REPORT

IAF - Waitawhiriwhiri/Central City ICMP

Geotechnical and Hydrogeological Interpretative Report

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Table of contents

Executive summary

This Geotechnical and Hydrogeological Interpretative Report forms part of the Integrated Catchment Management Plan (ICMP) for the Waitawhiriwhiri and City Centre catchments in Hamilton City. The report serves to advance understanding of the ground conditions present in the catchment, identify geotechnical and hydrogeological challenges, and propose measures to mitigate potential adverse effects.

Critical geological characteristics of the Waitawhiriwhiri and City Centre catchments were assessed using various resources, including geological maps, LiDAR survey data, and the active fault database. These areas reveal diverse geomorphological conditions including a broad plain, low hills, and various stream and river systems, underlain by multiple geological units, notably the Walton Subgroup, the Hinuera Formation, peat, and Holocene sediments. The report addresses potential seismic hazards, chiefly the risk of liquefaction and lateral spreading during an earthquake. Of geotechnical and environmental concern is the presence of peat deposits which can cause issues with settlement when loaded or when drained. Drainage and subsequent oxidation of the peat may also result in the loss of an important carbon sink and the potential for acidification of groundwater and soil.

Hydrogeological observations point to multiple consents within the catchment that could influence groundwater levels and quality. Including effluent discharge from agricultural activities, groundwater takes, and stormwater discharge. Hydrogeologic properties of sediments across the focus area range significantly due to a diversity of depositional environments and subsequent variability in geology.

Acid sulfate soils are also discussed as potential geotechnical concerns. Acid sulfate soils, which are present in specific areas, could potentially acidify groundwater when oxidised.

Finally, the report proposes several potential mitigation strategies for the identified geotechnical challenges, including hydrogeological modelling, engineering design modifications, specific development controls, and updates to the Regional Infrastructure Technical Specifications. These interventions are suggested to help inform planning decisions, optimise stormwater management practices and engineering solutions, mitigate geotechnical risks, and protect Hamilton City's hydrogeological environment as the city develops further.

1 Introduction and background

Hamilton City Council (HCC) is preparing the Integrated Catchment Management Plan (hereafter the ICMP) for the Waitawhiriwhiri and City Centre catchments in Hamilton City. This report presents the Waitawhiriwhiri/City Centre ICMP Geotechnical and Hydrogeological Technical Report (hereafter the Geotechnical and Hydrogeological Report) to support the ICMP development.

1.1 Purpose

The purpose of this report is to develop a high level understanding of ground conditions in the catchment, identify geotechnical and hydrogeological issues contributing to effects on catchment values, and identify options and actions to address adverse effects. The report is to inform ongoing stormwater practices for managing geotechnical and hydrogeological effects and identify opportunities for enhancement.

1.2 Scope

The scope of the Geotechnical and Hydrogeological Report is in general accordance with HCC's ICMP Geotechnical and Hydrogeological module with the scope refined and agreed through a series of workshops with Waikato Regional Council (WRC) and internal HCC stakeholders.

This report has been prepared in accordance with T+T's offer of service and HCC's Instruction for Service (PSP00002771-2024) dated 25 September 2024.

1.3 Data sources

The Stormwater Master Plan (SMP) viewer (V3) provides a central source of current information relevant to stormwater knowledge and management. In line with the ICMP Geotechnical and Hydrogeological module, gaps in information were identified in 2023 and additional datasets were produced to inform this report. These new datasets will be made available on the SMP V3.

In addition to the datasets curated by HCC, this report draws on information from the following sources:

- Geological maps
- Soil maps
- LiDAR survey
- The Waikato Regional Council hazard portal
- GNS active fault database
- Natural Hazard Commission natural hazards portal
- Research papers
- Industry guidance documents

2 Catchment description

2.1 ICMP boundary

The ICMP covers two catchments with a combined area of ~2,400 ha, including the 300 ha City Centre catchment and the 2,100 ha Waitawhiriwhiri catchment, refer Figure 2.1. Key features of these catchments are described in further detail below.

