Recent 100 year hydrograph (green) used for a site-specific assessment overlain against the hydrograph used in this modelling (orange).

Based on the above the design hydrograph adopted for modelling is represented in the following figure.

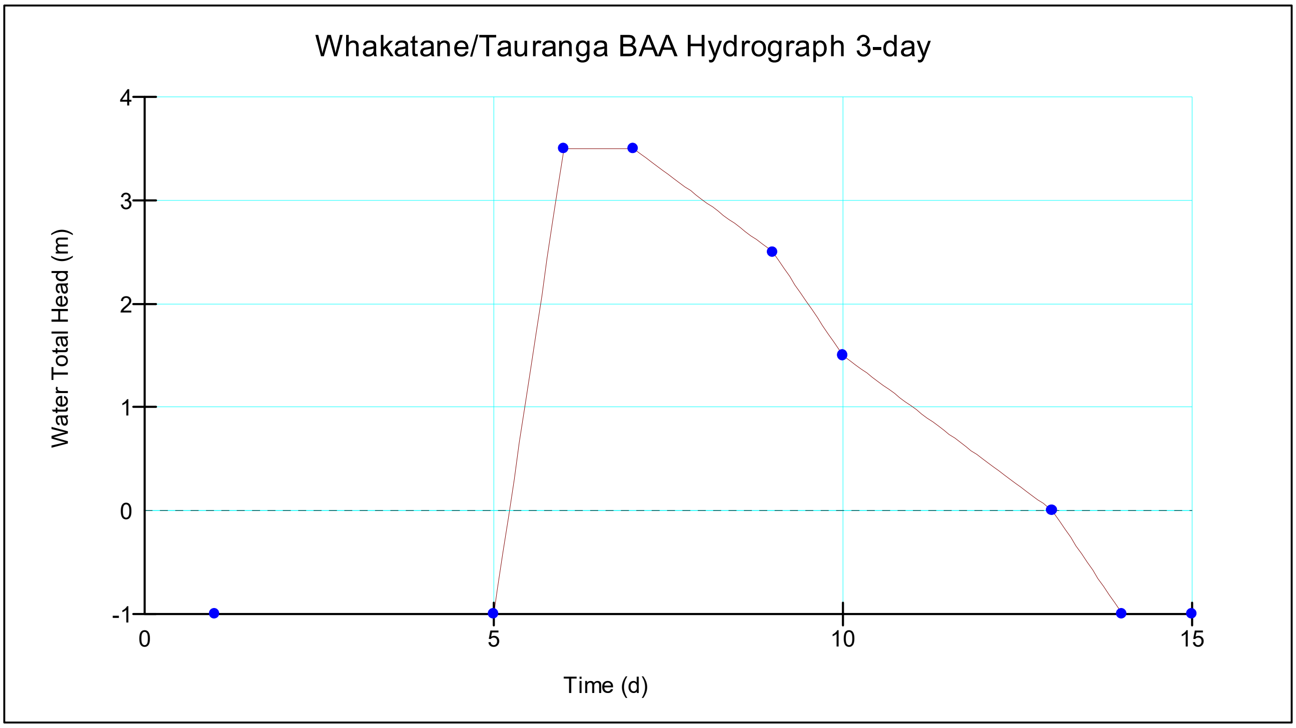

Figure 39: Whakatāne/Tauranga Flood hydrograph used for bylaw modelling.

5.1 Seepage face review

For the simulations the length to which a seepage face can develop is summarised in the table that follows:

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground				Transitional ground at 60 m			
	Measured distance to where a seepage face develops (m)		Measured distance to an exit gradient of 0.4 (m)		Measured distance to a seepage face develops (m)		Measured distance to an exit gradient of 0.4 (m)	
	Transient	Steady State	Transient	Steady state	Transient	Steady State	Transient	Steady State
A (U/0)	**29**	**81**	**<1**	**D/O**	**76**	**104**	**<1**	**D/O**
B (U/0)	D/O	81	D/O	D/O	D/O	104	<1	D/O
C (U/½)	**90**	**200**	**71**	**140**	**201**	**234**	**148**	**169**
D (U/½)	8	107	3	32	79	133	D/O	25 Nearly R/S at hip
E (U/1)	**195**	**241**	**123**	**147**	**237**	**267**	**155**	**169**
F (U/1)	48	124	18	31	90	147	13	22 R/S to 0.3 at hip
G (U/2)	**219**	**281**	**111**	**135**	**267**	**303**	**144**	**158**
H	54	147	10	24	96	168	7	14

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground				Transitional ground at 60 m			
	Measured distance to where a seepage face develops (m)		Measured distance to an exit gradient of 0.4 (m)		Measured distance to a seepage face develops (m)		Measured distance to an exit gradient of 0.4 (m)	
	Transient	Steady State	Transient	Steady state	Transient	Steady State	Transient	Steady State
(U/2)								
K (2/½)	**10**	**57**	**6**	**23**	**7**	**91**	**-**	**18**
L (2/½)	-	23	-	4	-	12 R/S 48-70 m	-	4
Q (5/0)	**4**	**20**	**<1**	**D/O**	**4**	**8 R/S 54-69 m**	**D/O**	**D/O**
R (5/0)	-	25	-	D/O	D/O	8	-	D/O
S (5/½)	**25**	**91**	**19**	**46**	**81**	**114**	**42**	**65**
T (5/½)	D/O	34	D/O	10	D/O	75	-	9
U (5/1)	**58**	**114**	**34**	**46**	**89**	**129**	**44**	**63**
V (5/1)	11	43	3	8	8	78	-	7
W (5/2)	**57**	**133**	**25**	**35**	**84**	**139**	**26**	**35**
X (5/2)	9	50	1	4	4	78	-	4

All values in metres

- = Not assessed.

D/O = Doesn't Occur.

R/S = Re-surfaces; The seepage surfacing at ground level does not continue and so this phreatic surface is below ground, however due to boundary conditions of the modelling the ground-water reaches the end of the model and 'backs up' causing it to re-surface.

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note 2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 17: Results of Whakatāne / Tauranga assessment for the development of a 'seepage face'.

5.1.1 Commentary

For the low permeable soils the propagation of hydraulic gradients under transient conditions was greater for flat ground than transitional ground, however no values went past the change in slope at 60 m. For all steady-state cases with high permeability soils the flat ground resulted in lesser distances.

As deep sand thicknesses exist in this scheme in the lower catchment, the first data set presented relates to hydraulic gradients of 0.4 for unlimited foundation thickness models and includes:

{3, 10, 18, 71, 111, 123} for flat ground.

{7, 13, 144, 148, 155} for transitional ground.

The longer distances are all related to the high permeability soils. The use of 0.4 as the studied gradient is likely too conservative as a greater proportion of greywacke parent materials exist. This reduced the potential to be eroded in comparison to lighter, more buoyant pumice type soil. These distances are therefore considered too large for this catchment. Simulation E was re-run using a gradient of 0.7 and an intermediate permeability value with a resulting distance of 75 m, about a 50% reduction from the previously measured 155 m.

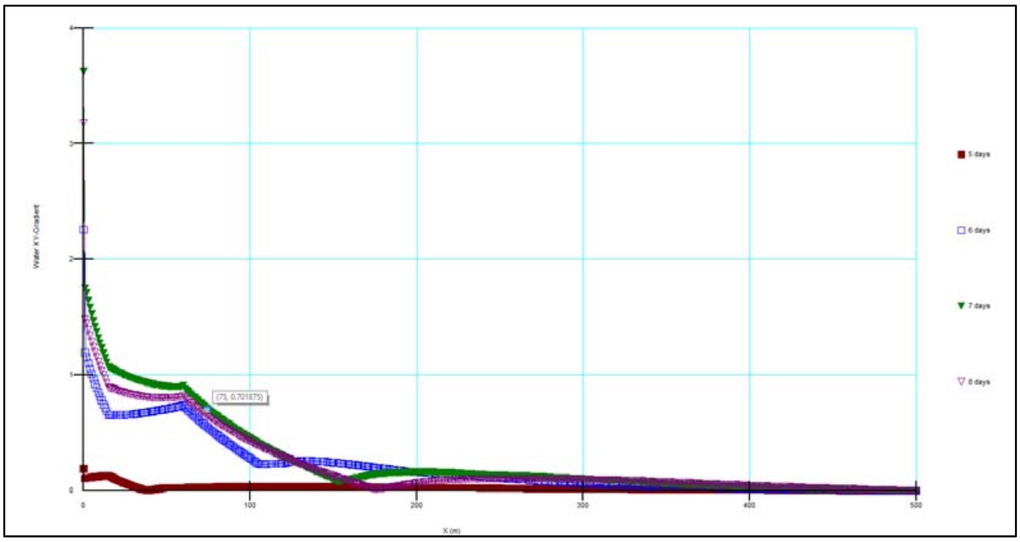

Figure 40: Addition simulation with intermediate permeability and exit gradient of 0.7 for the transitional 60 m model.

