APPENDIX W

Mangakotukutuku ICMP

Hydrogeological & Geotechnical Investigations – Stage 1

Mangakotukutuku ICMP

Hydrogeological & Geotechnical Investigations – Stage 1

Client: Hamilton City Council

Co No.: N/A

Prepared by

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Table of Contents

List of Tables

List of Figures

Executive Summary

The Mangakotukutuku gully system, in particular the undeveloped Peacocke Arm, appears to rely on groundwater infiltration to support baseflows. The Mangakotukutuku arm is also fed from the peat swamp in Waipa District so is less reliant on local groundwater infiltration. Wider groundwater flow contours cannot yet be defined but there is sufficient information to conclude that local infiltration is important.

The geology in the catchment allows rainfall to infiltrate and migrate to gully slopes and streams as seeps and springs which contribute to stream baseflows. The same regime could result in instability particularly if development mitigation involves concentrated infiltration.

The baseflows are higher than one would expect, and the seepages appear to be relatively uniformly spread along the channels and not concentrated. Given the strength of the base flow it suggests that infiltration rates and volumes across the catchment need to be maintained so that the strong base flow can be supported through development rather than reduced or diverted.

The catchment will benefit from dispersed infiltration to mitigate the potential effects of development, if the existing stream environment is to be maintained as far as practical. Care will need to be taken to ensure that the method of groundwater replenishment does not increase risk to the built environment through targeted assessment and recommendation of appropriate setbacks.

Geotechnical and hydrogeological conclusions are outlined below. Refer to Section 5.0 for a tabulated summary of issues, options and further investigation recommended by this report.

An overarching Stage 2 recommendation is to develop an integrated GIS map with multiple detail layers informed by further investigations. The GIS map will allow sites to be ranked and constraints to be highlighted as well as linking into other ICMP mapping later in the project.

Geotechnical

As part of the resource consent for development it is recommended the effects of the development on groundwater flows, stability and erosion as a result of landform changes, impervious surfaces and soakage infiltration systems is assessed. This will require groundwater modelling in the pre-development and post-development state.

Therefore, it is important to have an understanding of the baseline groundwater conditions, deep permeability characteristics and rainfall response over an extended period of time that can form the basis of specific assessments.

Groundwater and stream flow

Integrated catchment management pre and post development monitoring is recommended to fully implement objectives associated with best practice. Groundwater needs to be monitored so that groundwater flow can be determined, response to rainfall assessed, and potential development effects identified.

The spatial spread of monitoring points needs to cover all of the undeveloped catchment. More monitoring points may be required for groundwater and streamflow than are required only for geotechnical considerations. In the first instance a review is recommended of whether any of the bores in the WRC database are unused and would make suitable monitoring locations.

Stream flow monitoring is recommended to assess baseflow, and to support ecological and water quality monitoring. At least one permeant continuous flow recording station is recommended to be established in the lower catchment. Additional continuous recorder stations may be of benefit in the upper catchment for ecological and water quality monitoring.

Provisional development controls and BMPs

Additional investigation and assessment are recommended to set exacting requirements for development and infiltration setbacks. To do so the geotechnical risk should be determined in more detail for scenarios with increased infiltration around slopes and retaining walls. A higher level of assessment will enable the catchment to be mapped in high resolution and variable requirements set, as opposed to a single catchment wide requirement.

To achieve the desired outcome, it is considered that the following Best Management Practices (BMPs) are appropriate:

- Provide appropriate setbacks from slopes and walls for development to reduce risk of instability.
- Provide appropriate setbacks from slopes and walls for enhanced infiltration zones to reduce the risk of instability.
- Utilise swales and subsoil drainage to enhance infiltration at lot and minor road level (dispersed and distant from at risk gully slopes).
- Provide at source infiltration via District Plan mandated on-lot water efficiency measures.
- Apply similar approach to major roads where possible.
- Locate wetlands where outlet drainage can be connected directly to groundwater using vertical drainage when centralised collection and treatment is adopted.

1.0 Introduction

1.1 Background

An Integrated Catchment Management Plan (ICMP) is being prepared for the Mangakotukutuku Catchment in the south of Hamilton City. Hydrogeological and geotechnical investigations are required to inform the ICMP.

Geotechnical assessment will focus on the portion of the ICMP extent within the green field area which is known as the Peacocke Development Area. Hydrogeological assessment will focus primarily on the Peacocke area but also considers the developed portion of the catchment and the wider catchment within Waipa District.

1.2 Mangakotukutuku Catchment

The Mangakotukutuku hydrological catchment (Figure 1) is approximately 2,677 hectares and is located south of the Hamilton City Centre. The hydrological boundary extends beyond the Hamilton City Boundary into Waipa District. The catchment is bound to the north and east by the Peacocke Riverside catchment and to the west by the Waitawhiriwhiri catchment.

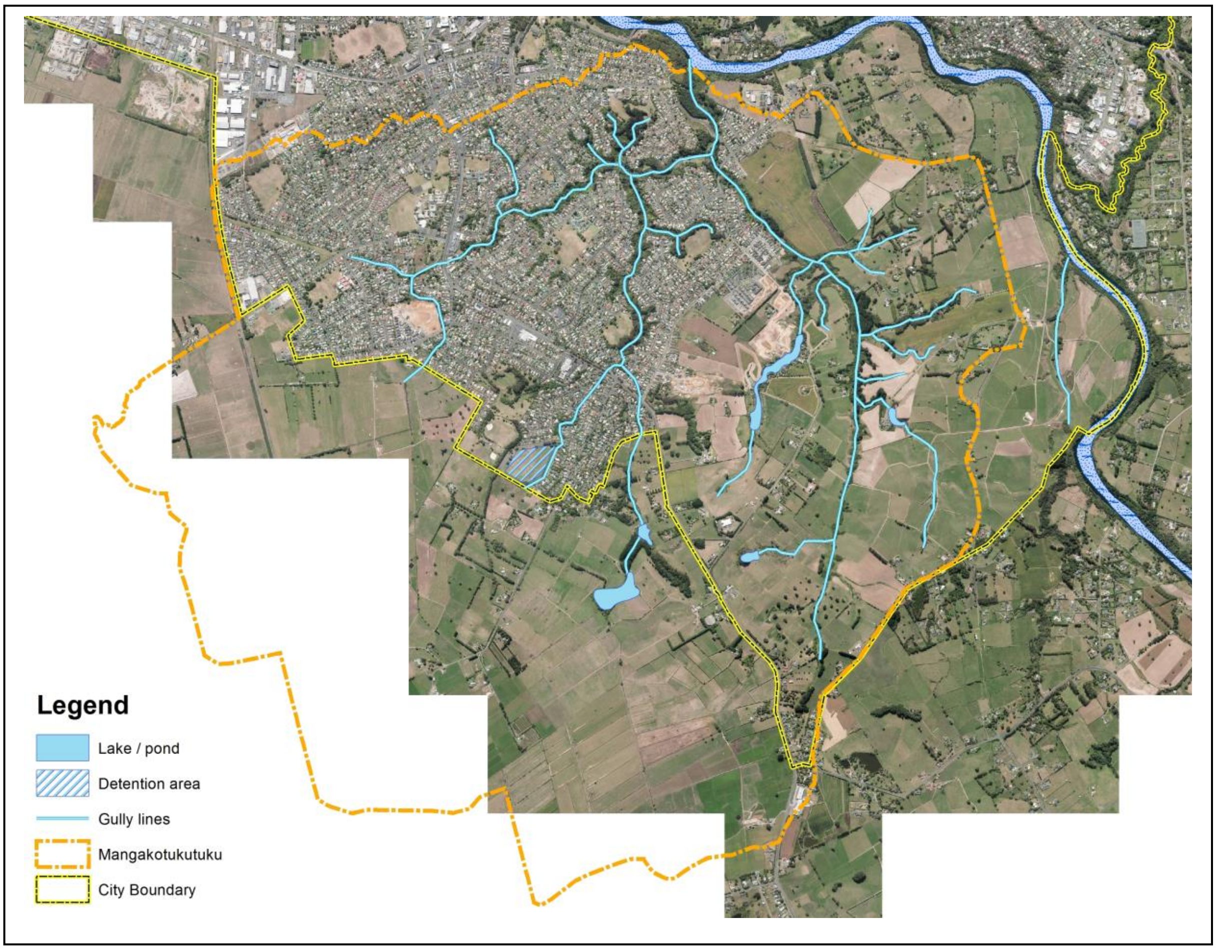

Figure 1 Mangakotukutuku Stream catchment

The hydrological catchment of the Mangakotukutuku Stream is shown in Figure 1.

The ICMP will also address the Peacocke Riverside area which is located between the main catchment and the Waikato River. The Peacocke Riverside area has separate discharge points direct to the Waikato River.

The brownfields area within the Hamilton City boundary is predominately residential with several commercial pockets and one area of industrial land use to the west. The land use beyond the Hamilton City boundary, in the Waipa district, is rural with predominantly pastoral farming, and includes a significant farm drainage network.

The green field area within the Hamilton City boundary is within the Peacocke Structure Plan area. Peacocke was incorporated into Hamilton City in 1989 from Waipa District Council with the main purpose being to provide an area for growth and eventually a community hub.

The dominant future zoning will be residential with an indicative future reserve zoning approximately 20 m from centre of the Mangakotukutuku stream. Furthermore, the designation of the Southern links roading project in the eastern sub catchment identifies this area to be one that will experience substantial change over the next few decades. Walkways and cycle ways will allow for increased access to gully systems and river corridors.

Residential development has started to occur in the western edge of the structure plan around Dixon Road which is referred to as Peacocke Stage 1.

1.3 Objective

The objectives of this initial investigation are broadly as follows:

- Identify potential effects of imperviousness on catchment springs, baseflow of the stream and / or ground settlement within the catchment.
- Advise on soakage, stability and top of bank issues in relation to stormwater management and development setback requirements.
- Identify areas requiring specific geotechnical investigation in relation to the above.
- Identify the requirement for targeted investigations, such as stream gauging and the quantitative measurement of groundwater contribution to base flows. Targeted geotechnical and stream flow investigations will be undertaken during Stage 2 of the investigations if required.

This report covers the initial assessment which is Stage 1 of the project.

The initial hydrogeology assessment has informed the initial geotechnical assessment. The first objective and matter to address is to understand if groundwater recharge is important in maintaining base flows in the Peacocke sub-catchment. The initial assessment will seek to understand this using readily available information.

The geotechnical assessment presented in this report is based on a number of representative scenarios. The geotechnical assessment provides comment on the erosion susceptibility within the catchment and effects of development on catchment stability based on the initial hydrogeological assessment.

Further investigation has been recommended on the basis that groundwater recharge appears to be important. More detailed hydrogeological investigation and assessment and targeted geotechnical investigation and specific assessment is also recommended.

1.4 Scope

The Stage 1 scope of works has been carried out as a desktop assessment using information provided by Hamilton City Council and existing knowledge of the catchment from previous AECOM projects associated with Southern Links and the Peacocke Stage 1 CMP. The following tasks have been undertaken:

- Identify relevant geology, geological hazards, spring locations and water take consents.
- Interpret the results of previous hydrogeological studies and geotechnical investigations undertaken in the area.
- Estimate the influence of groundwater recharge on water balance and therefore the potential effect of increased impervious surfaces.

- Carry out representative geotechnical assessment to identify potential development controls to be confirmed through more detailed investigation and assessment.
- Identify future investigation requirements for Stage 2 of the project.

1.5 Methodology

The following methodology has been applied when undertaking the Stage 1 scope of works.