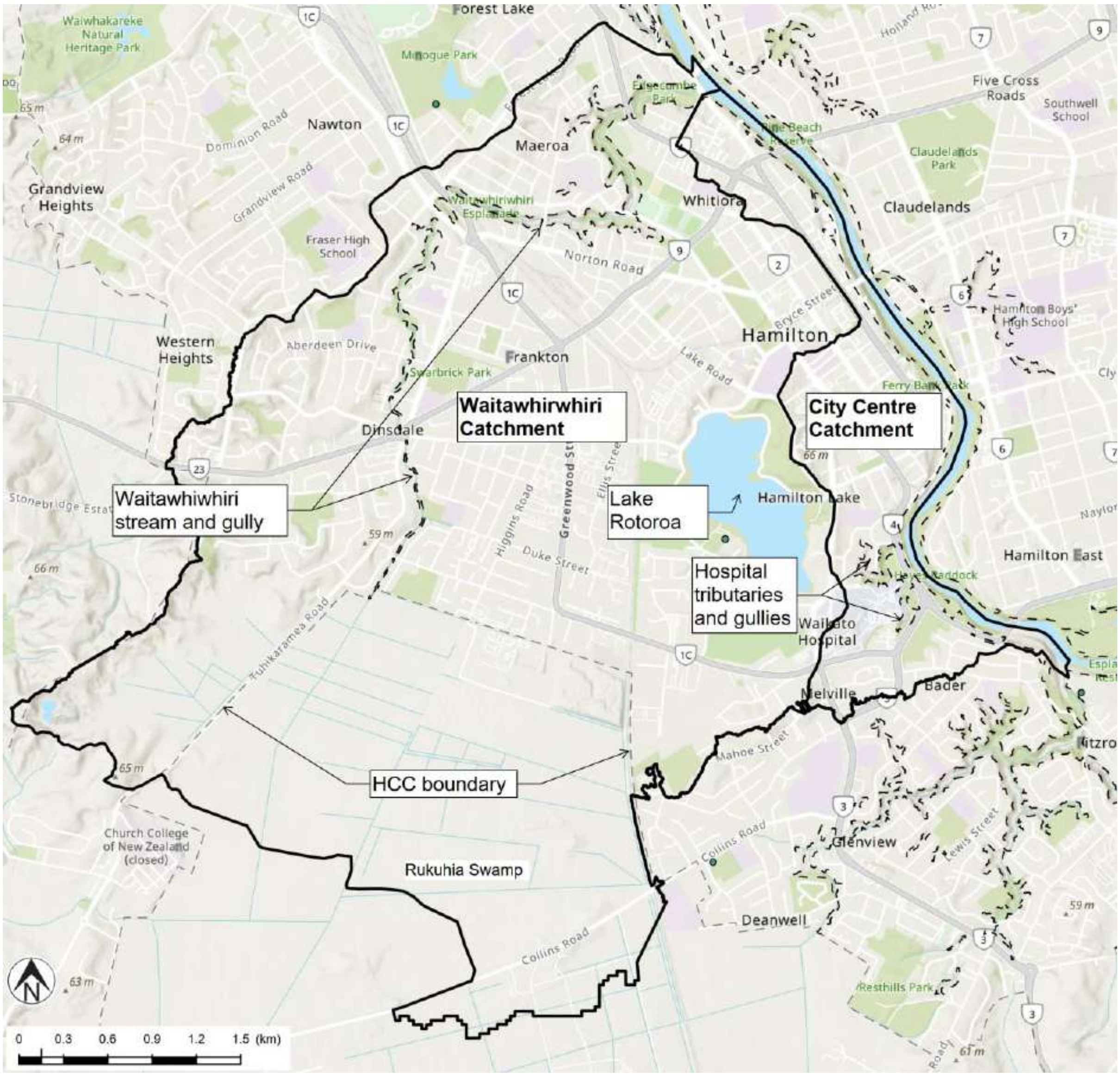

Figure 2.1: Waitawhiriwhiri and City Centre catchments which form the ICMP. Catchment boundaries shown in black.

2.1.1 Waitawhiriwhiri catchment

The Waitawhiriwhiri catchment originates within rural areas of the historic Rukuhia swamp and discharges to the Waikato River via the extensive Waitawhiriwhiri stream and gully system. The catchment includes a large area of residential and industrial city land which extends west of Lake Rotoroa – including Hamilton CBD, Frankton commercial/industrial centres, urban centres and rural land use.

The southern portion of the Waitawhiriwhiri catchment extends beyond the HCC boundary into Waipa District Council (WDC) territory.

2.1.2 City Centre catchment

The City Centre catchment extends east of Lake Rotoroa. The northern catchment areas discharge direct to the Waikato River, the southern areas via a minor stream and gully system (collectively referred to as the 'hospital tributaries').

3 Geomorphology and geology

3.1 Geomorphology

The ICMP catchment (refer to Digital Elevation Model, Figure 3.1) features a broad near level plain at approximately 35 to 40 m RL over much of the study area. A series of low hills emerge above the plain to approximately 60 m RL east of Lake Rotoroa and up to approximately 75 m RL at the north-western margin of the catchment. Gullies of the Waitawhiriwhiri stream and hospital tributaries cut into the plains and the Waikato River is deeply incised below the surrounding plains with bed level about 7 to 9 m RL (URS, 2013)[1]. The boundaries of the catchments follow the central ridge lines of the low hills.

The Waitawhiriwhiri stream and hospital tributary gullies feature moderate to very steep side slopes. The Waikato Riverbank features moderate to very steep slopes with some lower river terraces present. The vast historic Rukuhia swamp and peatland is present in the southern portion of the Waitawhiriwhiri catchment.

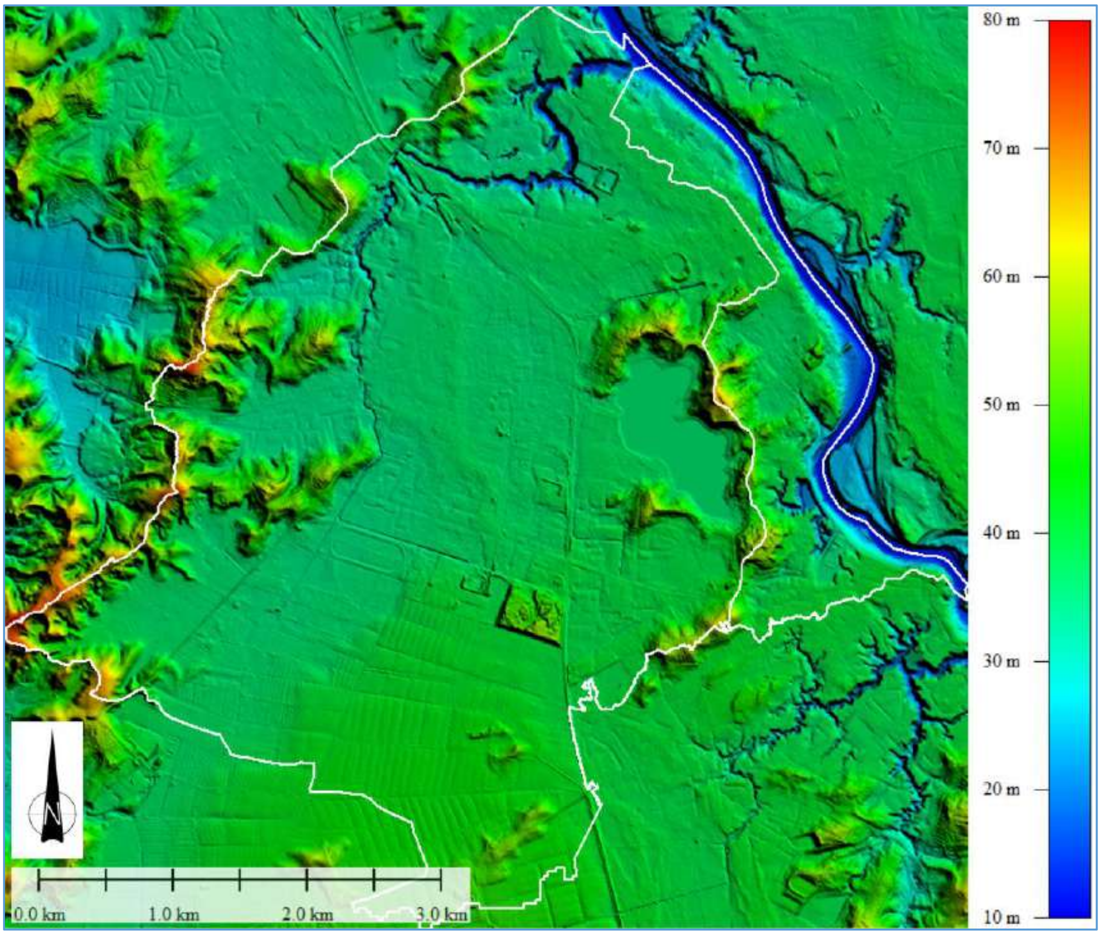

Figure 3.1: DEM of the ICMP. Source: 2019 LiDAR Hamilton City. Catchment boundaries shown in white.