Pumice soils are however still present in this catchment but likely exist more as isolated pockets of limited foundation thickness. The higher permeability results were then reviewed for the 5.0 m of foundation soils.

The data set is:

{<1, 1, 3, 19, 25, 34} for flat ground

{26, 42, 44} for sloping ground

Values in this bracketed data set are highlighted yellow in the table.

5.1.2 Conclusions

The selected distance was based on two data sets. This includes results from the low permeable models with unlimited foundation soil thickness and results from the high permeable soils with 5.0 m foundation soil thickness. The combined data set is:

{<1, 1, 3, 3, 7, 10, 13, 18, 19, 25, 26, 34, 44}

40 m is selected for the distance relating to hydraulic gradients for the Whakatāne-Tauranga catchment.

5.2 Heave analysis

Based on results from the seepage face review the simulations containing 5.0 m thick high permeability foundation soil with all blanket thicknesses were assessed together with the unlimited low permeability thickness simulations with a blanket soil cover of 2.0 m.

For these simulations the length to which heave is anticipated is summarised in the following table.

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground		Transitional ground at 60 m	
	Measured distance to FOS=1.0		Measured distance to FOS=1.0	
	Transient	Steady-State	Transient	Steady-State
G (U/2)	42	91	128	140
H (U/2)	D/H	9	D/H	7
S (5/½)	18	42	17	65
U (5/1)	25	39	28	33
W (5/2)	21	61	18	24

All values in metres

- = not assessed

D/H = Doesn't Heave

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note 2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 18: Results of Whakatāne-Tauranga assessment for development of 'heave'.

5.2.1 Commentary

Day 9 was the critical epoch for assessment of heave. This was deducted by checking a random scattering of nodes to see the time epoch that registered the highest pore-water pressure development. To validate the results a stress analysis that can compare pore-water pressure to total stress was checked for the critical epoch and 1 day either side. For Whakatāne-Tauranga the indicator nodes and results are shown in the figure below. It can be seen on the ninth day the greatest pressures developed.

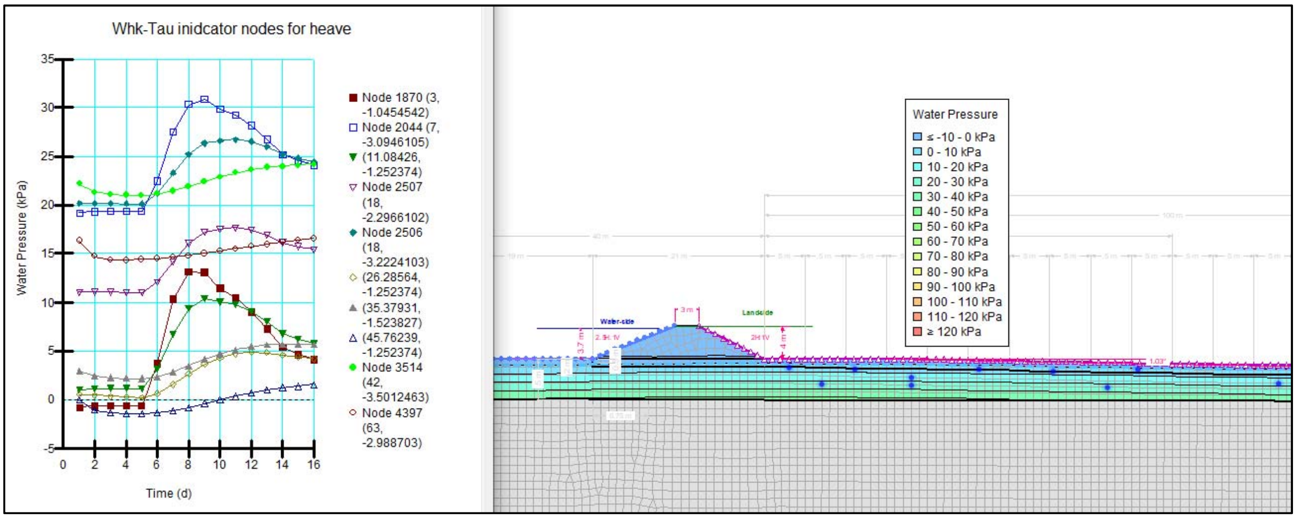

Figure 41: Day 9 was the critical time epoch for heave with the adjoining days, 8 and 10 checked for verification. Indicator nodes are demarcated by blue dots on the model.

A notable difference in distances is seen between steady-state and transient. Simulation S highlights this with steady-state resulting in double the distance for both flat and transitional ground. Only transient results were considered in the assessment as explained in section 1.4.

The unlimited foundation soil thickness simulations are considered to be representative of the lower reaches, and probably tend toward the lower permeability soil results which don't predict heave for transient assessment. For transitional ground the distance of 128 seems unlikely, considered due to this transitional ground profile less likely in the lower and flatter reaches. The flat ground with high permeability soil is more likely to be present, and is considered an upper bound for the data set. This means it tends toward the maximum expected distance, and was measured at 42 m.

The lower permeability model under transient conditions did not predict heave for the flat ground simulation as shown in the following image:

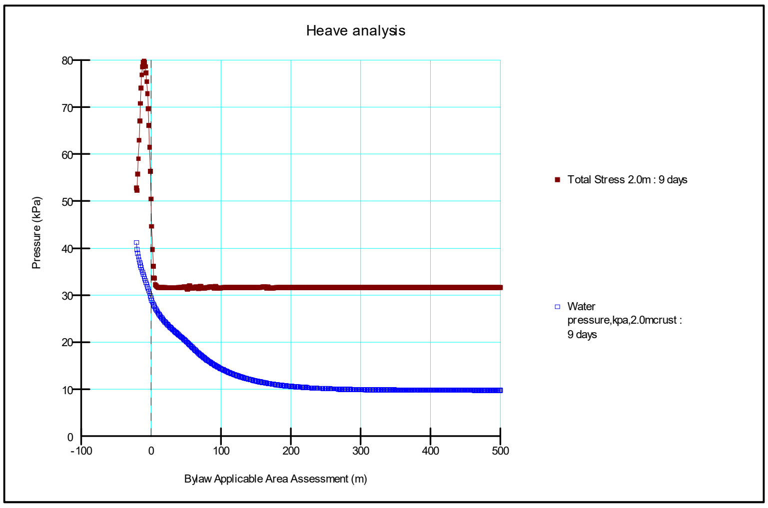

Figure 42: Heave was not predicted for the lower permeability soils and flat ground with pore-water-pressure not exceeding the total stress of the soil.

Simulation F with 1.0 m soil blanketing was checked given no heave was predicted for Simulation H. This did predict heave, but only to a distance of 11 m which would make it the lowest entry if included in the data set.

In the upper reaches of the stopbanking it is more likely that isolated pockets that reflect the higher permeability soil model exists.

The combined data set is from all transient analysis is:

{17, 18, 18, 21, 25, 28, 42, 128}

5.2.2 Conclusions

The value of 128 as explained above is an unlikely occurrence and has been excluded from the data set. Only one other entry doesn't measure under 30 m. That result, 42 m, is also based on an unlikely occurrence so was also excluded.

30 m be selected for the distance relating to heave for the Whakatāne-Tauranga catchment.

5.3 Hole Scenario

Results in the table are based on checks completed at 5 m increments. Increments were built into the models to 150 m, where gradients exceeded this distance the results was displayed as '>150 m' with the gradient value bracketed below the resulting distance.

Due to the less pumiceous nature of this catchment a critical hydraulic gradient of 0.4 has been assessed. Simulations were the same as for heave assessment but also included the full set of unlimited foundation soil simulation results.

The distances to which critical hydraulic gradients could be exceeded at a hole are given in the following table.

SIMULATION (Foundation thickness /Blanket Thickness)	Flat ground	Transitional ground at 60 m
	Measured distance to x-grad <0.4	Measured distance to x-grad <0.4
	Transient	Transient
C (U/½)	20	65
D (U/½)	D/O (0.28 at inland toe)	D/O (0.24 at inland toe)
E (U/1)	~55	85
F (U/1)	~15	20
G (U/2)	100	145
H (U/2)	50 (At 150 m the value was 0.23)	95
S (5/½)	D/O	D/O (0.33 at inland toe)
U (5/1)	D/O (0.39 at inland toe)	D/O (0.38 at inland toe)
W (5/2)	5	5

All values in metres

Note 1: Red has unlimited foundation thickness, Green has 2.0 m foundation thickness, Blue has 5.0 m foundation thickness

Note2: Blanket soil in order from zero, 0.5, 1.0, 2.0 is represented by light to dark shading.

Note 3: Darker orange highlights numbers that represent the higher permeability soil model, lighter orange the lower permeability models.