Hydrogeology

- Collate previous reports already held by AECOM with HCC supplying additional reports prepared as part of previous projects within the catchment.
- Collate GIS database information that is available in relation to geology, consents, spring locations (i.e. layers of all relevant factors will be sought from HCC and WRC as applicable).
- Review and interpret the existing reports and information obtained in (a) and (b) above.
- Map the geology, streams, springs etc. to enable GIS analysis for the identification of patterns and connections.
- Assess the likely role of groundwater in base flows.
- Consider and comment on the location of springs in relation to stormwater management device location (especially the role of soakage) and erosion and geotechnical investigation sites.

Geotechnical

- Review existing geological information of the project area including investigation logs and maps.
- Create typical sections and scenarios based on the identified geology and slope angles observed within the catchment.
- Compare the reaction of the gully slopes within each typical section during an empirical storm event and the subsequent infiltration through soakage trenches.

2.0 Conceptual hydrogeology

This section outlines the conceptual hydrogeology used in Stage 1 based on information from the previous reports and other readily available sources.

2.1 Climate and rainfall

Rainfall and potential evapotranspiration data were obtained from the NIWA Cliflo site for the period 2007 to 2017. The data were obtained for Site 26117 which is located at Ruakura. Mean monthly rainfall and evapotranspiration are shown in Figure 2.

Mean annual totals for the period were 1,107 mm for rainfall and 903 mm for evapotranspiration. Annual rainfall totals varied between 951 mm and 1,395 mm. Rainfall exceeds evapotranspiration from April to October while evapotranspiration is greater than rainfall for the remaining five months from November through to March.

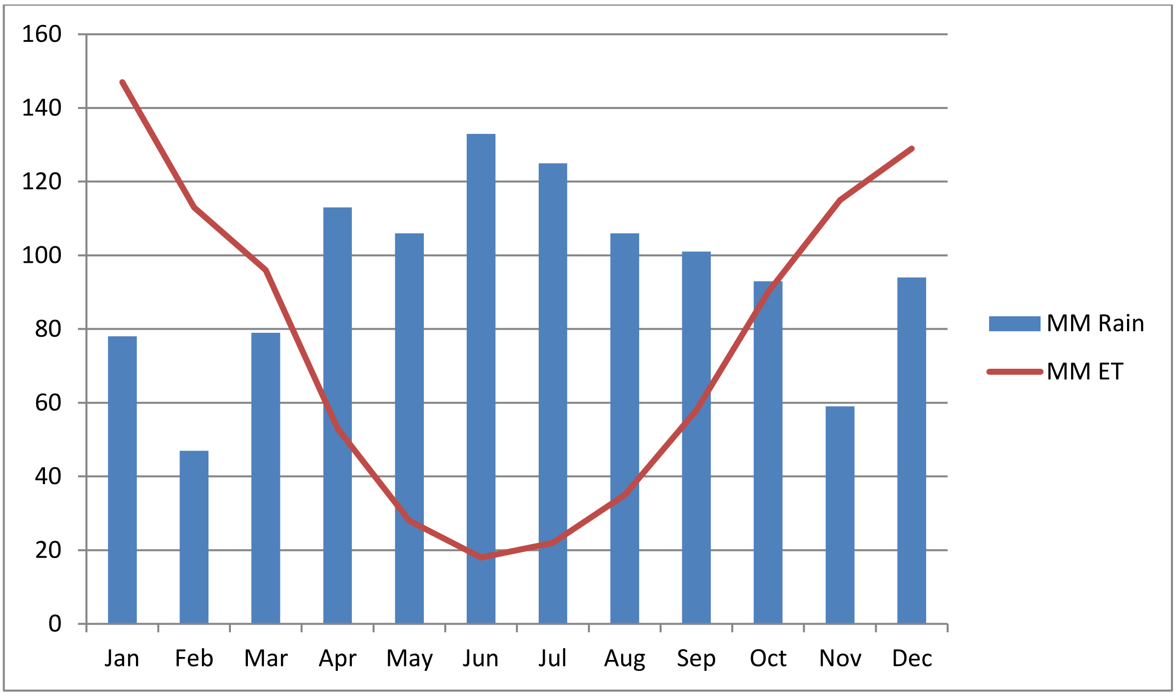

Figure 2 Mean monthly rainfall and evapotranspiration (2007 – 2017)

2.2 Geology

2.2.1 Regional geology

The Mangakotukutuku Stream catchment is situated in the south east of Hamilton City. Hamilton City is situated approximately centrally in the Middle Waikato Basin (Hamilton Lowlands). The Hamilton Lowlands is a broad, low angle alluvial fan built by the Waikato River in the late Quaternary.

The Hamilton Lowlands fan extends from Karapiro in the south to Taupiri in the north. The fan comprises mainly sandy volcaniclastic sediments, derived from rhyolitic eruptions in the mid North Island. The rhyolitic eruptions were deposited on an older highly eroded surface underlain by mixed alluvial sediments, peat and pyroclastic flows referred to as the Walton Subgroup.

The eroded surface of the Walton Subgroup was covered by beds of weathered airfall tephra (Hamilton Ash formation) prior to deposition of the fan materials (known as the Hinuera Formation). The fan materials only partly covered the older ash-covered surface, leaving linear, sinuous and discontinuous ridges rising above the level of the alluvial fan surface. These are commonly referred to as the Hamilton Hills.

Gullies within the Hamilton Basin are the result of head ward erosion as the Waikato River degraded and cut down through alluvial sediment. The gully erosion process exposed groundwater confined by impervious silt layers and forming springs. Over time these springs eroded and collapsed the heads of small gullies forming the system of tributaries common in Hamilton City.

2.2.2 Catchment geology

A recent geological map of the Waikato region (GNS QMAP4 Waikato 1:250,000) maps the Mangakotukutuku Stream catchment as Hinuera Formation alluvium and older Pleistocene age Walton Subgroup alluvium and distal weathered ignimbrite. Areas of elevated land within the catchment are likely to consist of Puketoka Formation and Karapiro Formation (both belonging to Walton Subgroup) weathered ignimbrite and weathered alluvium.

The Rukuhia peat bog forms broad flat plains surrounded by the elevated Hamilton Hills to the south and west of Ohaupo Road. Figure 3 shows the extent of the Hamilton Hills in the catchment and the Hinuera Formation alluvium.

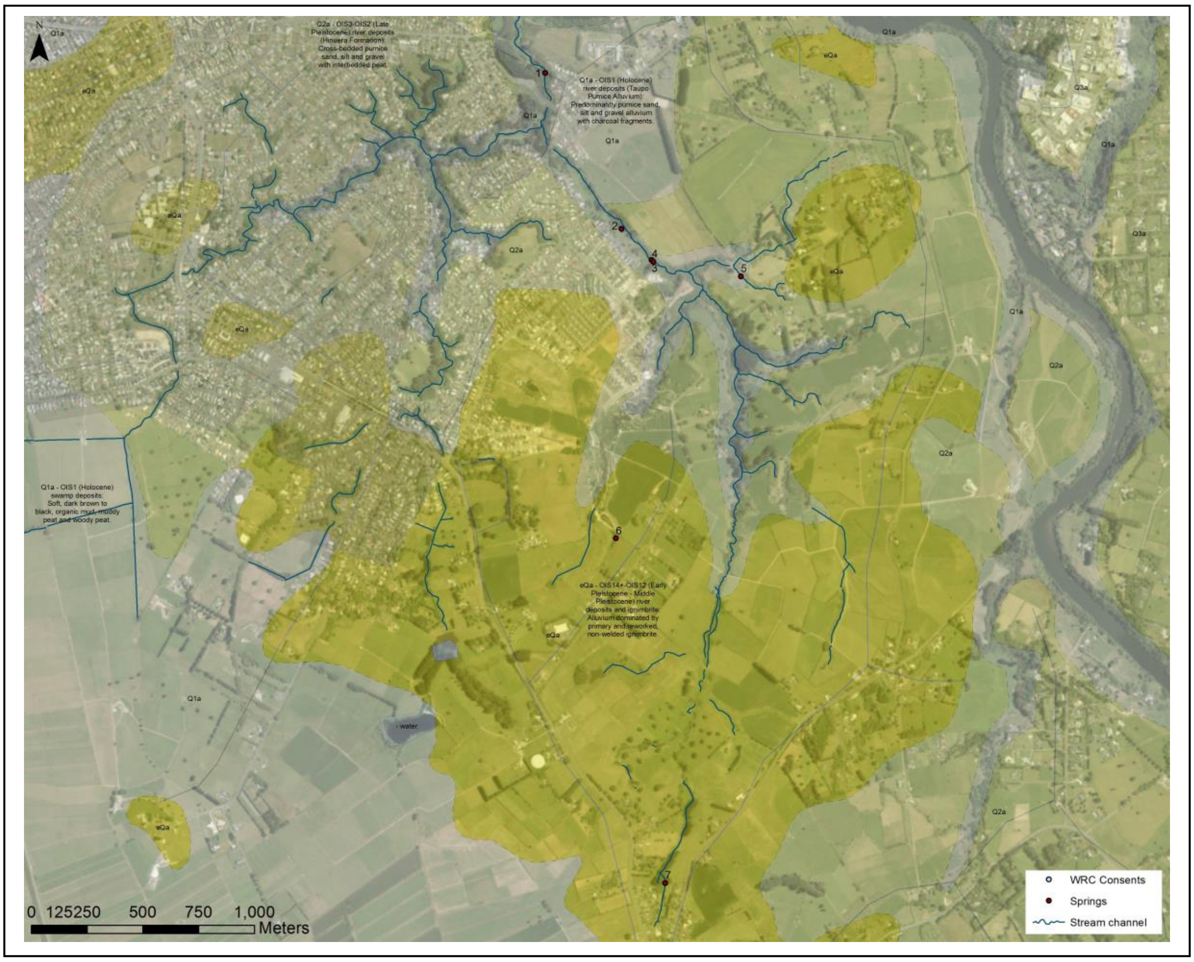

Figure 3 Catchment geology

Darker areas labelled eQa are Hamilton Ash soils likely to be of low soakage. Lighter areas of Q2a and Q1a are Hinuera formation with better soakage. Refer to Section 2.3 and 3.3.2 for further information in regard to likely soakage.

2.3 Soils

Soils information has been derived from the Landcare Research S-Map ONLINE. The S-Map database provides information on soil type, soil water holding capacity and soil drainage.

Soils over the Hinuera formation generally have a deep profile, high water holding capacity and are free draining. Hamilton Ash soils over the hills have more clay content, are shallower with reduce water holding and drainage capacity. Within the gullies soils tend to have a lower drainage capacity.

Soils within the catchment are diverse and their spatial extents indicate a potentially complex hydrogeology with respect to groundwater and spring discharge to support stream baseflow. Figure 4 shows the variability in soil drainage across the catchment. This variability in the soils across the catchment will result in variable groundwater recharge and surface runoff.