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[1] Riverbed cross sections 148 to 151 (Fairfield Bridge to Victoria Bridge) - The riverbed was indicated to be undergoing scouring of about 12 mm/year between 1998 and 2012.

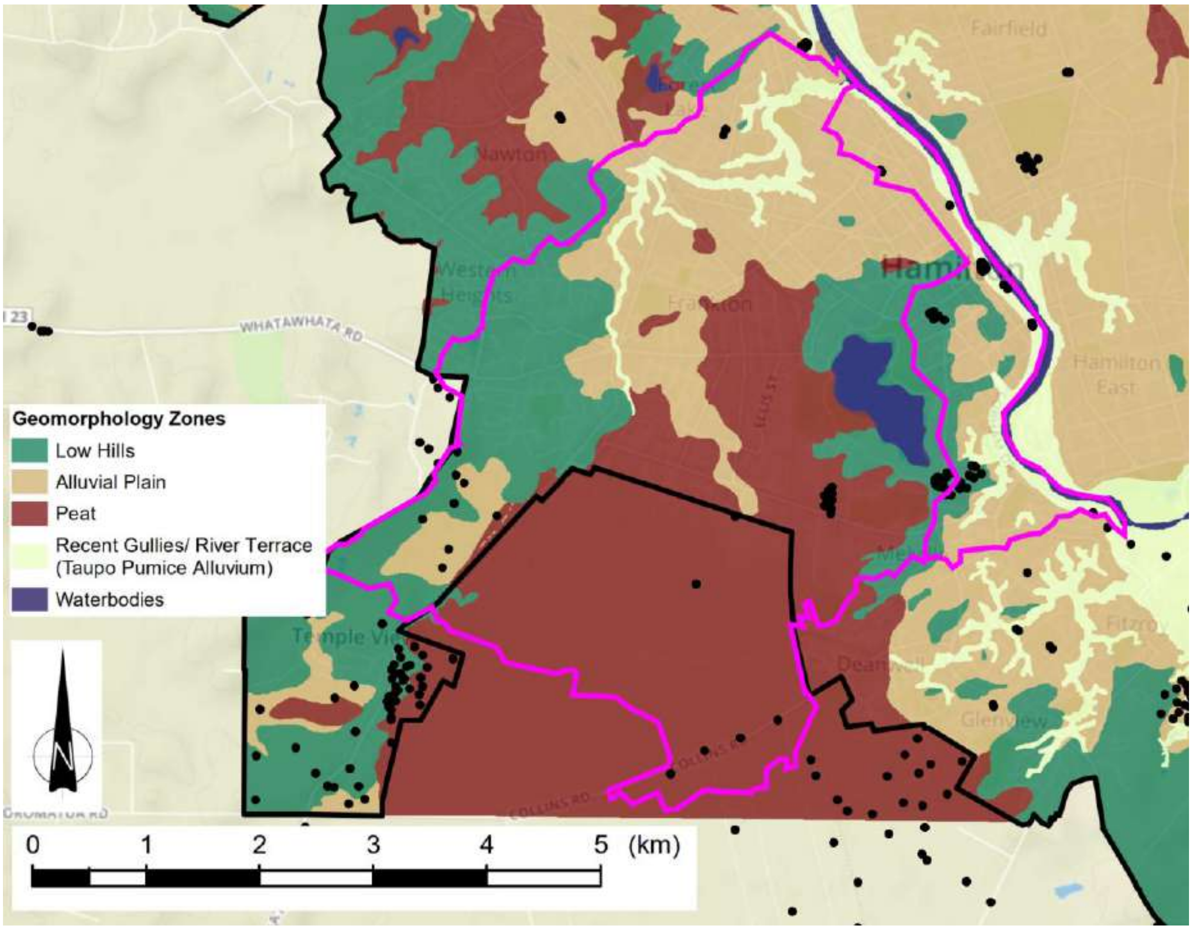

Figure 3.2: Geomorphology Zones within the ICMP. Image source: (T+T, 2019). Catchment boundaries shown in magenta with territorial boundaries shown in black.

3.2 Geology

Hamilton City is situated within the Hamilton lowlands or basin (Figure 3.3), a graben that has been progressively infilled with a complex sequence of volcanogenic alluvium and various ignimbrites and tephra c. two million years ago (McCraw, 2011).