Table 19: Results of Whakatāne-Tauranga assessment for development of a 'hole scenario'

5.3.1 Commentary

Day 7 and 8 were the critical epochs for sloping and flat ground respectively. For limited foundation soil thickness the gradients did not propagate far beyond the inland toe. The graph below shows Simulation W where 0.4 was just exceeded on day 7 at the toe:

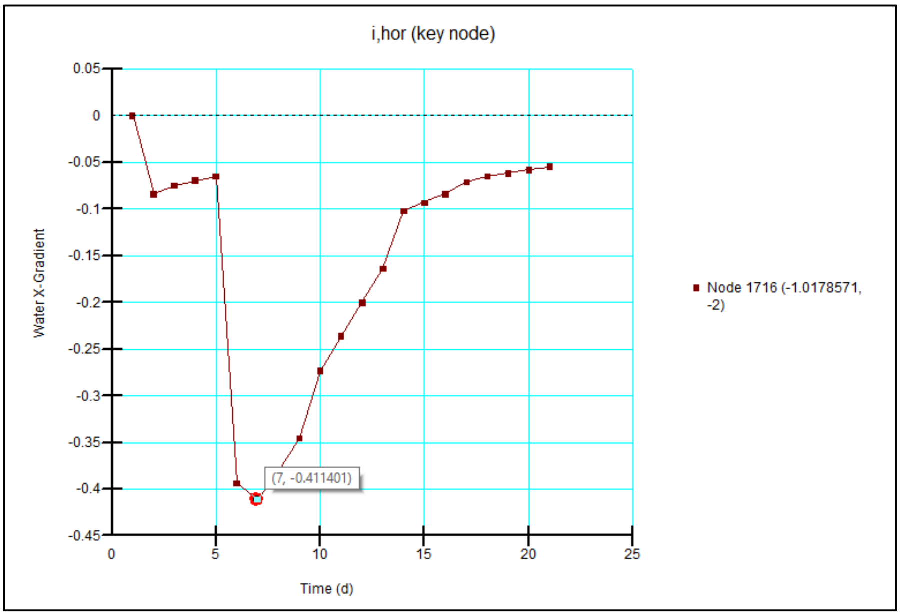

Figure 43: Horizontal gradients 'i,hor' of 0.4 did not propagate for flat ground models.

Noticeably the thickest blanketing with unlimited foundation soil thickness being Simulations G & H resulted in the largest distances of 50 and 95 m for the low permeability simulations. The high permeability results were 100 and 145 m. While the 1° slope is considered conservative, as explained in the topography screening, the result of 50 m for the low permeability soil and flat ground requires justification if it is to not govern the data set (given that the "hole" scenario has not dominated in any of the previous assessments).

Two of the deeper CPT traces available on the New Zealand Geotechnical Database were overlain. The location of these is in the lower reaches, near Ferry Rd in Whakatāne. They were both completed inland of the stop-banks. The permeability correlations show the values used in assessment are relative. However, around 22-25 m depth there is inferred to be layering meaning that the unlimited model which used a 40 m depth is too conservative. Results therefore are expected to be intermediate between the data sets.

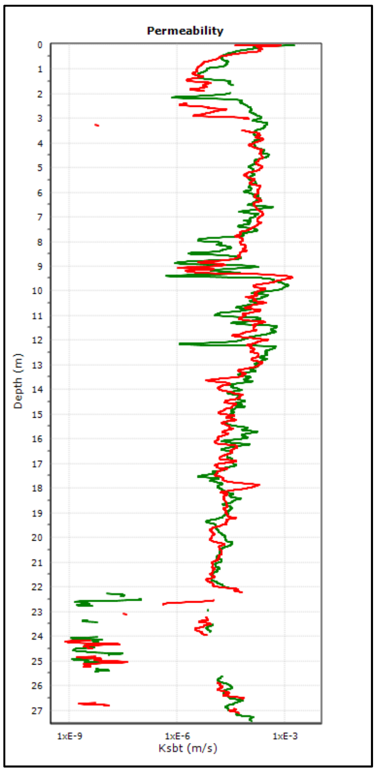

Figure 44: Overlain CPT correlations of permeability used to justify selection of the distance relating to a hole scenario.

Logically this data then identifies benefit in considering a 22 m foundation soil thickness. This fraction of the unlimited soil thickness would be 22/40, or 55%. For linear data extrapolation the distance would interpolated to 27.5 m. Applying conservatism and checking for a 30 m foundation soil depth gives the fraction 30/40, or 75%. A distance of 37.5 m is interpolated.

5.3.2 Conclusions

<u>Consequently, 37.5 m be selected for the distance relating to a hole scenario for the Whakatāne-Tauranga catchment.</u>

5.4 Whakatāne/Tauranga Summary

Key results are shown in the summary table that follows:

SEEPAGE MECHANISM	DISTANCE
Seepage propagation	40 m
Heave	30 m
Hole scenario	37.5 m
BAA Recommendation	**40 m**

Table 20: Whakatāne-Tauranga Results Summary Table

Part 6: Waioeka/Otara Assessment

Governing Cases

The hydrographs from rivers on this scheme are different to those of the Whakatāne/Tauranga scheme. Three hydrographs considered to represent these schemes were underlain below the design hydrograph on an arbitrary elevation datum to reflect pressure head. Hydrographs were taken from a location near the upstream and downstream extent of the Otara stopbanks, and one from the Waioeka with the numerical value indicating the chainage upstream. Because the design hydrograph used for modelling encompasses the stage differential from normal to peak flows, and provides for a longer duration of saturation it is considered that results from the Whakatāne/Tauranga assessment are transferable to this scheme. The following figures illustrates the underlain hydrographs against the design.

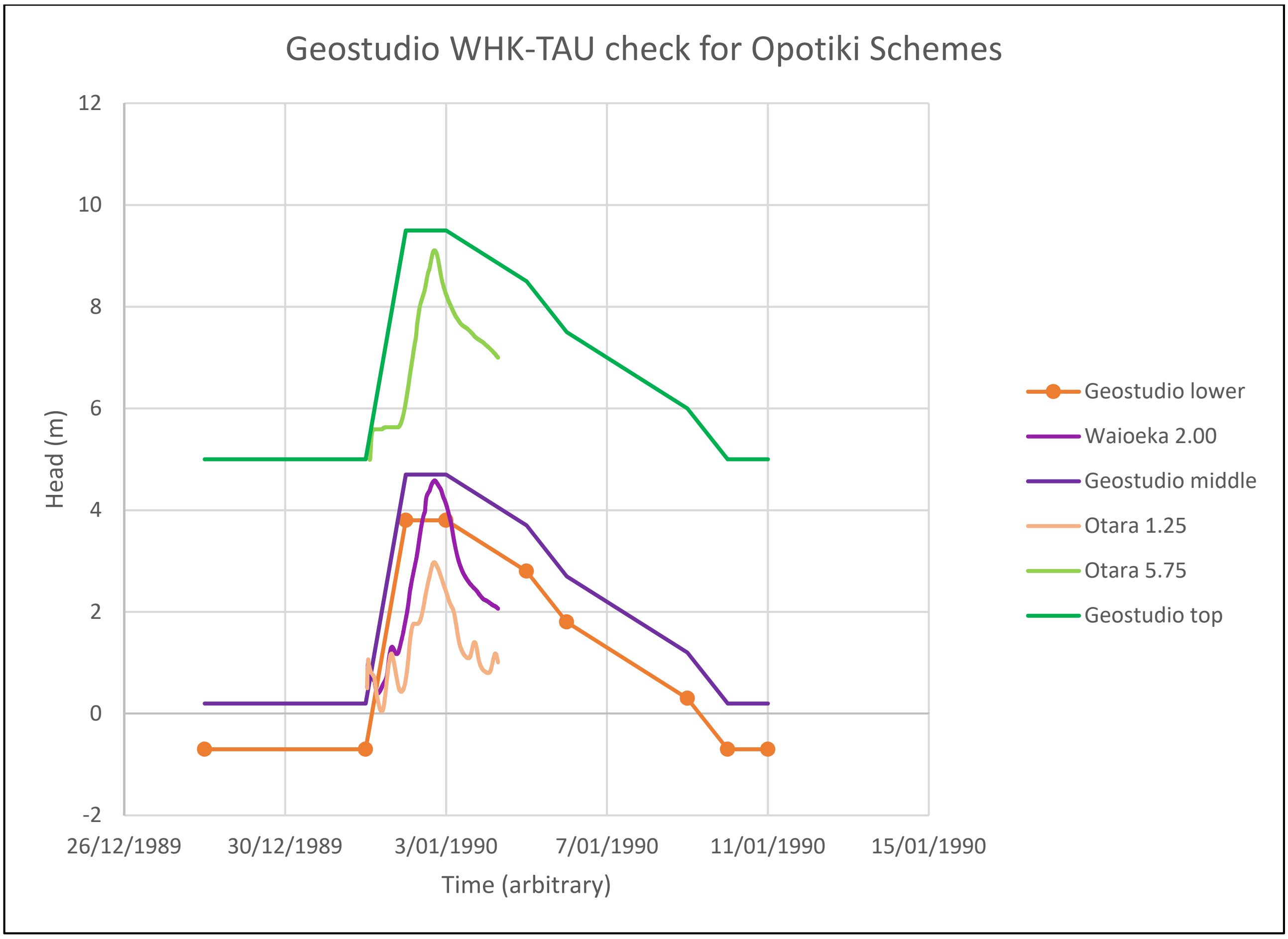

Figure 45: Check on design hydrograph for Whakatāne-Tauranga for applicability to the Waioeka-Otara

The interaction at a confluence between two rivers such as the Waioeka and the Otara adds complexity to the flood hydrograph and can increase the duration of high river water levels. In some instances one river will act as a detention basin for the adjoining river to reduce the peak water level during a flood. If there are floods in both rivers at the same time very high and long duration floods can occur downstream of the confluence. It is envisaged this is allowed for by the model hydrograph having a longer peak duration and slower receding rate.