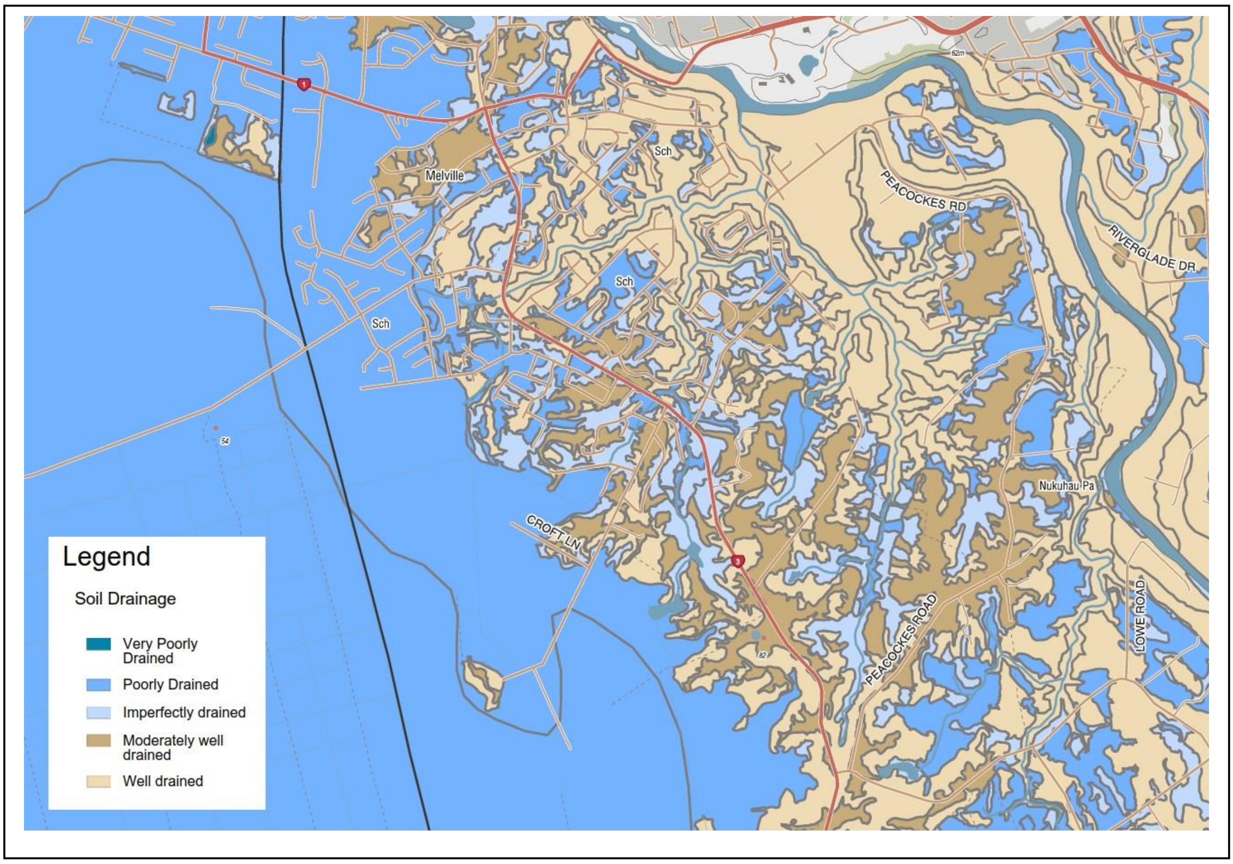

Figure 4 Catchment Soils (S-Map ONLINE)

2.4 Geomorphology

The Mangakotukutuku Stream catchment encompasses the system of tributaries south east of Hamilton City and west of the Waikato River. The stream is generally orientated north south beginning as a series of drainage channels in the eastern extent of the Rukuhia peat swamp. The stream eventually discharges into the Waikato River near Bader Street, Melville.

The catchment topography is characterised by generally flat to low rolling terrain bounded by low Hamilton Hills to the east and south that protrude above the Hinuera Formation alluvial surface. The Mangakotukutuku Stream gully is generally well defined and meanders across flat Hinuera formation topography, dissecting low hills of the Walton subgroup.

The gully geomorphology is typical of a low gradient, incised dendritic gully system with the base level at the Waikato River. Geometry varies downstream from the head of the catchment, with a generally shallow but narrow base in the upper reaches of the catchment and a well-defined and broad base near the confluence with the Waikato River at Melville.

The gully can be broadly described based on proximity to the Waikato River and the gradient of the stream.

<u>Upper Waipa (peat swamp)</u>

South of Houchens and Ohaupo Road, and Saxbys Road, the eastern and western branches of the stream head north, crossing pastoral farmland entrenched 2 m to 3 m below the surrounding land. The stream banks are typically moderately steep and sparsely vegetated where land use is pastoral farmland.

As the stream enters the city limits, the channel remains narrow and shallow with residential development less than 5m from the stream banks. Structures such as retaining measures and culverts are common where residential properties are bounded by the stream and gully.

<u>West branch</u>

From Saxbys Road, gully slopes steepen as the stream intersects the base of low Walton Subgroup hills. Slopes are generally greater than 25° and up to 8m high. Vegetation cover within the city is variable and often affected by residential development. Sections of this portion of the stream gully have been cleared of vegetation.

The central sub-catchment crosses the low Hamilton Ash hill that Ohaupo Road follows. East from Ohaupo Road the stream is entrenched some 20 m below the level of the surrounding residential land with gully slopes exceeding 35° in places. The channel is generally centralised and 3 m to 4 m wide. As the stream is deeply entrenched, the stream banks consist of dense and partially cemented Walton Subgroup materials. The portion of the catchment east of Ohaupo Road is generally well vegetated.

<u>Central branch</u>

The gully is shallow and poorly defined South of Pelorus Street near where it begins as a series of drainage channels in pastoral farmland. The upper gully is generally shallow at 3 m to 5 m deep with a 5 m to 6 m wide base and an approximately 3 m wide channel. The stream meanders around low Walton subgroup hills and is commonly channelised by engineered erosion protection and in the vicinity of culverts and pedestrian bridges. The stream banks are generally very steep to near vertical and the gully slopes sparsely vegetated.

The central branch of the gully crosses flat to undulating residential land and council reserve (Te Anau Park) from Pelorus Street to the confluence of the central and western branches of the stream near Sanford Park. From Te Anau Park to Sanford Park the gully is approximately 6 m to 8 m deep with well vegetated slopes up to 30°. A significant portion of the gully between Te Anau Park and Sanford Park is inaccessible so no direct observation of geomorphology has been recorded.

<u>Peacocke branch</u>

The Peacocke Branch is a shallow infilled channel that from the headwaters flows north through farmland. Some ponding has been created within the upper reaches. As the stream progresses downstream it has developed in a manner similar to that described above for the progressive channelization of the central branch. The upper sections are shallow in farmland and become progressively incised with distance downstream.

<u>Waikato River confluence</u>

Near the confluence of the Mangakotukutuku Stream and the Waikato River, the gully is broad and deeply incised with a generally narrow channel. The gully floor is typically up to 20 m to 25 m wide and approximately 25 m below the level of the surrounding residential land.

Walton Subgroup materials are exposed and form the lower gully slopes in the base of the gully. More recent alluvium forms the channel banks where the gully is broad. Slopes are steep, locally up to 40° and variably vegetated. The gully narrows and the slopes steepen where the low hills of the Walton Subgroup group are dissected by the stream. Shallow gullies have formed in the true left catchment slope where groundwater seeps from the contact of the Hinuera Formation and Walton Subgroup materials.

2.5 Groundwater Levels

Groundwater has been measured as part of specific investigations within the catchment. This has been in the Dixon Road area and associated with the Southern links route investigations. These are ad hoc measurements so there is no data that is really suitable for temporal or spatial application. However, the range in water level from the spot measurements indicates that water levels range between 0.6 m and 1.5m below ground level from summer to winter. This is a broad generalised interpretation and all that can be inferred is that water levels do fluctuate as expected with the seasons and all bore records seem to exhibit a similar response.

A number of other bores in the catchment appear on the Waikato Regional Council website maps but there is no indication of water levels.

2.6 Recharge and Discharge

Groundwater seepage from side slopes and the gully slopes has been reported along or close to the channels. Seepage appears to occur between soils of varying permeability and occurs from the contact between Hinuera Formation materials and the less permeable underlying Walton Subgroup materials.

Figure 5 shows mean monthly rainfall, evapotranspiration and the combined recharge and discharge for the period 2007 to 2017. Overall, from November to March there is a rainfall deficit and so any soil moisture or groundwater storage will generally be depleted during those months even though rainfall occurs. From April to October there is a surplus which either discharges or recharges groundwater.

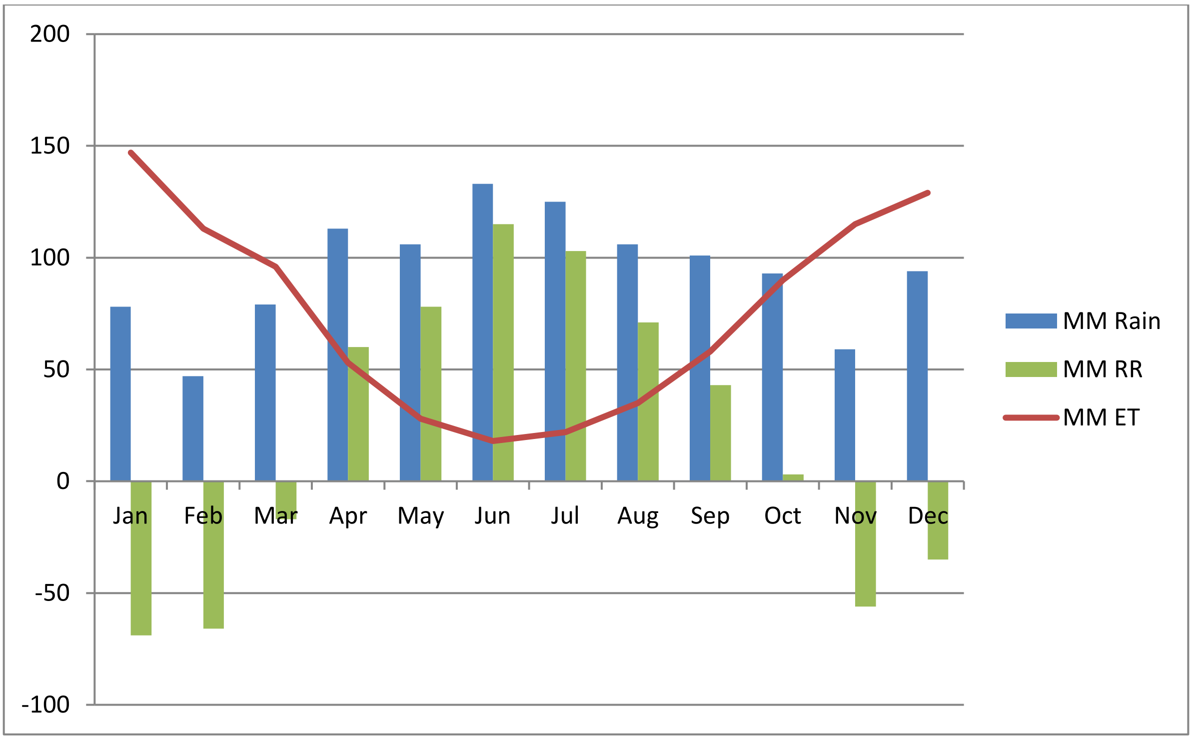

Figure 5 Mean monthly recharge and discharge (2007 – 2017)

This annual pattern is generalised for the whole catchment. The amount of surface runoff and groundwater recharge depends on the extent of routing the excess through the soil. With the variable soil drainage as shown in Figure 4 the amount of infiltration into the soil will vary. The poorer the soil drainage is the greater the surface runoff. The better drained soils will have higher infiltration and groundwater recharge.

Consequently, development of impervious surfaces on poorly drained soils is likely to have less of an impact on groundwater recharge than if the same area was developed on free draining soils. Therefore, it is not a simple matter of estimating the increase in impervious land cover with development and assuming that percentage can be directly applied to the recharge reduction. The proportions have to be weighed against the soil types.