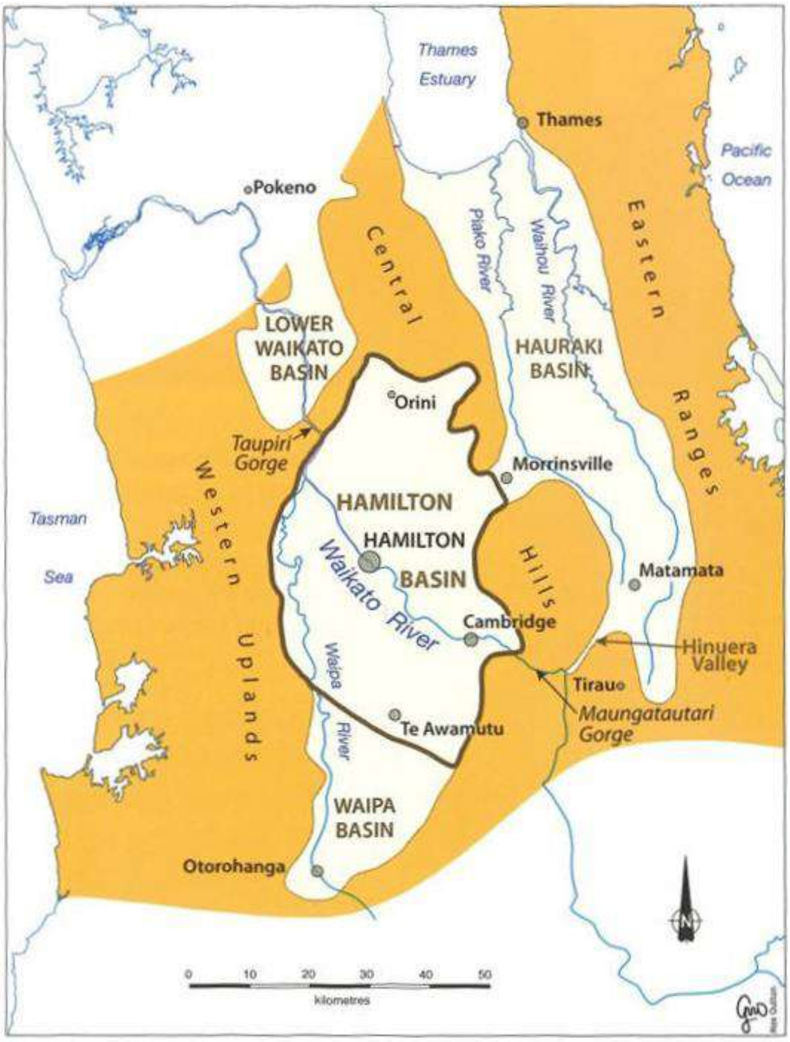

Figure 3.3: The Hamilton lowlands or basin in the upper central North Island is bounded to the west and east by ranges and bisected by the Waikato River (McCraw, 2011).

3.2.1 Geology of the Hamilton Basin

Two distinct periods of deposition can be characterised in the Hamilton lowlands and are observed in the present day landscape as older materials (Walton Subgroup) forming the broad hills and younger materials (primarily the Hinuera Formation of the Piako Subgroup) forming extensive plains. The Walton Subgroup and Piako Subgroup are part of the Tauranga Group. Younger Holocene sediments are also present in the Hamilton basin within gullies, peat bogs and along river terraces. The geological units within the project area are illustrated in conceptual form in Figure 3.4.

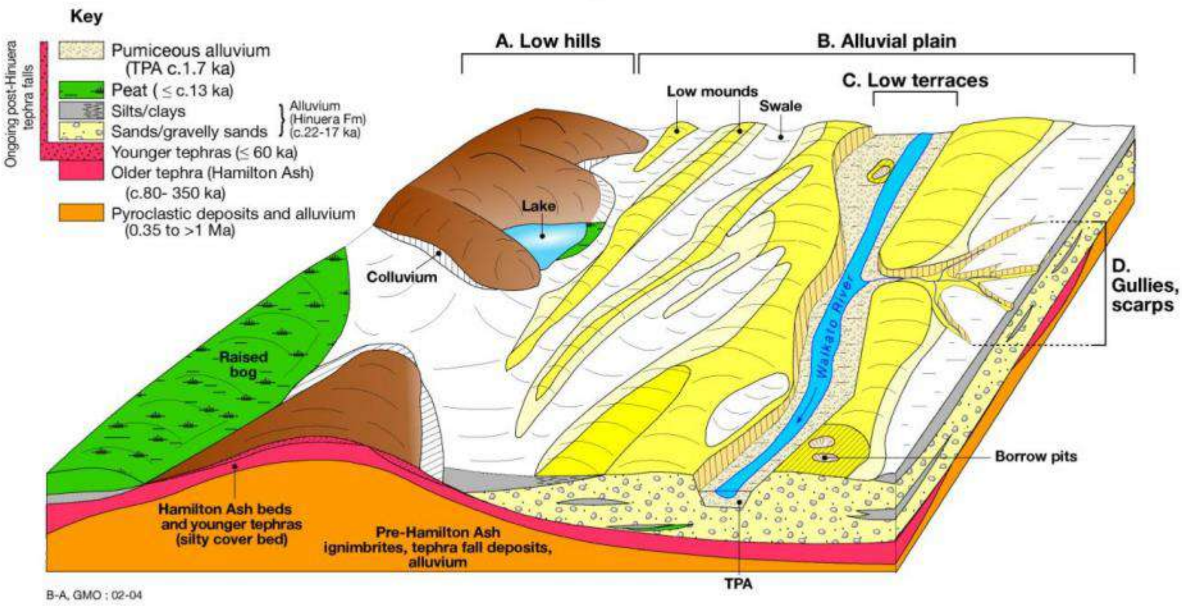

Figure 3.4: Main landscape units and geological materials, Hamilton Basin (Lowe D. J., 2010).

3.2.2 Geology within the ICMP area

All units depicted in Section 3.2.1 are present within the ICMP. Detailed descriptions are provided below. The published geological units are presented in Figure 3.5 with some refinements based on a liquefaction study for Hamilton City (T+T, 2019) and previous geological mapping (refer Section 3).

Walton Subgroup

The Walton Subgroup, forming the present day low hills, comprises a sequence of ignimbrites and tephra from several sources and fine grained volcanoclastic alluvium (Edbrooke, 2005). The deposition of the Walton Subgroup occurred between two million years ago to 27,000 years ago in the Pleistocene Epoch. During later stages these materials eroded forming hills and valleys. The Walton Subgroup deposition ended upon the Oruanui eruption approximately 27,000 years ago.

The Hinuera Formation

Following the Oruanui eruption, the landscape was infilled by sediments of the Piako Subgroup, specifically the Hinuera Formation, which formed the extensive plains observed in Hamilton lowlands. The Hinuera Formation comprises interbedded coarse alluvium, pumice gravels, peat and silts deposited by braided river systems of the ancestral Waikato and Waipa Rivers. These rivers continued to deposit vast amounts of sediment into the Hamilton lowlands until climatic conditions changed c. 17,000 years ago and the river systems entrenched into present day positions (Molloy, 1998).

The Hinuera Formation is highly variable both laterally and vertically. Loose sands and gravels are found in the higher energy environments and levees, and finer grained sediments such as silt represent the low energy environments such as embayed channels and on the inside of river bends.

Peat

The deposition of the Hinuera Formation also led to many of the braided channels being impeded which subsequently formed lakes and swamps. This led to the development of vast peat deposits building over the Hinuera Formation or at the slope margins of the Walton Subgroup. Singleton (1991) also attributes the peat bogs visible within Hamilton Basin to a warming of the climate and associated to the river carrying less sediment, therefore, changing the morphology of the river from a braided system to becoming entrenched into more discrete channels. The Rukuhia raised bog is present over a large portion of the southern ICMP area.