6.1 Seepage assessment

The soil parameters and the hydrograph were set using the Whakatāne/Tauranga model. These catchments are considered to resemble greywacke fed catchments as opposed to pumice in the other catchments, so their geotechnical attributes are comparable. The model hydrograph was also shown to encompass and have good representation of the Otara and Waioeka hydrographs.

Refer to the Whakatāne-Tauranga scheme for methodology and assessment.

6.2 Waioeka/Otara Summary

Seepage, Heave, Hole assessments results are all based on the Whakatāne-Tauranga scheme and are reproduced in the summary table that follows:

SEEPAGE MECHANISM	DISTANCE
Seepage propagation	40 m
Heave	30 m
Hole scenario	37.5 m
BAA Recommendation	**40 m**

Figure 46: Waioeka- Otara Results Summary Table

Part 7: Drainage Scheme Flood Defences and Other Scheme Assessments, ‘other schemes’.

Philosophy

Stopbanks comprising flood defences along canals, drains and streams are referred to as ‘other schemes’. Historically, they were constructed with less quality control than the stopbanks along the main river channels. Usually the nearest source of material was used in their construction. This may include peat, drain cleanings, sand or pumice gravels. These materials have some disadvantages.

• Peat has low permeability but is weak and can cause slope failures and stopbank settlement.

• Porous sands and gravels - particularly if pumiceous - reduce pressure build-up but can result in high seepage flows and the development of piping failures.

Due to variable soils within and beneath stopbanks, modelling a typical section is complex. Hydraulic controls/structures, changing hydrograph levels and topography further complicate this matter. Therefore there is considered to be a higher probability of failures associated with these stopbanks compared to those along major rivers because previous work has been completed to remediate weaknesses and river schemes were constructed to tighter design requirements with better construction monitoring practices.

Other schemes often are constructed where there was no previously existing water-course. Because of this the topography doesn’t tend to characteristically slope away inland as it can alongside rivers. As the flat ground models do not differ in the results for a varied bed width, the flat ground model also provides control over this variable.

Due to other schemes likely to have crest levels lesser than required for river schemes, as they are usually tributaries, it is assumed there will be less driving head. The Tarawera geometry reflects this to a certain degree, and provides the full set of simulation results, so is further studied to infer conclusions for other schemes. Using this simulation for flat ground, and knowing that steady-state conditions provide an upper bound to the transient case then the distances presented in the following table were selected for analysis.

It is worth noting that for other scheme defences in the Tarawera catchment the drain values should be less as they eventually drain to the river once flooding recedes or pumps are activated.

Tarawera Model Only	Heave FoS=1		Hydraulic Gradient < 0.4		Comment
Type of assessment	Transient	Steady State	Transient	Steady State	
Simulation D (U/½)	66	108	74	124	Unlikely to get unlimited foundation soil thickness however large debris fans do exist.
Simulation F (U/1)	88	96	109	119	
Simulation K (2/½)	48	74	51	81	Likely to be in this range. For Tarawera results are likely to be less as this data is taken from the river scheme analysis.
Simulation M (2/1)	43	54	57	64	Likely to be in this range. For Tarawera results are likely to be less as this data is taken from the river scheme analysis.
Simulation S (5/½)	92/**52 GWT@2.0m**	105	96	147	Further illustrates the effect GWT has on heave.
Simulation T (5/½)	21	25	22	39	Likely to be in this range for the less pumiceous catchments.
Simulation U (5/1)	101	117	129	138	Would expect more documented failures. This model is assumed too conservative.
Simulation V (5/1)	25	28	31	35	Likely to be in this range for the less pumiceous catchments.

All values in metres

Note: Some simulations extended to the far-field boundary condition.

Table 21: Heave values from Tarawera assessment that were considered for 'other schemes'.

It is suggested for drains that:

• For other schemes in the Rangitāiki catchment the Simulation U represents the higher permeability model and given the longer duration of saturation because the connecting river scheme is controlled upstream by dams, the upper value of 129 m seems fitting. The theory is that should excavations occur beyond say 130 m, then hydraulic gradients would not be sufficient to erode away soil on the cut-face.

• For other schemes in the Tarawera catchment it is suggest a value less than 129 m should be selected as the duration of flooding will not be prolonged from regulated dam outflows. The proposed BAA for the Tarawera is 100 m, therefore this value is also proposed for the feeder drains. These drains may not experience the same peak stage but are likely to be saturated for a longer duration, thus a value less than 100 m was not selected.

• For other schemes in the Kaituna catchment the same characteristics that could exist within the Tarawera were considered possible. 100 m is also proposed.

• For other schemes in the Whakatāne, Tauranga, Waioeka and Otara catchments the lower permeability models with a limited thickness were considered. Based on Simulation V a value around 31 m is suggested. 30 m is proposed.

For the drainage and other schemes the following table summarises the proposed BAA values:

Feeder catchment	Current (m)	Proposed (m)
Tarawera	20	**100**
Rangitāiki	20	**130**
Kaituna	20	**100**
Whakatāne/Tauranga/Waioeka/Otara	20	**30**

Table 22: Drains/streams/canals etc., proposed BAA distances.

Part 8: Recommendations

The Bylaw Applicable Areas (BAA) that were determined in the original version of the Bay of Plenty Regional Council Floodway and Drainage Bylaw 2008, were determined utilising observation and rudimentary analysis. The analysis undertaken for this review has been a lot more thorough and is thus considered more robust.

The modelling set out to analyse the extremes for each scenario to determine upper and lower bounds. The results were then scrutinised to eliminate values that were either too conservative or were not applicable to the individual river or scenario. The recommendations below are therefore the values that produced the greatest value of the seepage, heave and hole analysis for each respective river.

Rangitāiki

Based on the propagation of seepage gradients and anticipated length in which heave could occur it is recommended to increase the BAA to 200 m.

Tarawera

Based on the propagation of seepage gradients and anticipated length in which heave could occur it is recommended to increase the BAA to 120 m.

Kaituna

Based on the propagation of seepage gradients and anticipated length in which heave could occur it is recommended to increase the BAA to 140 m.

Whakatāne/Tauranga

Based on the propagation of seepage gradients and anticipated length in which heave could occur it is recommended to increase the BAA to 40 m.

Waioeka/Otara

The results are based on the Whakatāne/Tauranga scheme, it is recommended to increase the BAA to 40 m.

Drainage scheme defences against water and other schemes

130 m is proposed for other schemes that feed into the Rangitāiki river.

100 m is proposed for other schemes that feed into the Tarawera and Kaituna rivers.

30 m is proposed for all other schemes.

Universal recommendations

Any water ways that can openly connect to a river control scheme using should have the same BAA as the scheme where the inflow will originate from. This includes the Rangitāiki floodway having the same BAA as the Rangitāiki river scheme.

Any areas with landward topography of lower elevation than that at the stopbank toes should be subject to a simple calculation. The slope in degrees should be measured, and if in exceedance of 1° then a site specific assessment shall be required.

The thicker the blanket soil the greater the theoretical seepage hazard should the blanket fabric be compromised because hydrostatic pressure increases with depth. Where several metres of blanket cover exists there is benefit in that shallow embedded objects may not pierce through - and contrarily - penetrations that do will experience larger hydraulic concentrations from the thicker blanket soil. Thinner blanket soil therefore only result in energies building up proportional to that thickness, but should not be considered safer because the risk of heave increases. Sites should always be assessed based on their actual geometries and composition.

Land-users should be encouraged to inform the Bay of Plenty Regional Council of any peculiar ground behaviour or seepage during flood events. Localised treatment can then be considered for problematic areas. Extra attention should be given to topography that transitions from sloping to flat, not just during a flood but also when the land is being used or proposed to be used for agricultural activity such as ploughing, ripping, tree planting or installing posts.