Land development practices including cut, fill and compact along with the conveyance of runoff to specific locations will alter the natural recharge with lower infiltration rates and the concentration of runoff to point sources rather than the dispersed natural recharge pattern.

2.7 Groundwater consents

Waikato Regional Council mapping shows a number of bores across the catchment. The bores are located in urban and rural areas. The bores range in depth from less than 25 m to over 100 m deep.

There is no specific bore information that indicates whether groundwater is abstracted, or if it is, how much water is taken. Given that most of the bores are in the rural area it could be assumed that their use is domestic and stock water supply. There does not appear to be extensive use of water for irrigation in the catchment.

Consequently, the groundwater take is assumed to be relatively small and unlikely to be a significant component of the catchment water balance.

3.0 Assessment

This section describes the outcome of the desktop assessments undertaken and the implications on development.

3.1 Groundwater & baseflow

The monthly water balance shows that there is significant infiltration from April through to October. This is generally where groundwater recharge and baseflow comes from although large storm rainfalls during November to March will also contribute to groundwater recharge. Any change to the water balance components will impact stream baseflow.

In a catchment baseflow originates from springs at specific locations or general bank seepage along the length of a channel. For the most part this baseflow originates from infiltration within the catchment. The exception being sometimes spring flow comes from deeper groundwater and from areas outside of the topographic catchment boundary.

There is no indication in the Peacocke arm of the Mangakotukutuku catchment that baseflow originates from beyond the catchment boundary. This is recommended to be confirmed through more detailed groundwater measurement and modelling. The main Mangakotukutuku arm is likely to be fed partly from the Rukuhia Peat Swamp but the degree to which this is the case is unknown.

The variability of soil properties across the catchment means that infiltration rate and volume is also likely to vary. This could lead to variable bank seepage rates along the channel. Combined with some variability in the underlying geology related to the fluvial deposition process it is likely that there will be preferential underground flow paths that concentrate discharge points as springs. Establishing the sources of baseflow along the channels requires specific flow measurement and the assessment of baseflow recession characteristics which needs to be undertaken as part of stage 2 investigations.

Changing land use changes infiltration properties of the surface. Hard surfaces eliminate infiltration. Engineered soils with urban development also change infiltration characteristics. For example, if 50% of the surface area is converted to hard surface the water balance will change and infiltration will be reduced by approximately 50 % and surface runoff increased. Typically, initial rainfall loss to infiltration ranges from about 20 mm to 32 mm so an increase in impervious surface by 50 % will reduce initial infiltration by 16 mm in a storm event. Ongoing infiltration during any storm will also be reduced. Therefore, changing land use will alter baseflow rate and total volume such that in drier spells the streamflow may deplete more quickly, or it may simply not be sustained for as long so in a drought the stream will dry up more rapidly.

In the Mangakotukutuku catchment the spatial distribution of infiltration is likely to be significant for baseflow given the variable soil properties. In developing the catchment, it will be important to replicate natural runoff processes as close to source as possible. Consequently, the existing volume of water that infiltrates the soil will need to be maintained along with the existing spatial distribution of infiltration for baseflow and a natural low flow recession to be maintained.

3.2 Stream flow gauging

Two rounds of stream flow gauging were undertaken in the Mangakotukutuku catchment on 4 May 2018 and 9 May 2018. The gauging locations were agreed with HCC and Morphum prior to undertaking fieldwork. The locations where the stream flow was measured are shown in Figure 6.

A third gauging round was planned but the winter wet weather season began with a series of significant rain events after the 9th of May which prevented further useful measurement.

Location G will need adjusting if used for future gauging because access to the stream channel was found to be limited and not ideal. Measurements were undertaken but a more suitable site would be preferred.

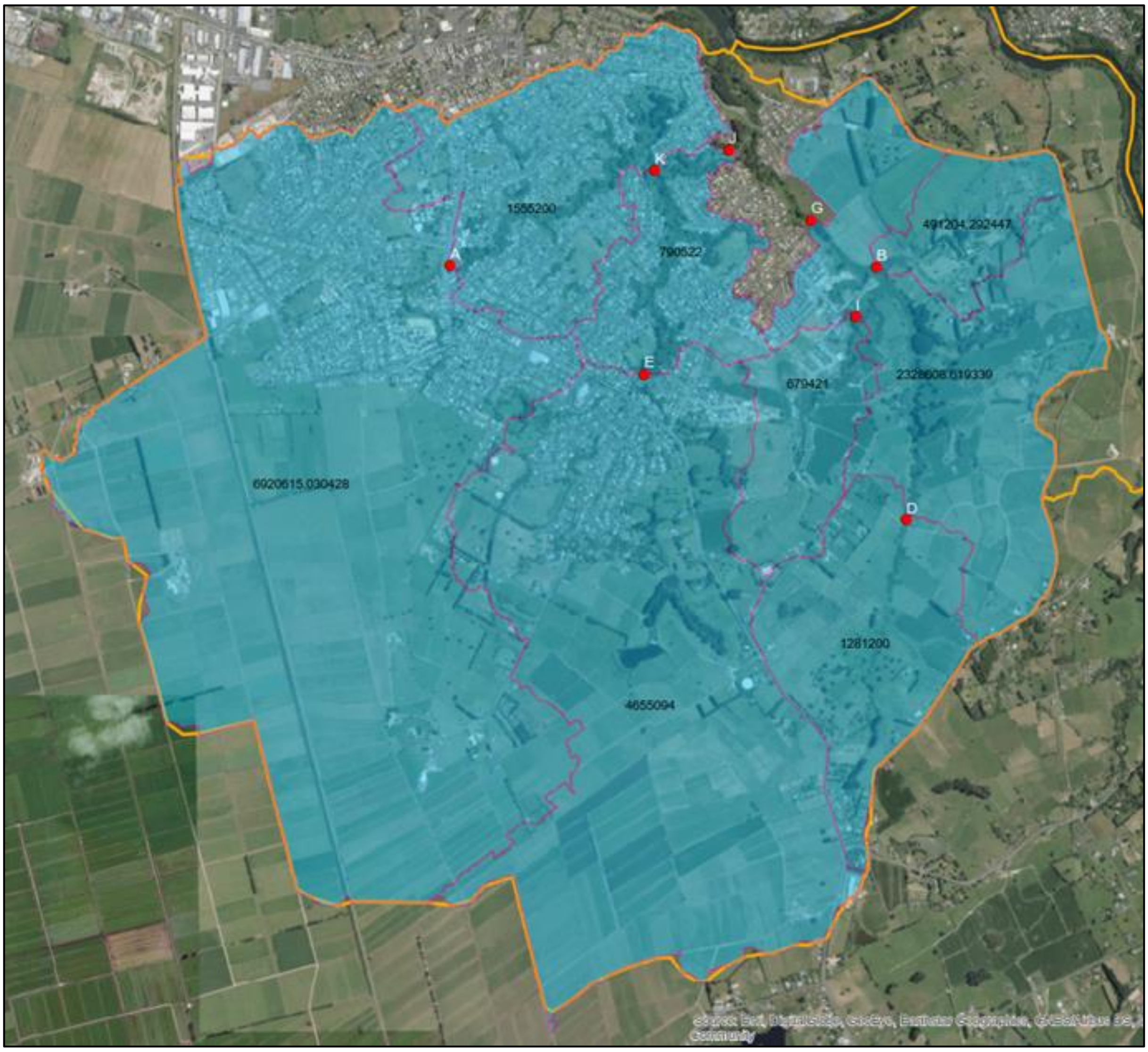

Figure 6 **Mangakotukutuku Stream Gauging Locations and sub-catchment boundaries**

The purpose of the gauging was to:

- Establish low flow characteristics within the catchment
- Assess whether spring flow was significant
- Determine at a coarse level whether base flow occurs due to concentrated generation in specific locations (i.e. springs).

The results of the two rounds of streamflow gauging are shown in Table 1.

Table 1 **Mangakotukutuku streamflow gauging results**

Location	GPS (NZTM)	Flow 4 May (L/s)	Flow 9 May (L/s)
A – Ohaupo Road	E1800897	69.1	53.88
	N5811869		
B – Plateau Drive	E1803160	1.94	2.34

Location	GPS (NZTM)	Flow 4 May (L/s)	Flow 9 May (L/s)
	N5811861		
D – Stubbs Road	E1803317 N5810521	11.15	7.68
E – Pelorus Street	E1801926 N5811294	48.23	29.97
G – Plateau Drive	E1802812 N5812110	39.6	27.53
I – Dixon Road	E1803047 N5811596	7.06	4.32
J – Sanford Park D/S	E1802375 N5812481	137.4	120.3
K – Sanford Park U/S	N1801983 E5812371	83.35	67.5

The results show that flows increase with distance downstream and there doesn't appear to be any significant flow loss zones along the channels. Flows reduced from the 4 May to 9 May in all catchments except for sub-catchment B because there was no significant rainfall between those days.

The gauged flows have been converted to specific discharges in terms of Litres per second per square kilometre (L/s/km^2) to further understand the flow characteristics in the catchment. The specific discharges are shown in Table 2.

Table 2 Sub-catchment specific discharges

Sub-catchment	4 May Flow (L/s/km^2)	9 May Flow (L/s/km^2)
Western brownfield catchments		
A	9.98	7.79
K	9.16	8.76
A+K	9.83	7.96
E	10.36	6.44
J	7.36	28.86
E+J	9.92	9.70
A+K+E+J	9.87	8.64
Eastern greenfield catchments		
B	3.95	4.77
D	8.70	6.00
I	10.40	6.36
G	8.35	5.66
G+B+I+D	8.09	5.63

The specific discharges indicate the following:

- The base flow generation across the overall catchment is reasonably similar. This suggests that spring flow inputs are not significant.

- Sub-catchment B has a lower baseflow than the other sub-catchments. This suggests there is a small amount of groundwater storage in that area.
- Sub-catchments E and I appear to have a higher depletion rate than other sub-catchments. Given they are adjacent to each other it may indicate a faster depletion of groundwater in that area.
- While the total catchment flow at J has decreased only slightly the changes in each of the upstream sub-catchments between the 4th and 9th of May vary.
    - Sub-catchment J was the most significant with an increase from 5.82 L/s on the 4th to 22.83 L/s on the 9th. The specific discharge had risen significantly.
    - Given the absolute small flows that are involved it could be a gauging error or a combination of abstraction or discharge within the catchment. It is unlikely that a spring discharge has suddenly started in Sub-catchment J.
    - Additional gauging would be required to know whether the first or second measurement was an issue.

The specific discharges are higher than one would expect for a 5-year low flow. Even though the preceding weather conditions where not ‘drought like’ the flows suggest that there is a strong base flow component in the catchments. This is consistent with the conclusion that infiltration is impeded by deeper less pervious soil layers so that flow is concentrated into seepage areas along the channel.

The gauging that has been done suggests that the seepages are relatively uniformly spread along the channels and do not concentrate flow in any one particular channel reach. Given the strength of the base flow it suggests that infiltration rates and volumes across the catchment need to be maintained so that the strong base flow can be supported through development rather than reduced or diverted.

3.3 Imperviousness & groundwater

3.3.1 Introduction

A proportion of rainfall infiltrates into the ground from undeveloped surfaces. Rainfall that does not infiltrate runs off as sheet flow or is concentrated by topography into overland flow paths that eventually form streams and rivers. Development increases hard impervious surfaces, reduces infiltration and increases runoff.

Rainfall is collected and concentrated by the stormwater management system when soakage is used as a primary method of disposal for developed areas. Increased runoff from hard area or poor performing soakage systems can contribute to surface erosion. Soakage can contribute to subsurface erosion such as piping or tomo development in susceptible soils.