Holocene Sediments

Following the deposition of the “Hinuera Surface” a network of gullies has formed within the Hamilton basin, including the Waitawhiriwhiri and hospital tributaries of the ICMP area. The gullies formed in response to the Waikato River becoming incised below the plain level and from groundwater seepage through the peat bogs. Gully floors contain deposits of Holocene aged (<c.12,000) colluvium and alluvium. These deposits consist of reworked sands, silts and gravels derived from Hinuera Formation and Walton Subgroup, as well as localised organic silt and peat. Holocene deposits are also present along the banks of the Waikato River.

The most recent volcanic activity of the Taupo eruption, c. 2,000 resulted in large volumes of pumiceous material being conveyed down the Waikato River. The river flooded the Hamilton basin leaving lower terraces and some channels covered in the pumiceous silts, sands and gravels known as the Taupo Pumice Alluvium (TPA) (Manville & Colin, 2004); (Edbrooke, 2005). Subsequently, the Waikato River entrenched again through the TPA which is mapped on the eastern riverbanks, outside the current ICMP area.

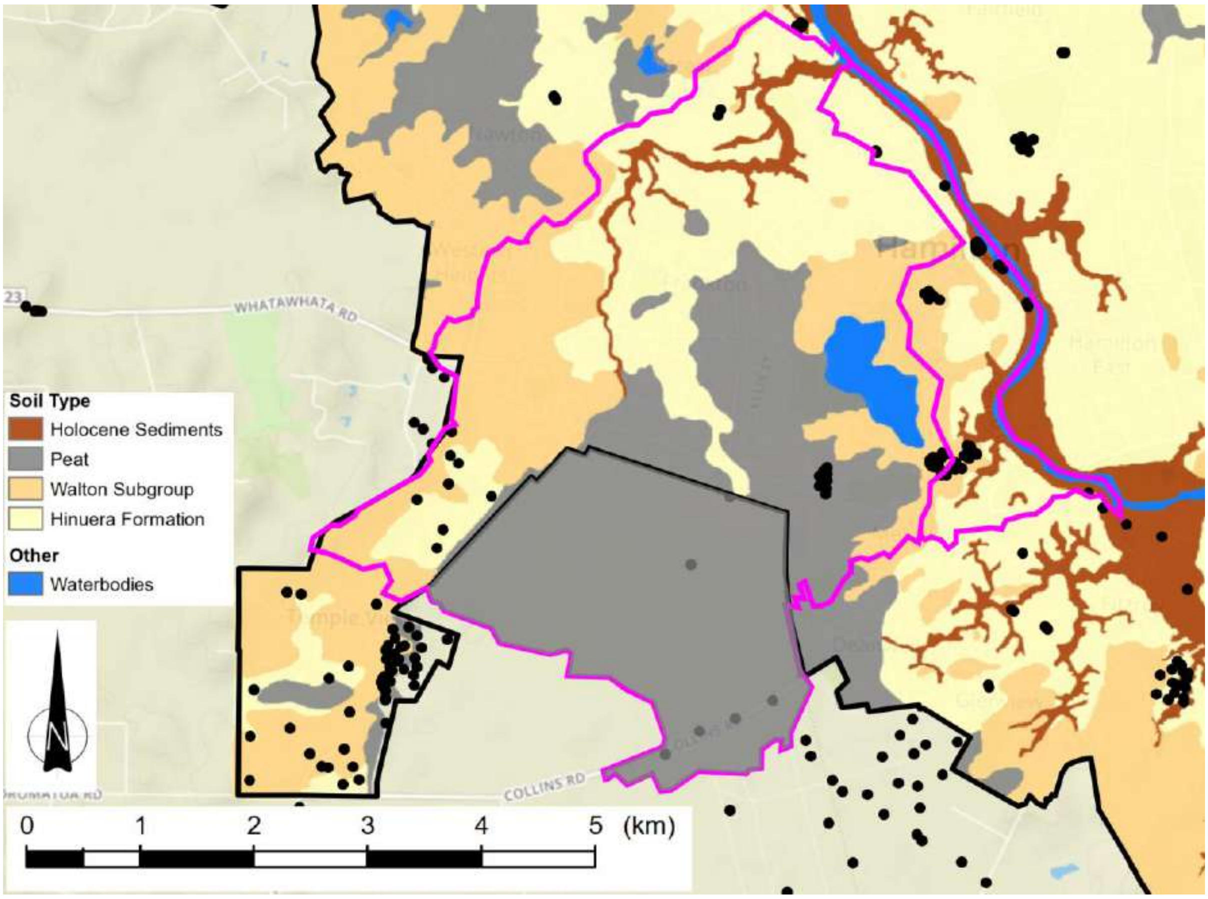

Figure 3.5: Geology of the Waitawhiriwhiri and City Centre catchments, (T+T, 2019).

3.3 Faults

Active Faults

The GNS New Zealand Active Fault Database[2] identifies the Kerepehi fault as the closest active fault to Hamilton at approximately 48 km to the north-east. Active faults mapped by GNS are defined as those that have ruptured the ground surface during the last 125,000 years.

Figure 3.6 shows the active faults mapped in the vicinity of Hamilton.