Part 9: References

Bay of Plenty Regional Council. (2018, October). Flood Warning Manual - 2018 revision 12 October.

Bay of Plenty Regional Council. (2018, July 1). Rivers and Drainage Asset Management Plan 2018-2068.

Environment Bay of Plenty. (2007, April). Hydraulic Design of the Awarua Drain Stopbanks. (P. West, Ed.)

Geo-slope. (2020). Geostuido Bundle (Seep-w, Sigma-w, Slope-w).

Microsoft. (n.d.). Microsoft Office (Word, Excel, Powerpoint, Publisher).

Part 10: Closure

Future and best practice

As with all computer aided modelling, the ability to calibrate and test the sensitivity of models is limited to the user's ability. There will be exciting developments as 3D seepage modelling software becomes widely used. There is a need to promote finite element modelling amongst learning institutes especially in the field of geomechanics. Climate change is not only attributed to recent/current weather events, but it is requiring projections of future events which demand ongoing and retrospective assessment of flood defences. This phase of modelling attempts to set a base level assessment, and it is envisaged that with development and advances within this field, these models will be manipulated to the engineer's satisfaction, or provide for comparative assessment against future versions whether they be new, improved or more detailed.

Statement

The effect of seepage confinement from fine grained soils, referred to as soil blanketing, allows sub-surface water to migrate beneath the ground surface in deeper soils layers with higher permeability's which causes high water pressures to develop at considerable distances from the water source. This can lead to the upper soil becoming buoyant. This is what is known as the development of heave. Greater thicknesses of highly permeable soil promote further migration of seepage pressures. Whilst the thicker blanketing resists better against heave it can be more problematic for deep penetrations in comparison to thin soil blanketing. Deep penetrations that pierce a thin soil blanket can be readily remediated with filter collars, and vice versa shallow penetrations that don't pierce a thick soil blanket may function adequate without any remediation required. Shallow penetrations in shallow blanket soil and deep penetrations in deep blanket soil will likely require remediation to any extent that short-circuiting the seepage connection to the ground surface could have sufficient hydraulic energy to erode soil particles.

This modelling is primitive in respect to the complexity of soils in this region. This calls for conservatism which means that site specific assessments may frequently find areas not restricted to possible development within the BAA. Development should not be carried out on land immediately adjacent to stopbank toes and where possible these areas should remain accessible with grass cover so that observations can be made during a flood.

The definition of BAA provides guidance on the areas requiring inspection to those carrying out flood monitoring.

Land within BAA for which proposed developments could exacerbate the effects of seepage can be subjected to conditions listed on a FAD Bylaw authority. It should be expected that pressure relief or other seepage treatments will be required in some situations and these should be allowed for during any feasibility studies prior to lodging an application. The effects of any proposed development on stopbank security should be assessed by a suitably qualified and experienced professional and a report should accompany any FAD bylaw applications.

Appendices

Appendix A: Modelling outputs illustrations

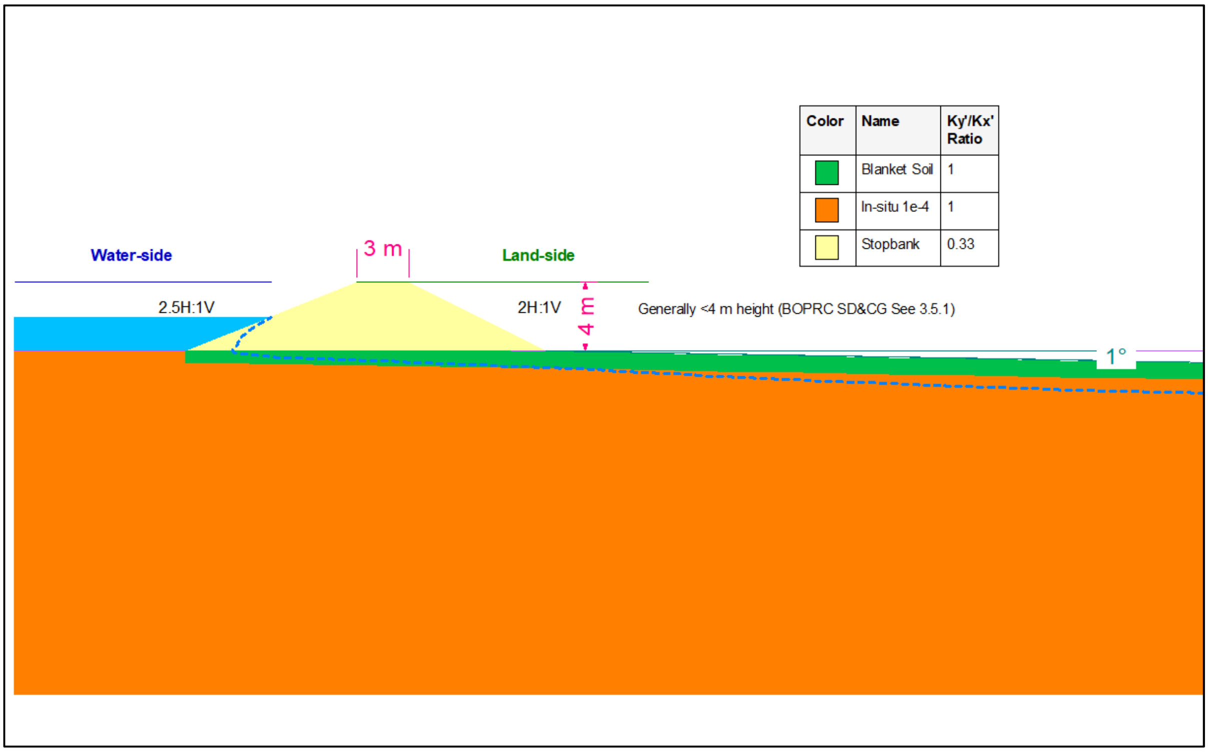

Figure 47: SEEP/W example simulation. The light orange represents the lower range of the permeable foundation soils. This model is slope at 1°.

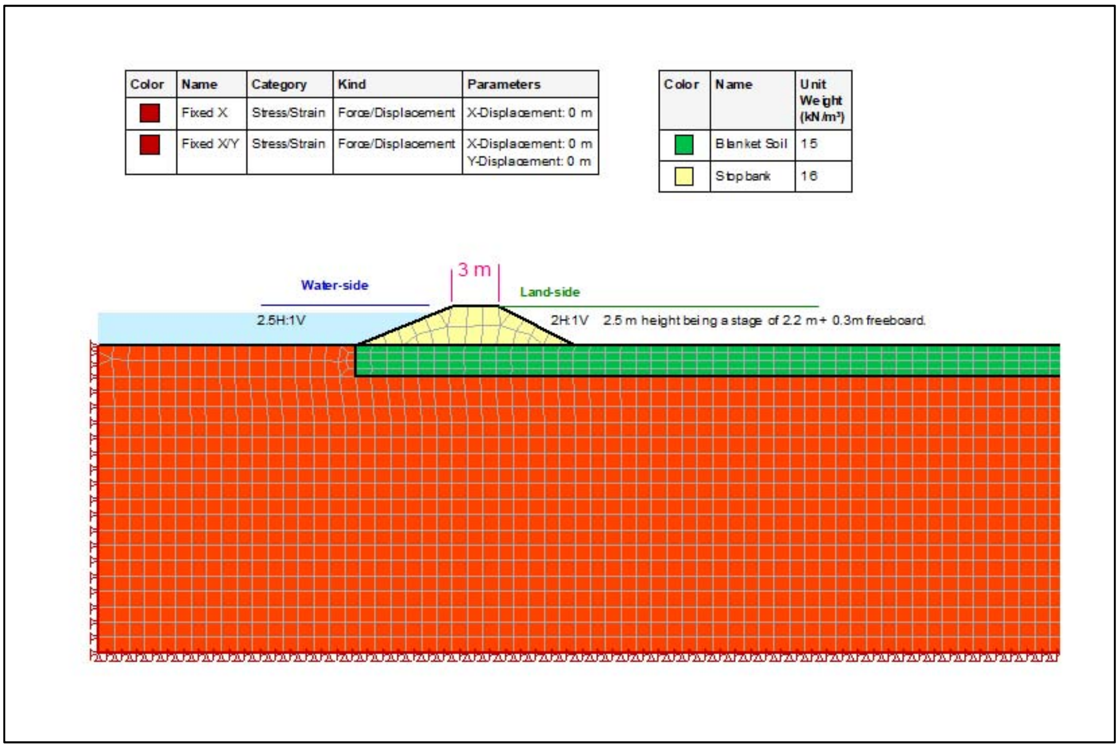

Figure 48: Sigma-w setup file (example). Note the dark orange represents higher permeability foundation soils.