Runoff is injected into the soil profile typically at a depth of 1 to 2 metres in developed stormwater devices. There is more stormwater infiltrating in a concentrated location and the natural attenuation through the broader soil matrix is bypassed as a result. If singular or cumulative effects are sufficient, either a loss of matric suction in partially saturated soils, or an increase in pore water pressure in saturated soils can occur. Both can result in land slippage or erosion of slope faces.

The natural hazards associated with stormwater soakage are not always isolated to the source property. Excess water can affect other properties through overland flow and contributing to ponding or existing flood hazards. Changes in groundwater flows because of soakage may also result in slippage, subsidence and erosion on other property.

The behaviour of the infiltrating water depends on the vertical and horizontal permeability of the soils that constitute the slope. If uniform conditions are present, then infiltration is generally downwards with some pluming until the ground water table is encountered. If a high permeability layer overlies a low permeability layer, then infiltration will be vertical until the low permeability layer is reached and horizontal infiltration will be preferable.

3.3.2 Relevance to Mangakotukutuku

Variable permeability is common near Hamilton gullies where the Hinuera formation is the dominant geology. This results in perched water tables and seepages on gully slopes. The Hinuera formation is typically sub-horizontal so flows tend to be horizontal.

The volcanic ashes (Hamilton Ashes) that typically overlay the Walton Subgroup are typically fine grained. There is a fully saturated zone in fine grained soils but the phreatic surface (upper surface of the water table) can be several metres higher due to capillary actions. This means that pore water pressures can increase in the lower part of the slope without raising the water table because the infiltration intercepts the phreatic surface (Wesley).

For example, an unlined pond in fine grained soils will have a hydraulic connection to the fully saturated soils. The connection will increase the pore water pressures in any underlying adjacent slope. Fissures, pipes and tunnels have all been identified in Hamilton Ash soils, which create preferential horizontal flow paths.

Hamilton Ash areas

Hamilton Ash tends to follow the topography unless past slippage has altered the topography. In this instance it is possible to have more sandy layers which have higher permeability that forming a blanket drain within the slope. As there is often colluvium near the toe of the slope the drain has no outlet. Tension cracks and the phreatic surface can result in elevated pore water pressures within the permeable layer and result in slope failure.

The Mangakotukutuku study area is broad and geological conditions are variable. While generalised assumptions regarding geological conditions can be made, local variations will exist. It is also likely that the topography, particularly where ash soils are present, will be highly modified by development works.

It is anticipated that areas mapped as Hamilton Ash will not have soakage rates that meet requirements of the New Zealand Building Code for primary stormwater management systems. Soakage is unlikely to be adopted for primary disposal but may be beneficial to maintain the base flow of gully streams. Where the stream baseflow or seepage habitats rely on infiltration it will be important that development allows for soakage.

Another challenge in the built environment may be the proliferation of retaining walls which will have drainage that may intercept horizontal flows. This should be considered in conjunction with bulk earthworks design.

Hinuera Formation areas

For Hinuera Formation sites it is likely that anyone undertaking a simple soakage test will conclude that there is adequate soakage and not consider the cumulative effects of discharge to ground, or the erosion and instability potential. We consider the 5m setback from the crest of gullies to be insufficient for soakage systems (refer to analysis Section 3.4 for more details).

3.4 Geotechnical analysis scenarios

3.4.1 Introduction

A representative analysis has been undertaken in lieu of site-specific investigations and analysis. The representative analysis is intended to show how typical gully slopes in the catchment may react to rainfall and infiltration. The analysis seeks to estimate development setbacks and the implications of groundwater recharge in the vicinity of slopes.

3.4.2 Methodology

A combined seepage and slope stability analysis was undertaken using the software Slide version 7, produced by Rocscience. The purpose was to assess changes in slope stability and identify potential erosion from increased impervious surfaces and soakage systems in close proximity to the gully slopes.

The analysis is noted to be hypothetical for the purpose of comparison and approximation of the conditions in the catchment. Three dimensional effects such as concentration of flow to preferential discharge points due to dipping flow barriers is not addressed in the modelling. Ongoing rainfall will result in additional infiltration which is not accounted for in the high-level assessment undertaken in this report.

Typical slope shapes were modelled with simplified geological conditions that represented two cases; barriers to flow or preferential flow. In reality the slope heights and gradients in the catchment are variable. The geological situation is also more complex with perched water tables and multiple barriers to flow likely in reality.

Groundwater seepage was modelled using a finite element method. Initial steady state groundwater was set using a combination of water tables and boundary conditions. Rain infiltration was set using dynamic infiltration boundary conditions on the ground surface and at the base of the soakage trenches. The dynamic groundwater response was assessed at Day 0, Day 1, Day 2, Day 7, Day10 and Day 14. Soil permeability was taken as typical for the soil types e.g. sand, silt or clay based on published values and our experience.

Rain infiltration is based on typical initial losses yielded from rainfall and runoff analysis in Hamilton soils. Soils with SCS Curve Numbers ranging from 61 to 71 yield initial losses in the range of about 20 mm to 32 mm respectively. An initial infiltration loss of 32 mm/day was adopted for this assessment.

The infiltration was applied to the ground model as simple hydrograph occurring in Day 0. The hydrograph starts and finishes at 0 mm/day with a peak of 64 mm/day in the middle of the day (i.e. total infiltration is 32 mm/day). In the post development case (above the slopes only) the infiltration rate was reduced to 10 mm/day to approximate 65 % reduction in impermeable surfaces.

Infiltration through soakage systems was modelled so that the rate peaked at the soil infiltration rate and accounted for a lag. A head of water was represented in the model in order to reach full permeability and soakage. The soakage system was modelled as simple soakage trenches 1 m wide and 1 m below the surficial silt layer.

Slope stability was assessed at each stage of the dynamic groundwater assessment using the GLE Morgenstern-Price method. Soil parameters used for the stability assessment were based on our experience with the local geology and ensure that the steeper slopes were stable in the initial steady state condition. While actual parameters will vary, the intent was to assess changes in stability, rather than actual stability.

Development loads such as fills, and buildings are not included in our modelling and will need to be considered specifically as part of development proposals.

The assessed scenarios are presented in Table 3.

Table 3 Modelled scenarios

Scenario	Depth	Soil type	Permeability (m/s)
Uniform permeability	0 m to 0.6 m	Silt	1×10^{-6}
	0.6 m to base	Sand	1×10^{-4}
High permeability over low	0 m to 0.6 m	Silt	1×10^{-6}
	0.6 m to 9.6 m	Sand	1×10^{-4}
	9.6 m to base	Clay	1×10^{-8}
Low permeability over high	0 m to 0.6 m	Silt	1×10^{-6}
	0.6 m to 9.6 m	Clay	1×10^{-8}
	9.6 m to base	Sand	1×10^{-4}
Ash mantle	0 m to 3.5 m	Ash clay	1×10^{-9}
	3.5 m to 8 m	Pumice sand	1×10^{-5}
	8 m to base	Clay	1×10^{-8}

Scenario	Depth	Soil type	Permeability (m/s)
	N/A	Ash sand lens	1×10^{-4}

3.4.3 Assessment results and discussion

The results of the combined seepage and stability analysis generally agree with the outcomes we anticipated given the local geological conditions. Selected outputs are presented in Figure 7 to Figure 13. The key observations from the assessment are as follows:

- In uniform soils there is slight increase in slope seepage and decrease in stability, however the stability of the slope remained such that failure should not occur, i.e. the minimum factor of safety was greater than 1.0.
- With high permeability over low permeability soils the rain infiltration was sufficient to result in instability with and without soakage trenches. Both resulted in high volumes of seepage at the soil type interface and the modelled the results were quite similar.
- With low permeability over high permeability soils the slope was marginally stable near the toe of the slope during Day 1 and Day 2 with soakage trenches present. In contrast without the soakage trenches the slope had higher factors of safety. Overall, these scenarios did not fail, but the factor of safety reduced so consideration is still recommended in design.
- With an ash mantle there was no noticeable effect on stability except where there was a sandy layer creating a flow path within the ash soil. In both the cases with and without soakage trenches the presence of a sand layer or lens was shown to be very adverse to stability.

The high over low permeability result was probably the most surprising. A significant decrease in stability had been expected in upper part of the slope with trenches in place but only a minor decrease was observed (still enough to result in some instability). It was thought that a soakage device would concentrate the discharge and bypass the natural attenuation of dispersed soakage. This may be a limitation of the high-level analysis for the following reasons:

- The high-level scenario may have insufficient infiltration points to represent the reduction in direct surface infiltration. More points may be of benefit in reality to achieve maximum soakage and recharge potential.
- The result of the high-level scenario may be worse if a large infiltration basin (pond) is tested as opposed to trenches (i.e. larger soakage footprint).

Notwithstanding the potential limitations, the assessment has shown that there is potential for instability if soakage is adopted in close proximity to the gully slopes, in permeable soils. It is possible that larger soakage devices will make the situation worse.

The model has considered what happens in a rainfall event large enough to utilise the initial soakage loss. The assessment has not considered more frequent small events, or extreme rainfall events. Soakage was set back 5 m to 15 m from the crest of the slope in the scenarios and the effects were apparent in all of the analysis outputs.

Overall, the results highlight the importance of understanding the geological model and how development and discharge concentration can result in increased seepage from slopes which could result in instability as a result of increased poor water pressures.

The typical five metre development setback used on HCC development projects is unlikely to be sufficient for long term stability in many instances. It is not possible to define a setback based on the high-level study we have undertaken because variable setbacks will be needed. Setbacks for soakage devices and buildings should be established based on seepage/stability modelling of the pre and post development slopes and post development loadings.