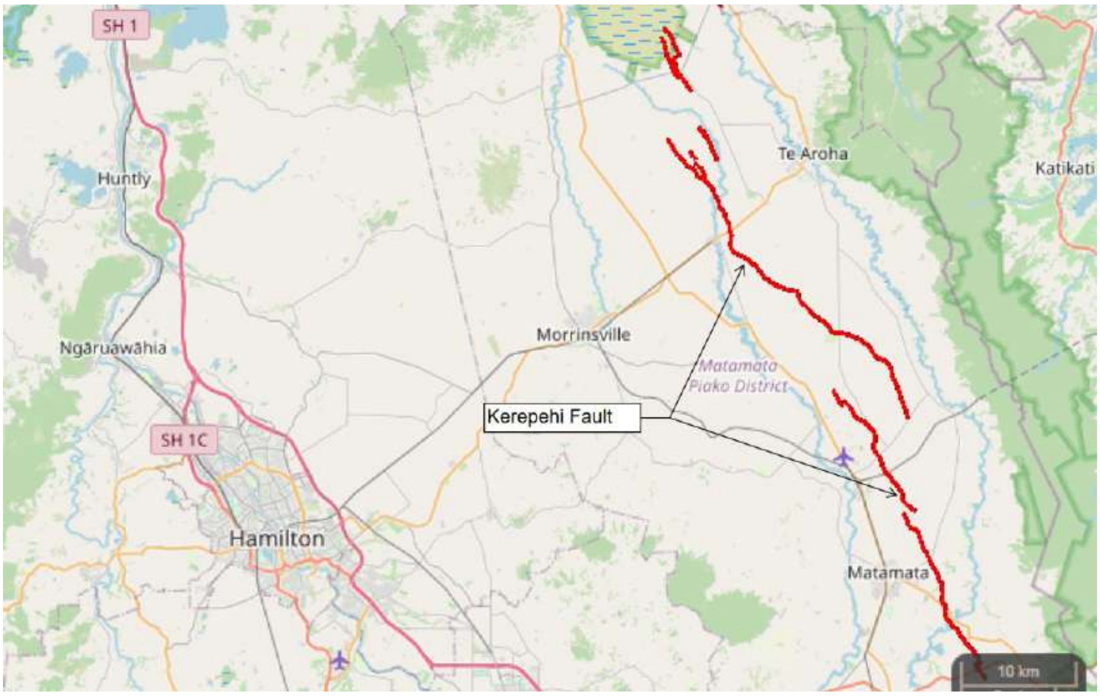

Figure 3.6: Map of active faults in the vicinity of Hamilton, GNS[2].

Inactive faults

Other faults affecting the Hamilton basin include the inferred non-active Waipa and Taupiri faults to the north proposed by (Kirk, 1991). Recent studies by the University of Waikato (Spinardi, et al., 2017) propose the presence of faulting within the Hamilton Basin. Whilst the evidence does suggest that these faults may exist at depth, to date no definitive evidence of activity within the last 350,000 years has been identified.

Figure 3.7 shows the location of the mapped inactive faults in the vicinity of Hamilton.

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[2] GNS Active Faults Database - https://data.gns.cri.nz/af/

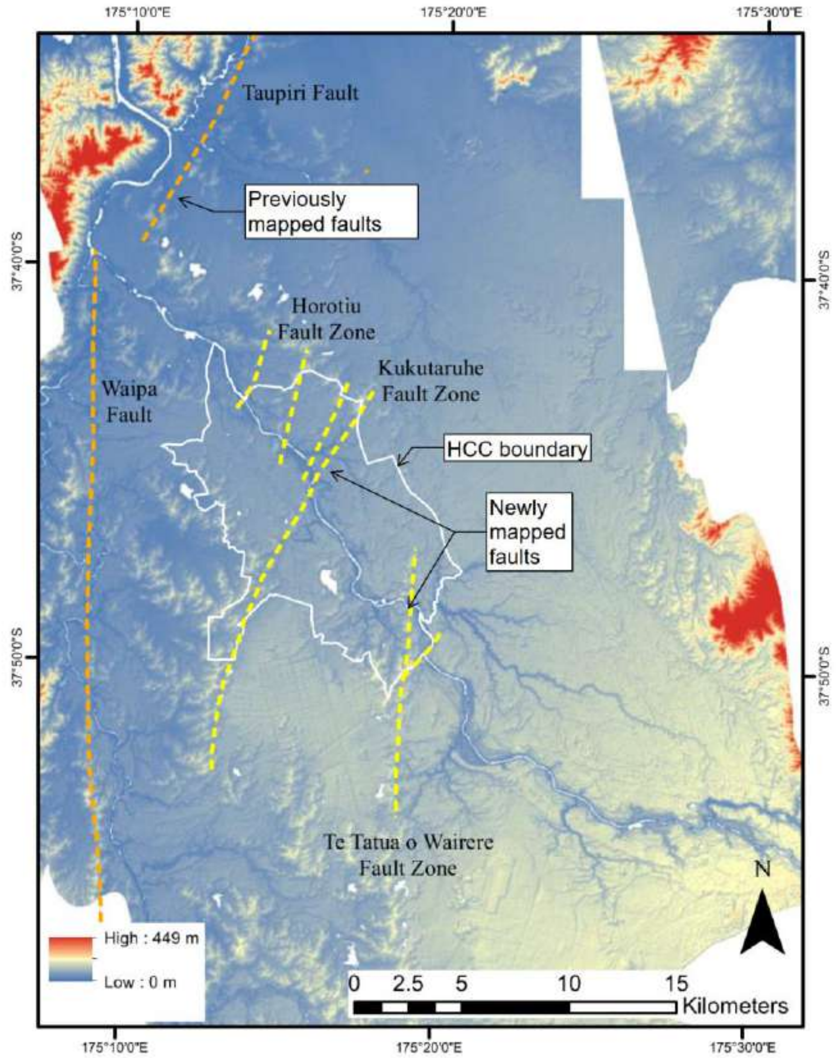

Figure 3.7: Map of inferred fault zones recognised from surface exposures and geological mapping of the Waikato River, (Spinardi, et al., 2017).

4 Hydrology

4.1 Lake Rotoroa

Lake Rotoroa has a depth of between 2 m to 6 m and is situated near the eastern boundary of the Waitawhiriwhiri catchment. Stormwater runoff from the surrounding topography is directed toward and into the lake where it discharges toward the west via an artificial (modified from natural) outlet. The water is directed through piped infrastructure where it discharges into an artificially lined section of the Waitawhiriwhiri Stream near Dinsdale roundabout.

4.2 Waitawhiriwhiri Stream

The Waitawhiriwhiri Stream flows generally in a northward direction. Stormwater runoff is collected via the urban stormwater network and discharged to the gully system at many locations before being and conveyed to the Waikato River. There are several small channels and gullies that form the Waitawhiriwhiri stream system. Contributions to stream flow are also likely from shallow groundwater seepage along gully slopes.

4.3 Waikato Hospital tributaries

The hospital tributaries are two short watercourses situated in two gullies adjacent to Waikato Hospital that drain (separately) to the Waikato River. Both watercourses are relatively short (neither exceeding 1 km in length) and have a small number of minor tributaries. This gully system is also used as a point of discharge for the Council stormwater network.

4.4 Waikato River

Both the Waitawhiriwhiri and City Centre catchments discharge to the Waikato River which forms the northern and eastern boundary of the catchment. The river is generally the final point of discharge for many gully and stream systems within Hamilton City. The Waikato River level is controlled upstream via the Karāpiro hydro power dam and discharges out to the Tasman Sea at Port Waikato to the north.

4.5 Rukuhia Swamp and farm drainage

Much of the area at the head of the Waitawhiriwhiri catchment is within the historic Rukuhia Swamp within the Waipa District. This area has been partly drained for agricultural purposes through a network of drainage channels which discharge to the Waitawhiriwhiri stream and gully. A thick deposit of peat is present in this area of the catchment.