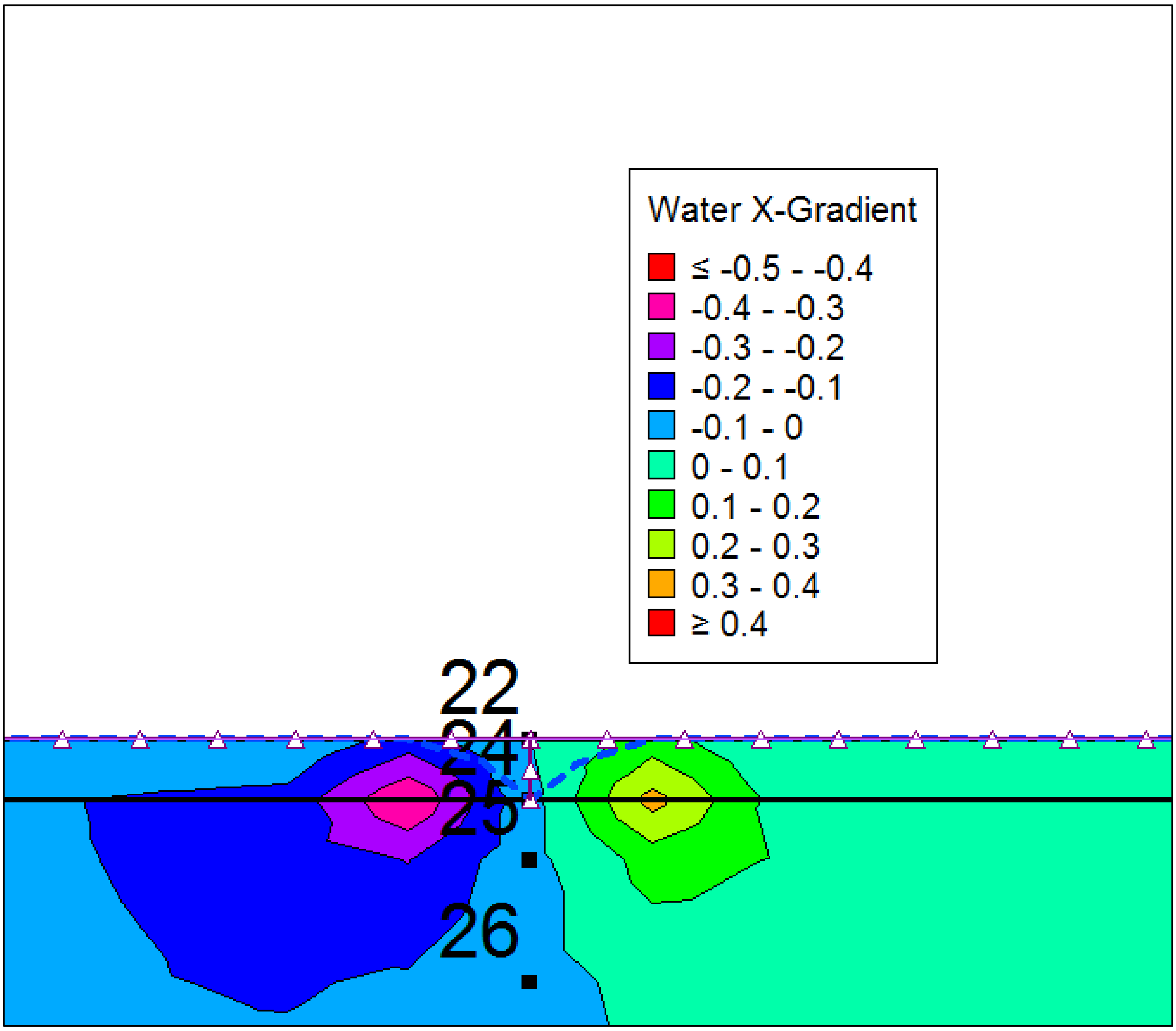

Figure 49: Example illustration during assessment of 'hole scenarios'.

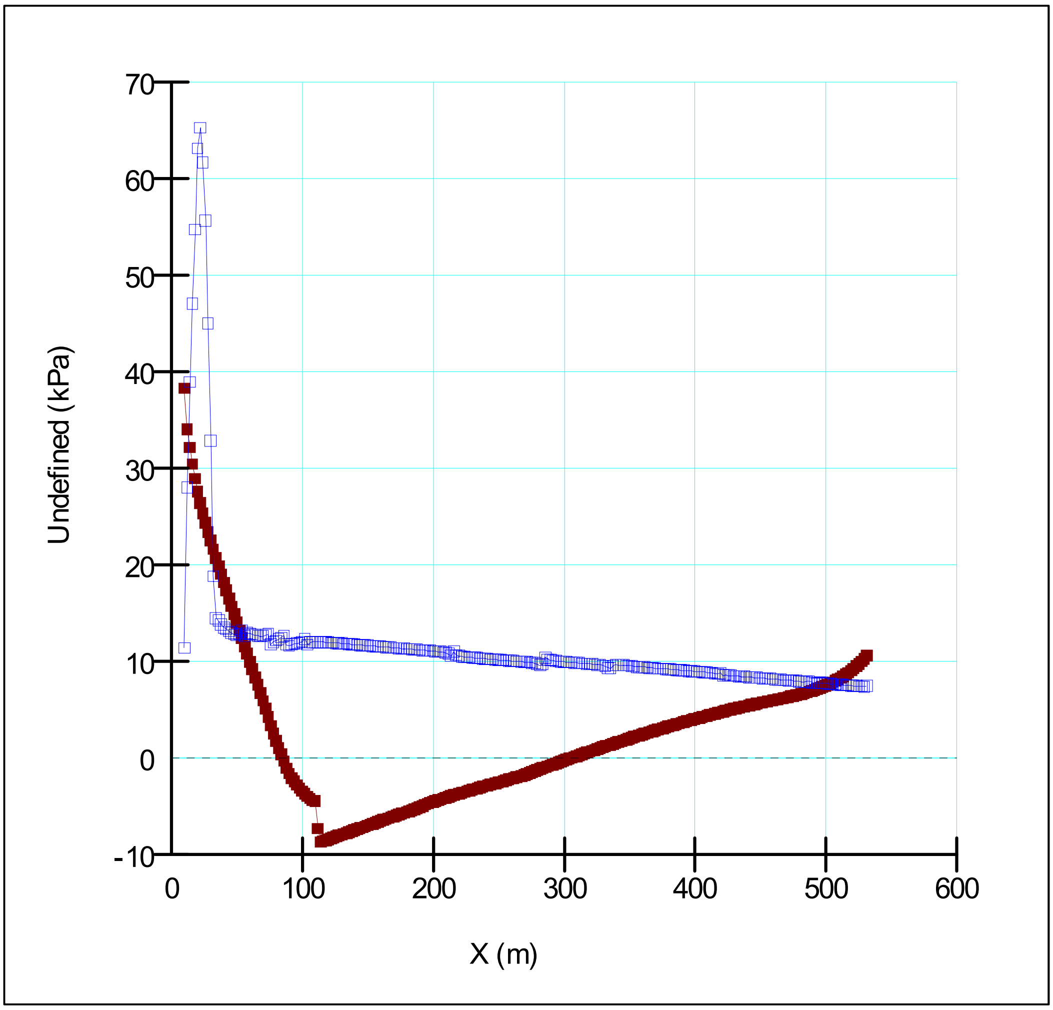

Figure 50: Example of a heave simulation output governed by model boundary conditions where re-surfacing occurs around 500 m.