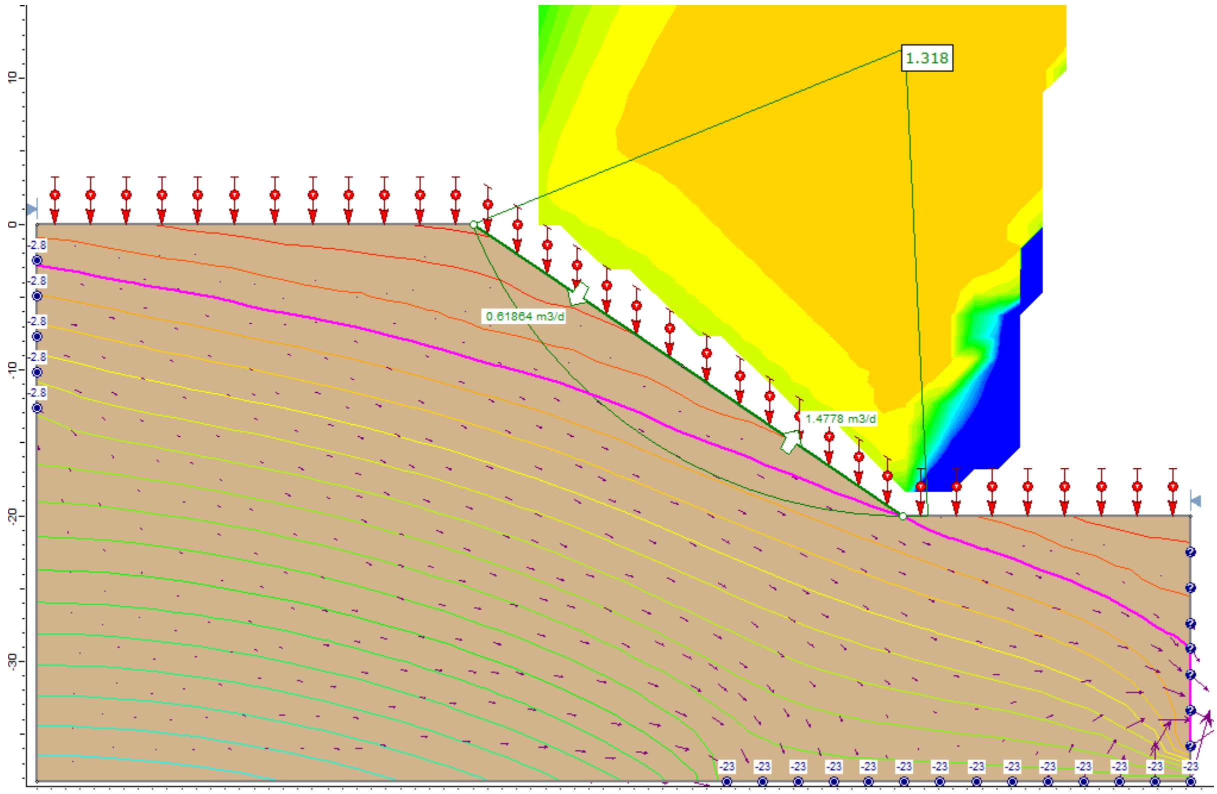

Figure 7 Uniform permeability with no soakage on Day 2

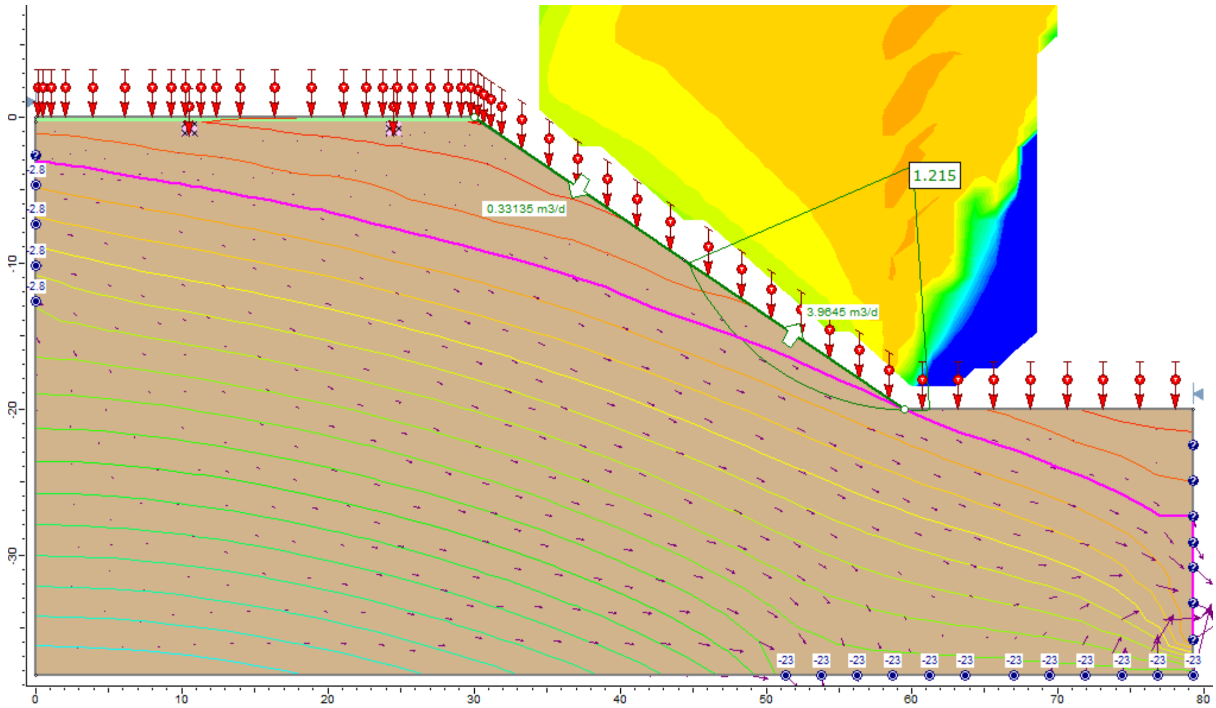

Figure 8 Uniform permeability with soakage on Day 2

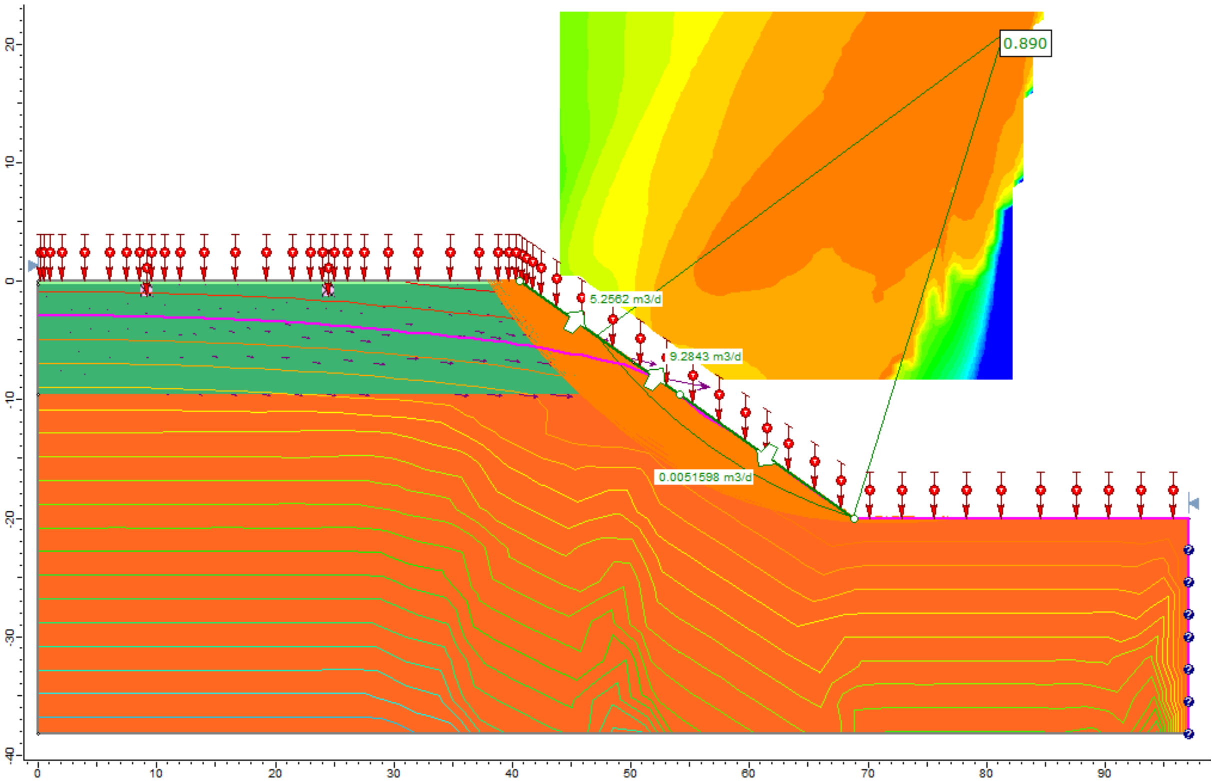

Figure 9 High over low permeability with soakage on Day 2

Note that the high over low permeability case without soakage is similar to the with soakage case that is shown in Figure 9 above.

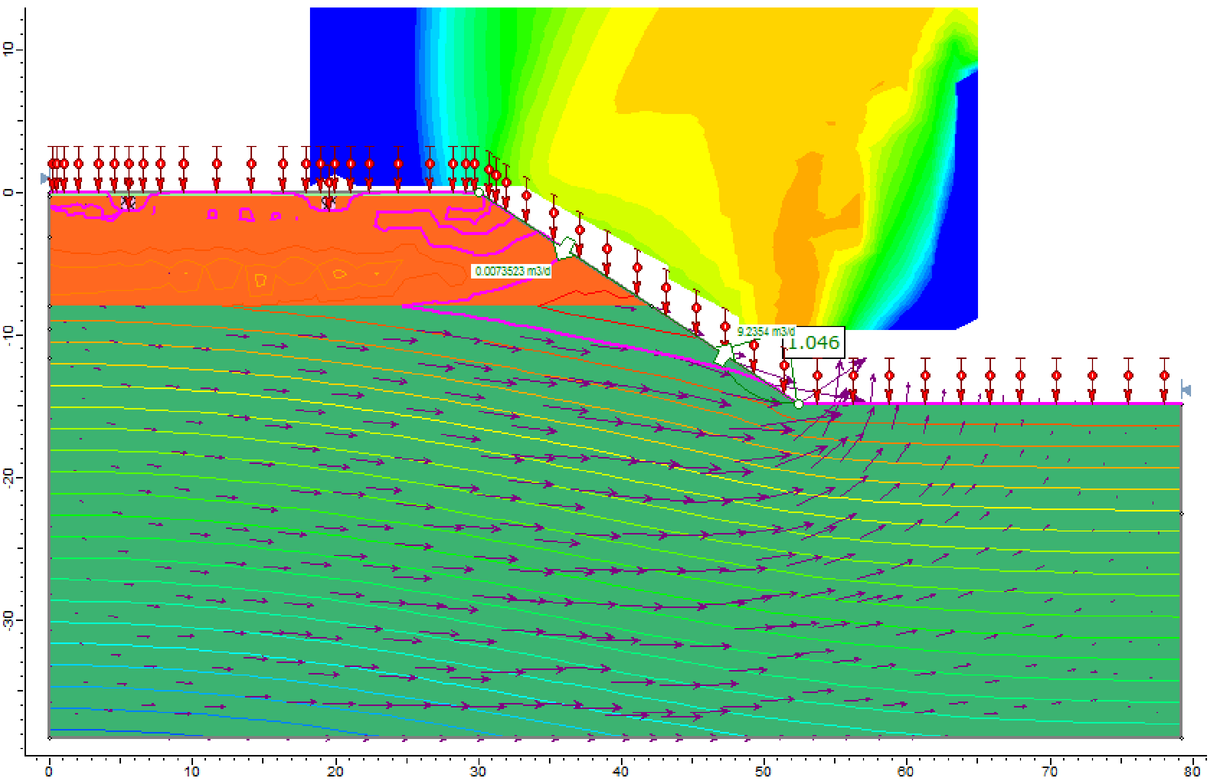

Figure 10 Low over high permeability with soakage on Day 1

Figure 10 yields a minimum factor of safety near the toe of the slope of 1.04 which is close to failure.