5 Waikato Regional Council consents

A review of Waikato Regional Council's GIS maps[3] indicates that there are several types of consented activities within the catchment that may influence groundwater levels, groundwater/surface water quality.

These include:

- Effluent discharge from agricultural activities.
  - These are situated at the southern end of the catchment on existing farmland generally outside of the city boundaries.
- Groundwater takes.
  - These are indicated to be for the use of domestic supply, agricultural activities and construction dewatering.
  - Domestic supply and agricultural activities are within the southern end of the catchment.
- Stormwater discharge.
  - Discharge of stormwater to land associated with residential activities.
  - Leachate discharge from a historic service station (Maeroa Road) and closed landfill (Willoughby Street/Ulster Street).

It is also of note that while regional consents are not required, fertilizer application to land also has the potential to enter drainage systems/groundwater and influence surface water and groundwater quality.

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[3] Waikato Regional Council, *Consents and Permits, accessed 6 December 2024 at* *https://waikatomaps.waikatoregion.govt.nz/Viewer/?map=85bba12b5e4848bdadc005fea2a84b68*

Figure 5.1 below shows the distribution of these activities within the catchment and surrounding areas.

Figure 5.1: Distribution of consented groundwater takes (blue dots) and discharge permits (green dots)[3].

6 Hydrogeology

6.1 Hydrogeologic properties of sediments

The hydrogeologic properties of the soils within the various geomorphic zones is intrinsically linked to their depositional environment, particle size and the grading of the particle sizes within a deposit/formation.

Finer-grained soils such as silts and clays have poor drainage and low permeability characteristics. These soils often form hydrogeologic barriers which impede groundwater flow and form aquitards. Coarser-grained soils such as uniformly graded sands and gravels provide better drainage and higher permeability characteristics which promote groundwater flow. These sediments often form aquifers and more readily allow movement of groundwater through this matrix both vertically and horizontally.

The Walton Subgroup/low hills are predominately fine-grained and have relatively poor permeability and soakage properties.

Hinuera Formation and Holocene sediments/alluvial plains have soil permeabilities and drainage potentials that range widely from low to high due to the interbedded nature of fine-grained and coarser-grained soils. Additionally, their depositional environment has resulted in high heterogeneity (i.e., vertical and lateral variability) within the soils' composition. Zones of higher permeability, often forming lenses, exist within uniformly graded sands and gravels, but these features are too small to be mapped on a regional scale. Higher permeability deposits are often separated by strata with mixtures of lower permeability silts which can result in perched groundwater, typically at shallow depths.

Organic soils such as peat, have highly variable permeabilities which is often controlled by the fibrous organic content and whether the peat has been subject to consolidation. Areas where the organic matter has broken down, and/or an increase in silt content and/or have been subject to consolidation (i.e., dewatering, historic loading) are usually when the peat has a lower permeability, and this impedes local drainage.

6.1.1 Soil drainage

The variability in soil drainage conditions within the ICMP drawn from Landcare Research S-Maps online[4] is presented in Figure 6.1 below. Whilst this map's purpose is for agricultural use, it provides the following indication of the natural soil characteristics within the ICMP area:

- The southern portion of the Waitawhiriwhiri catchment area is very poorly drained and generally correlates with the extents of the historic Rukuhia Swamp.
- The City Centre catchment and the northern portion of the Waitawhiriwhiri catchment shows drainage conditions ranging from poorly drained (alluvial plains) to moderately well drained (low hills).

The variation in anticipated drainage conditions is a reflection of the variability observed in the alluvial plain's materials due to the changing depositional environments. Whilst the low hills have been noted as being moderately well-drained this is at odds with their low permeabilities. The classification of well-drained is likely to be a reflection of their raised elevation and the separation to the water table. Reliance on the S-map drainage properties is not recommended without site specific testing when considering soakage potential, and runoff.

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[4] S-Maps online: https://smap.landcareresearch.co.nz/maps-and-tools/app