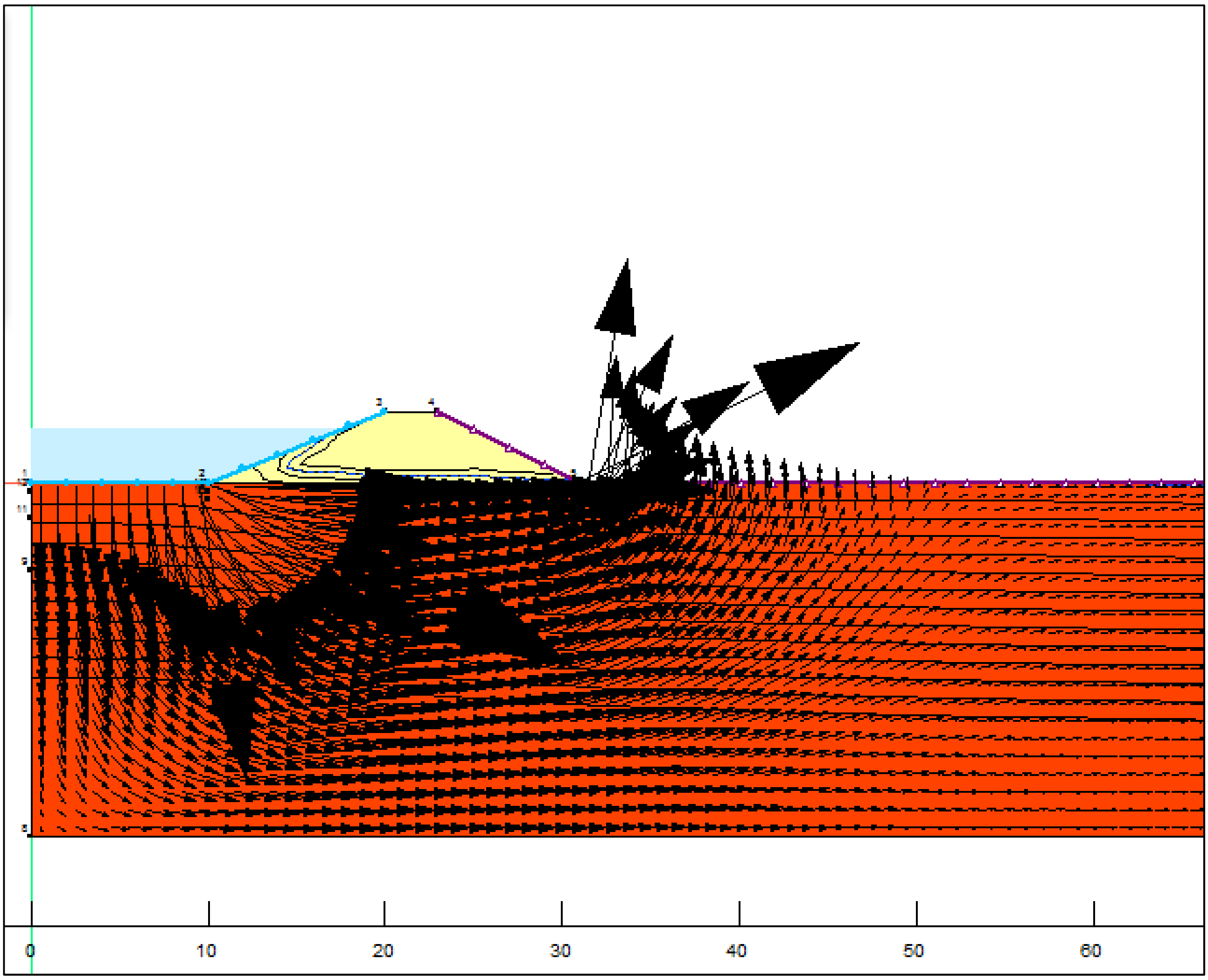

Figure 51: Models without blanket soils are unable to confine water pressure and develop a free-face where water ponds on the ground surface. The area at the inland toe of the stopbank is prone to the development of piping in this situation. In reality highly permeable layers in most places are covered by a layer of lower permeability soils derived from the settlement of fine particles when the river bank has over-topped, airborne soils or a build up of organic material. Exceptions to this include sand dune areas where cattle may have kicked out the surface soils and drains which have been cut down through the surface soil.

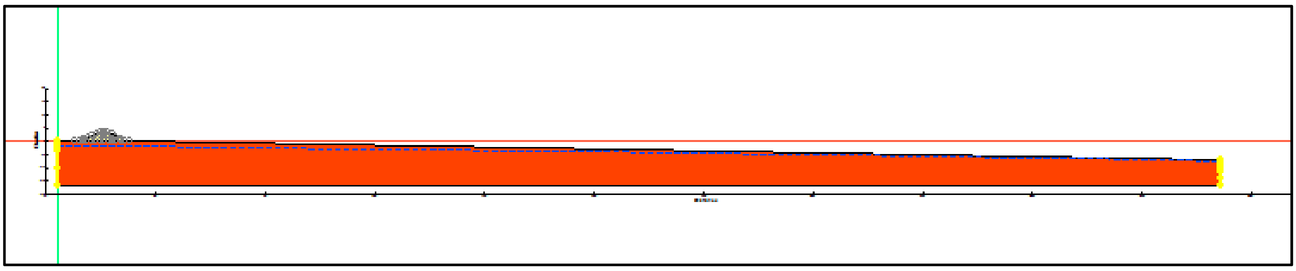

Figure 52: For the sloping ground simulations boundary conditions (yellow lines) were used laterally at both model boundaries to develop initial ground water conditions. For flat ground models a single lateral boundary condition was sufficient.

Appendix B: Tarawera Example Illustrations

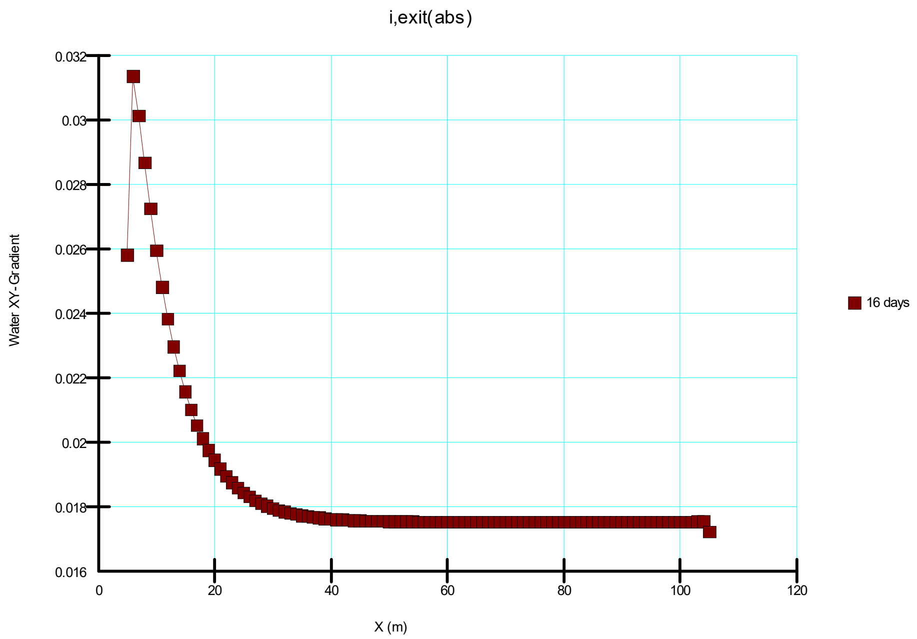

Figure 53: Tarawera - Simulation A/SS where exit velocities > 0.4 don't occur.

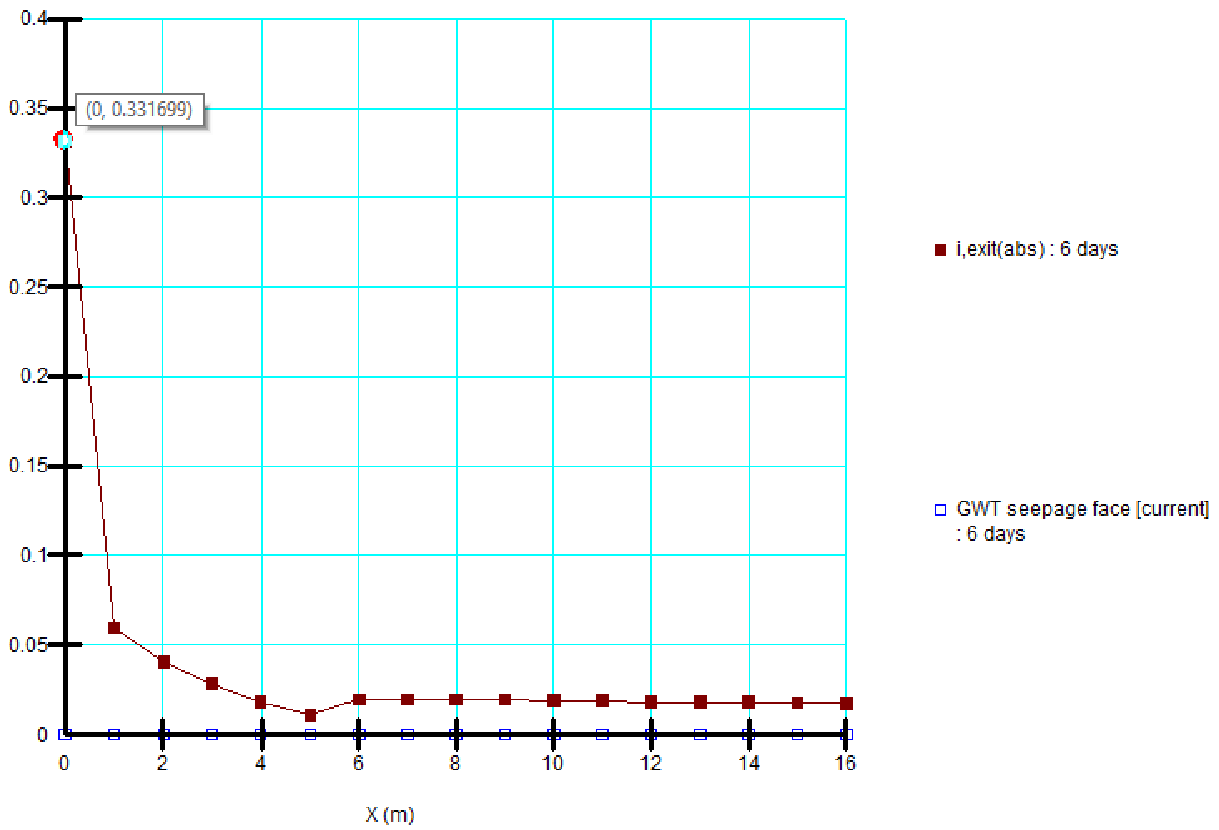

Figure 54: Tarawera - Simulation A/SS where the first measured node recorded an exit velocity of 0.33 which is <0.40 on day 6. Time epochs before and after were checked with smaller values recorded.