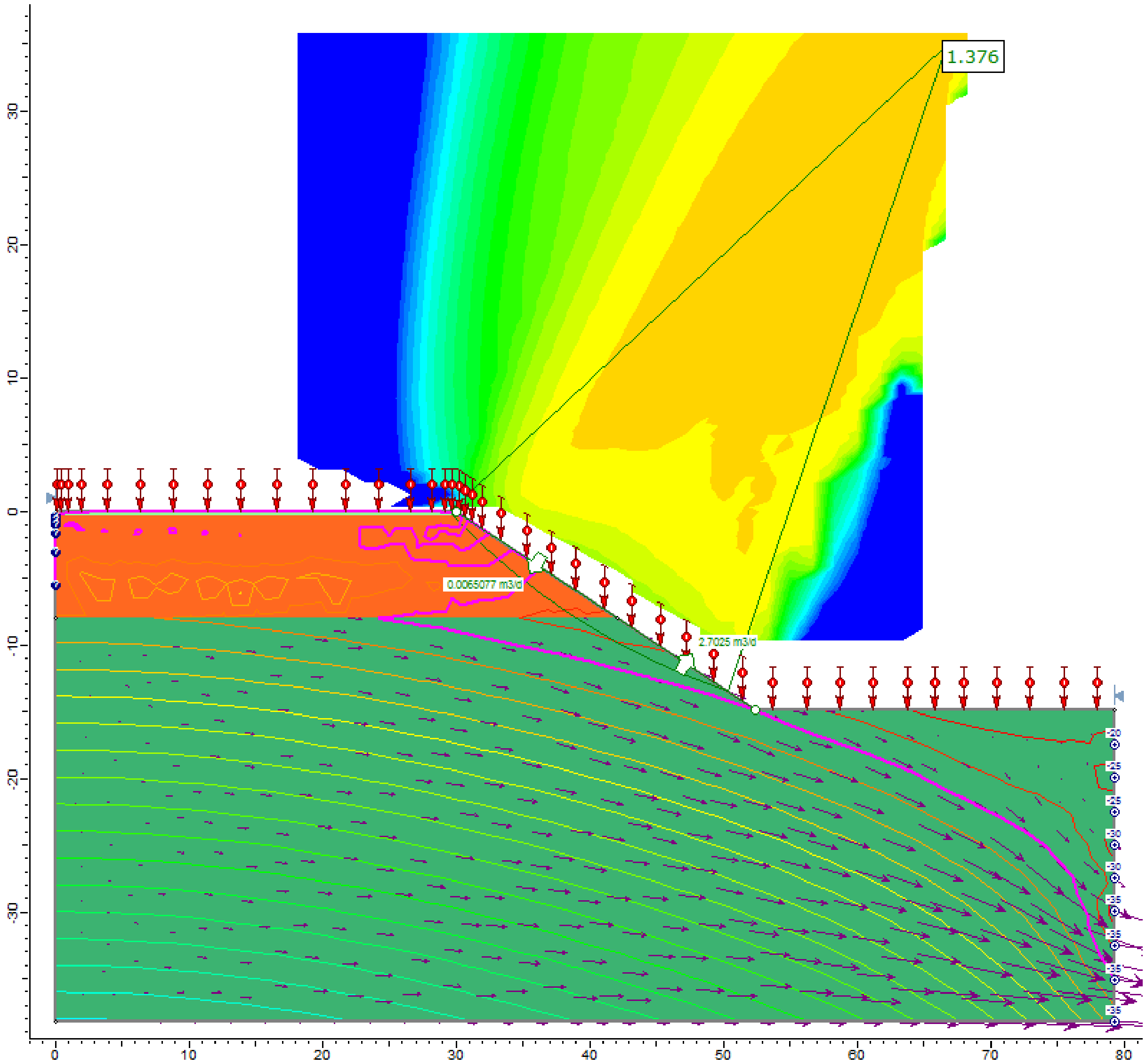

Figure 11 Low over high permeability without soakage on Day 1

Figure 11 yields a minimum factor of safety 1.37 and a shallow failure condition across the entire slope height.

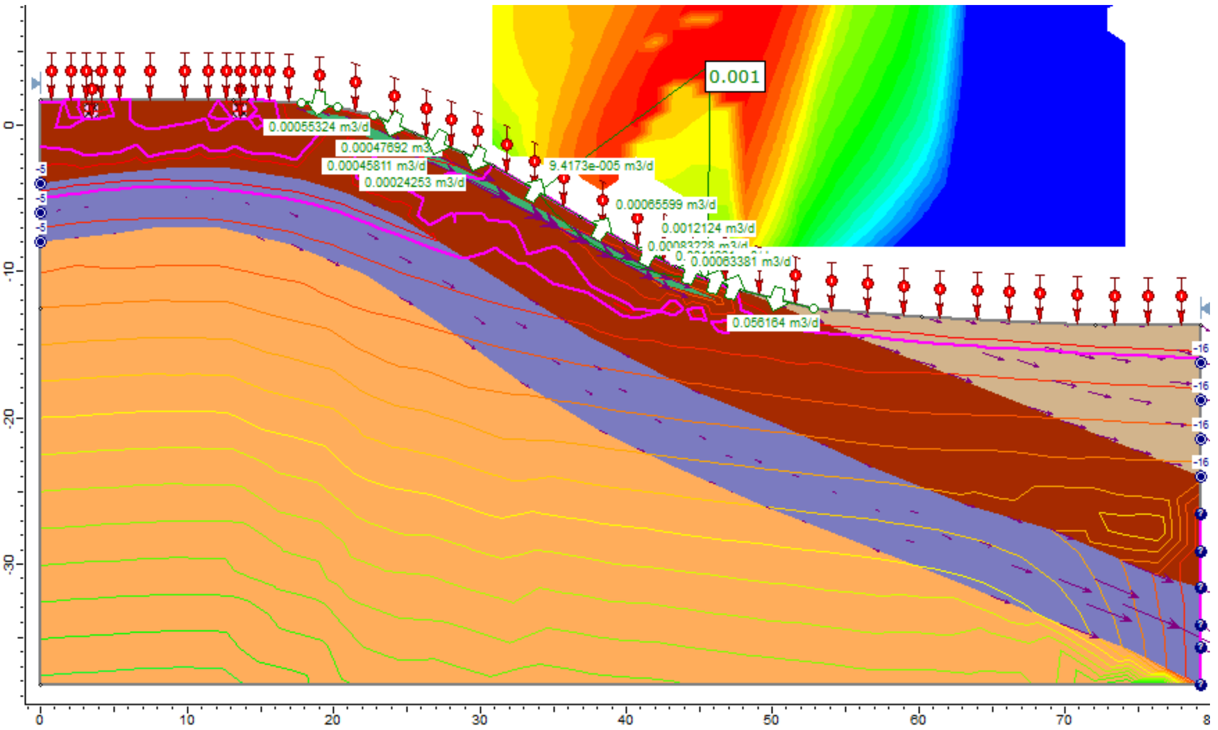

Figure 12 Ash mantle with flow path and soakage trench on Day 1

Figure 12 shows that there may be very low factors of safety with soakage trenches and a sandy flow path present.

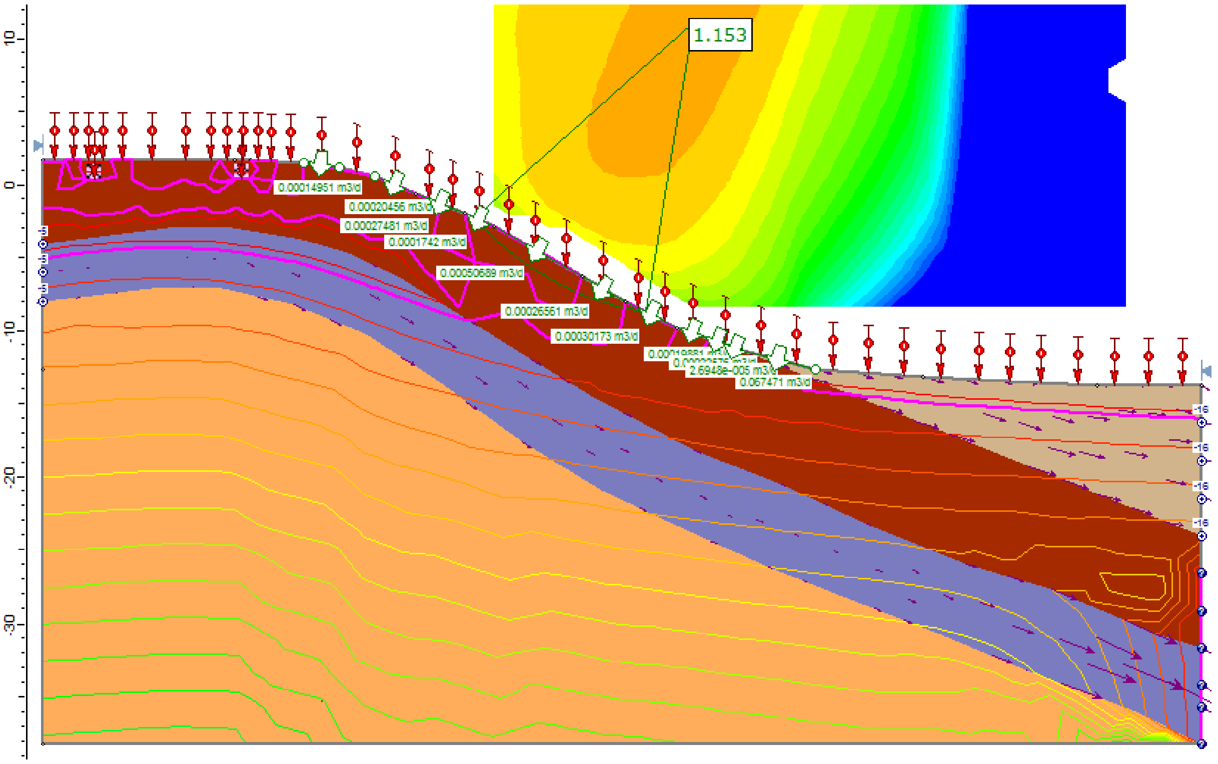

Figure 13 Ash mantle with soakage and no flow path on Day 1

Figure 13 shows increased factors of safety (compared to Figure 12) when soakage is utilised without a flow path present.

3.5 Piped discharges, culverts and overland flow to gullies

Piped discharges, culverts and overland flow to gullies all have the potential to cause, worsen or accelerate erosion or slope instability if poorly designed, constructed or maintained. Individual requirements will vary depending on the nature of the structure, the underlying soil and the frequency of use. Permanent culverts and outlets will have more significant protection than periodic overland flow paths.

Key considerations are as follows:

- Locate structures on less steep slopes wherever possible – for example terminate pipeline at stream level or flume flows to the bottom of the gully.
- Determine site specific erodibility of the soils during design. Lab tests can be used to assess erodibility and engineered solutions selected based on individual location risk.
- Sloping trenches in erodible soil should adopt best practice bedding and seepage block design together with monitoring during construction.
- Overland flow paths may need to have protection. Unlined overland flow paths should be avoided over slopes where erodible soils are present. Various options exist (green or hard engineered) depending on the scale and frequency of the overland flow path.
- Gully slope infrastructure should be located on council reserve, and sufficient provision should be made to allow access with the plant that will be required for repair or maintenance. Development plans should show sufficient detail to demonstrate maintenance access and safe setback from properties and structures. Easements should be avoided in these situations.
- Structures and culverts in the gully base will need to consider foundation conditions and erosion scour potential around or below the structure. In highly erodible soils that could be encountered in some areas of the gullies, extended depth foundations and impervious erosion protection may be required as opposed to simple rock and geotextile solutions. Care will need to be taken when arranging structures that will affect the flow of water and potentially exacerbate erosion.
- In stream structures should be avoided within the normal channel up to the bank full level (if there is a defined channel). This could be achieved by bridging, arch culverts with no invert, or embedded culverts with a generous width and carefully designed approaches.
- Hard invert structures could be utilised in the lower stream where degradation of the Waikato River may cause the stream to degrade. These types of structures act as a bed controls but could need periodic works to maintain downstream gradients and fish passage (due to the formation of perched outlets).

A single solution cannot be predefined for different structure types due to variability within the soils and gully depth therein, throughout the Mangakotukutuku system.