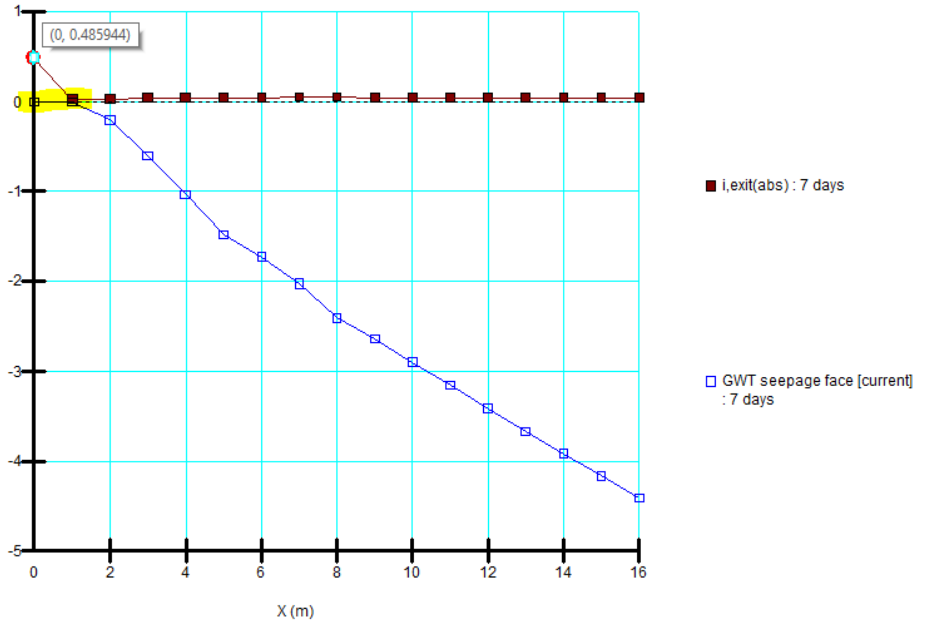

Figure 55: Tarawera - Simulation B/TR: Pore-water-pressures reaches the ground surface only for ~1.0 m and the exit gradient is only >0.4 at the first node.

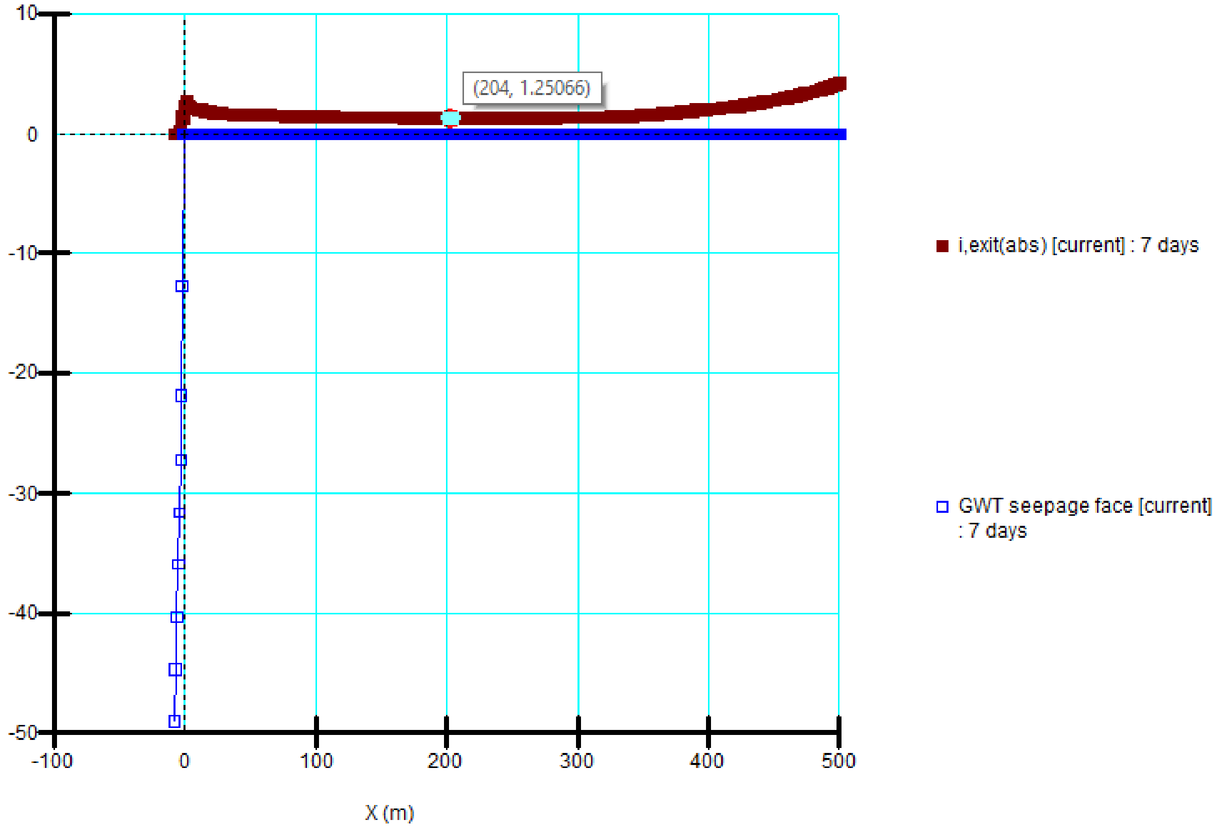

Figure 56: Tarawera - Simulation C/TR giving an example of the requirement to check exit gradients where seepage surfaces to ground (ie a seepage face develops). This graph shows the exit gradient at 204 m inland is 1.25.

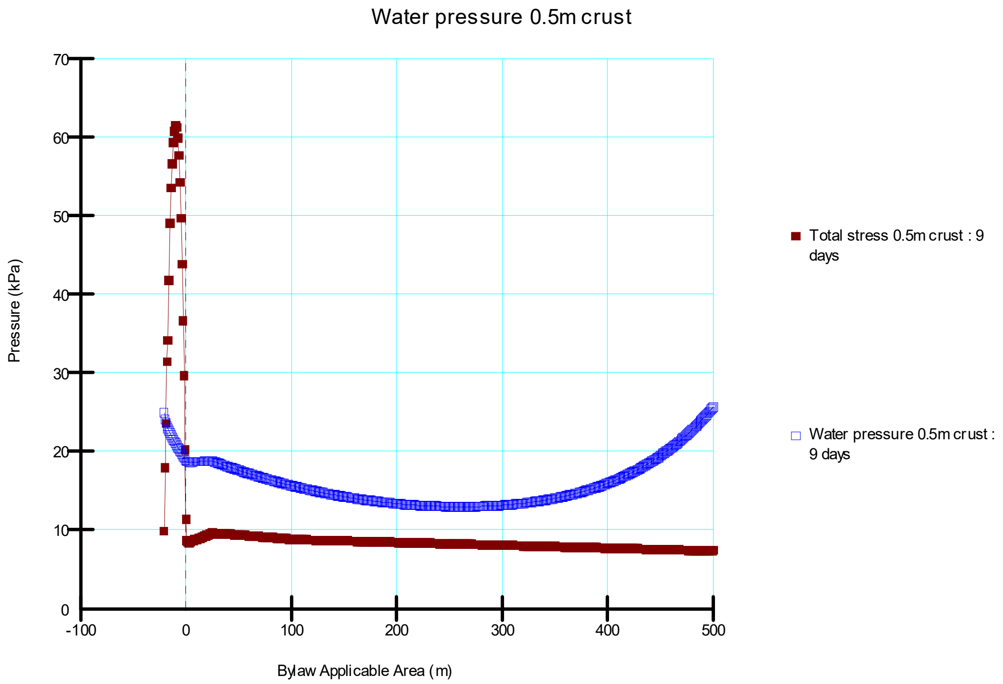

Figure 57: Tarawera - Simulation C/TR showing anticipated heave for the full model extent.