3.6 Maintaining water balance with development

Urbanisation will increase rapid surface runoff and reduce stream baseflow rate and volume based on the apparent hydrogeology, unless development ensures that the natural process is mimicked through design. To facilitate development while maintaining the water balance to ensure baseflow is going to require consideration of a number of issues as follows:

- What is the existing infiltration rate and volume and how that varies across the catchment?
- What is the best way to collect and engineer infiltration of surface runoff that would otherwise have directly infiltrated the natural soil?
- Will storage of initial runoff in on site tanks for reuse significantly alter groundwater recharge volume and how can this be mitigated?
- What methods are available to spread infiltration or discharge directly to groundwater to mimic the undeveloped environment and ensure that changes to infiltration pathways do not elevate geotechnical risk?

4.0 Summary and recommendations

4.1 Summary

The Mangakotukutuku gully system, in particular the undeveloped Peacocke Arm, appears to rely on groundwater infiltration to support baseflows. The Mangakotukutuku arm is also fed from the peat swamp in Waipa District so is less reliant on local groundwater infiltration. Wider groundwater flow contours cannot yet be defined but there is sufficient information to conclude that local infiltration is important.

The geology in the catchment allows rainfall to infiltrate and migrate to gully slopes and streams as seeps and springs which contribute to stream baseflows. The same regime could result in instability particularly if development mitigation involves concentrated infiltration.

The baseflows are higher than one would expect and the seepages appear to be relatively uniformly spread along the channels and not concentrated. Given the strength of the base flow it suggests that infiltration rates and volumes across the catchment need to be maintained so that the strong base flow can be supported through development rather than reduced or diverted.

The catchment will benefit from dispersed infiltration to mitigate the potential effects of development, if the existing stream environment is to be maintained as far as practical. Care will need to be taken to ensure that the method of groundwater replenishment does not increase risk to the built environment through targeted assessment and recommendation of appropriate setbacks.

Geotechnical and hydrogeological recommendations for Stage 2 are discussed in the following sections. An overarching Stage 2 recommendation is to develop an integrated GIS map with multiple detail layers informed by further investigations. The GIS map will allow sites to be ranked and constraints to be highlighted as well as linking into other ICMP mapping later in the project.

4.2 Geotechnical recommendations

As part of the resource consent for development it is recommended the effects of the development on groundwater flows, stability and erosion as a result of landform changes, impervious surfaces and soakage infiltration systems is assessed. This will require groundwater modelling in the pre-development and post-development state.

Therefore, it is important to have an understanding of the baseline groundwater conditions, deep permeability characteristics and rainfall response over an extended period of time that can form the basis of specific assessments.

We recommend that vibrating wire piezometers are established throughout the catchment in both perched water tables and deeper water tables. Two of these should be coupled with rain gauges. The purpose of this will be to determine the rainfall responses of both the perched water tables and the deeper water tables.

The hydraulic conductivity of the aquifer will need to be established by undertaking pump out tests, packer tests or laboratory tests on core recovered from piezometer installation.

We also recommend that seepage/stability modelling guidance is developed so that a consistent approach is adopted in support of resource consents. This would address typical hydraulic properties, infiltration curves for various storms and surface soil conditions and cases to be considered.

4.3 Groundwater and stream flow recommendations

Integrated catchment management pre and post development monitoring is recommended to fully implement objectives associated with best practice. Groundwater needs to be monitored so that groundwater flow can be determined, response to rainfall assessed, and potential development effects identified.

The geotechnical investigation (Section 4.1) has recommended piezometers and rain gauges. The spatial spread of monitoring points needs to cover all of the undeveloped catchment. Additional bores may be of benefit along with the recommended piezometers. In the first instance a review is recommended of whether any of the bores in the WRC database are unused and would make suitable monitoring locations.

Stream flow monitoring is recommended to further assess baseflow, and to support ecological and water quality monitoring. At least one permeant continuous flow recording station should be established in the lower catchment. Spatial variation in base flow can be assessed by occasional summertime flow gauging at upstream sites (existing sites that have been suggested for Stage 2 flow gauging or alternatives that may be identified during the initial gauging runs).

Additional continuous recorder stations may be of benefit in the upper catchment for ecological and water quality monitoring. If any are implemented, it would be appropriate to locate them where proposed Stage 2 gauging is undertaken.

4.4 Provisional development controls and BMPs

Additional investigation and assessment is recommended to set exacting requirements for development and infiltration setbacks. To do so the geotechnical risk should be determined in more detail for scenarios with increased infiltration around slopes and retaining walls. A higher level of assessment will enable the catchment to be mapped in high resolution and variable requirements set, as opposed to a single catchment wide requirement.

To achieve the desired outcome, it is considered that the following Best Management Practices (BMPs) are appropriate:

- Provide appropriate setbacks from slopes and walls for development to reduce risk of instability.
- Provide appropriate setbacks from slopes and walls for enhanced infiltration zones to reduce the risk of instability.
- Utilise swales and subsoil drainage to enhance infiltration at lot and minor road level (dispersed and distant from at risk gully slopes).
- Provide at source infiltration via District Plan mandated on-lot water efficiency measures.
- Apply similar approach to major roads where possible.
- Locate wetlands where outlet drainage can be connected directly to groundwater using vertical drainage when centralised collection and treatment is adopted.

5.0 Summary of issues and options

Issue Reference	Issue Description	Proposed Further Investigation	Options	Section Reference
Hydrogeology 1	Evapotranspiration is greater than rainfall for the five months from November through to March.	• Nil / not applicable	• Maximise groundwater recharge during winter to delay dry weather effects on gully baseflows. • Utilise stormwater devices that will maximise soakage and minimise volume discharge and flow variability during dry weather.	2.1
Hydrogeology 2	Groundwater measured as part of other projects within the catchment has been ad hoc so there is no data that is really suitable for temporal or spatial application.	• Determine the spatial spread of monitoring points needed to cover all of the undeveloped catchment. • Additional bores may be of benefit along with the recommended piezometers (refer Geotech 1) and existing WRC bores.	• Do nothing – groundwater may be influenced outside of the catchment and unnecessary control imposed via the ICMP. • Determine using existing WRC bores and proposed piezometers – possible data gaps. Utilise any existing available bores first. • Determine using existing WRC bores, proposed piezometers and additional bores for full coverage.	2.5
Hydrogeology 3	Land development practices including cut, fill and compaction along with the conveyance of runoff to specific locations will alter the natural recharge with lower infiltration rates and the concentration of runoff to point sources rather than the dispersed natural recharge pattern.	• At least one permanent continuous flow recording station should be established in the lower catchment. • Occasional summertime stream flow monitoring is recommended to assess baseflow, and to support ecological and water quality monitoring. • Additional continuous recorder stations may be of benefit in the upper catchment for ecological and water quality monitoring.	• Utilise swales and subsoil drainage to enhance infiltration at lot and minor road level (dispersed and distant from at risk gully slopes). • Apply similar approach to major roads where possible. • Provide at source infiltration via District Plan mandated on-lot water efficiency measures. • Locate wetlands where outlet drainage can be connected directly to groundwater using vertical drainage when centralised collection and treatment is adopted.	2.6 / 4.3
Geotech 1	Variable permeability is common in Hamilton gullies. It is important to have an understanding of the baseline groundwater conditions, deep permeability characteristics and rainfall response over an extended period of time that can form the basis of specific assessments.	• Establish vibrating wire piezometers throughout the catchment in both perched water tables and deeper water tables. • Couple the piezometers with rain gauges to determine the rainfall responses of both the perched water tables and the deeper water tables. • Establish the hydraulic conductivity of the aquifer by undertaking pump out tests, packer tests or laboratory tests.	• Do not provide specific recommendations to developers • Provide a catchment wide recommendation / preferred solution, subject to site specific assessment • Provide a suite of acceptable solutions as far as practical, in part to prevent solutions being adopted that are not preferred by HCC, also subject to site specific assessment and suitability.	3.2
Geotech 2	Increases in slope seepage due to concentrated infiltration near to slopes typically result in a decrease in stability, sometimes to the point of failure (dependant on soil consistency and layering)	• Determine the effects of the development on groundwater flows, stability and erosion as a result of landform changes, impervious surfaces and soakage infiltration systems as part of the resource consent for development. • This will require groundwater modelling in the pre-development and post-development state.	• Provide appropriate setbacks from slopes and walls for development to reduce risk of instability. • Provide appropriate setbacks from slopes and walls for enhanced infiltration zones to reduce the risk of instability. • Deep vertical soakage to avoid shallow gully slope adverse effects.	3.4 / 4.2
Geotech 4	Point discharges may cause erosion of gully slopes.	• Nil – site specific investigation and design is recommended	• Do nothing – undertake maintenance as required • Provide outlet protection measures from the discharge to the stream (low impact or engineered) • Flume discharges to the gully base / direct to stream • Construct pipelines to the base of the gully	3.5
Geotech 5	Overland flows may cause erosion of gully slopes.	• Nil – site specific investigation and design is recommended	• Do nothing – undertake maintenance as required • Provide overland flow path erosion protection measures from the discharge to the stream (low impact or engineered depending on frequency and scale)	3.5
Geotech 6	Culverts and other in stream structures may cause erosion of streams. Careful design is required.	• Nil – site specific investigation and design is recommended	• Avoid in stream structures (e.g. bridge the normal flow channel, no piers) • Utilise no invert culvert structures (e.g. arch culvert) • Utilise hard invert culverts for bed control (e.g. if needed to control degradation) while maintain fish passage • Generously embed culverts and other structures (wing walls, retaining walls)	3.5
Geotech 7	Many of the catchment hydrogeology and geotechnical issues require site specific investigation and design. Catchment wide solutions will not be practical or viable.	• Develop modelling and assessment guidance so that a consistent approach is adopted in support of resource consents. To address typical hydraulic properties, infiltration curves for various storms, depths and surface soil conditions, soil rehabilitation potential and cases to be considered.	• Rely wholly on developer led investigation and design. • Carry out catchment wide pre-development groundwater modelling to form the baseline for developed catchment modelling and assessment. • Develop standard guidance as per the recommended further investigations	3.6 / 4.0

6.0 References

a. 13 Morrison Crescent – Preliminary Geotechnical and Stormwater Assessment. AECOM (2016)

b. 21 Saxbys Road – Subdivision Suitability Assessment. AECOM (2016)

c. 39B Anthony Crescent Slip – Preliminary Geotechnical Assessment Report. AECOM (2017)

d. 71 Dixon Road, Hamilton – Subdivision Suitability Assessment. AECOM (2017)

e. 77 Dixon Road, Hamilton – Subdivision Suitability Assessment. AECOM (2017)

f. Dixon Road Development – NZS 4404:2010 Schedule 2A Completion Report. AECOM (2017)

g. Dixon Road Subdivision – House Pad Construction Observation. AECOM (2017)

h. Hamilton South Pipeline – Geotechnical Site Investigation. AECOM (2016)

i. Hawley, J. The Inclined Drainpipe Effect on the Stability of Natural Slopes, NZ Geomechanics News No. 23 1981.

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m. The Wandering River – Landforms and geological history of the Hamilton Basin. John McCraw (2011)

n. Wesley, L.D. Unconfined seepage behaviour in coarse- and fine-grained soils.

o. Watercourse Assessment Report – Mangakotukutuku Catchment. Morphum, (2017)

7.0 Limitations

The recommendations and opinions contained in this report are based upon data obtained from several historic site investigations (machine auger drill holes, cone penetration tests) and observations made during associated walkover inspections. Inferences about the nature and continuity of subsoil conditions away from drill holes have been made using geological principles and engineering judgement.

Further development of the options and solutions discussed in this shall be subject to further investigation assessment and design.

This report has been prepared for the particular project described in the owner’s brief to us and no responsibility is accepted for the use of any part of this report in other contexts or for any other purposes.

Appendix A

Catchment geology

Appendix A Catchment geology