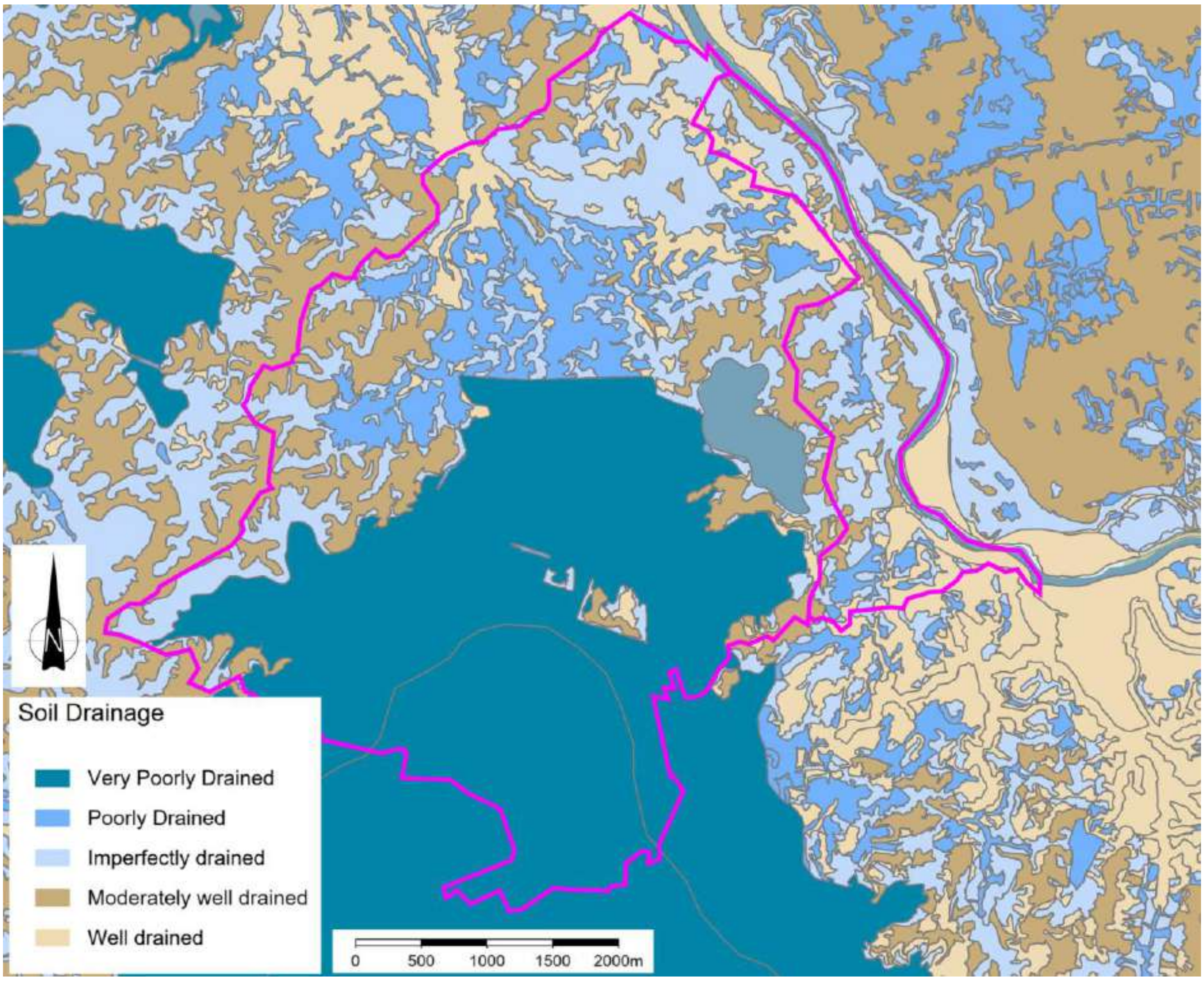

Figure 6.1: Soil drainage within the ICMP. Source: Landcare Research.

6.2 Regional groundwater setting

The regional groundwater within the Hamilton Basin generally follows the wider topographic landforms, with groundwater flow and hydraulic gradients from areas of higher topographic relief (i.e., hills) towards the historic lower lying flood plains and the Waikato River. In this sense, the regional groundwater flow is generally in a similar direction as the Waikato River in a north to north westerly direction.

Within the Hamilton Basin, the Tauranga Group sediments form the most productive aquifers (e.g., those that have the highest yield), with strata comprising well-sorted, coarse sand and gravel deposits. However, these strata are also interbedded with aquitards of lower permeability sediments such as silt, clay and peat strata[5].

Recharge of the groundwater within the Hamilton Basin occurs through infiltration of rainfall and deeper groundwater flows between aquifers from the southeast.

6.3 Catchment groundwater levels and aquifers

Shallow groundwater modelling completed for HCC (T+T GW, 2024) within Hamilton City was carried out to help inform stormwater management in all HCC catchments. Geostatistical modelling was

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[5] R.A. Petch, T.W. Marshall (1988). *Groundwater resources of the Tauranga Group sediments in the Hamilton Basin, North Island, New Zealand*. Journal of Hydrology, New Zealand. Volume 27, Pg. 81-98.

used incorporating ground elevation, geomorphology, distance to surface water features, and available groundwater information. Figure 6.2 below is derived from the groundwater model with the ICMP catchments outlined in magenta.

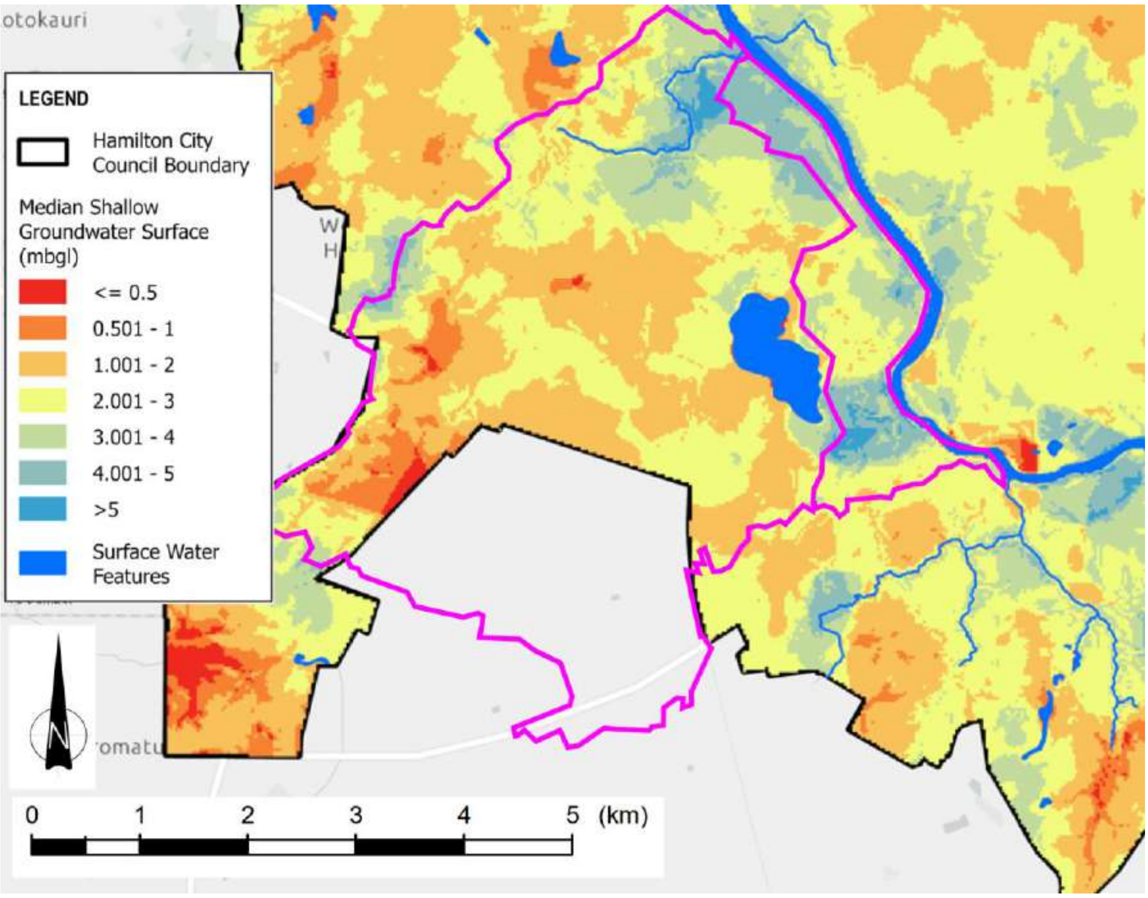

Figure 6.2: Shallow groundwater modelling for the Waitawhiriwhiri and City Centre catchments, (T+T GW, 2024).

From the groundwater model outputs, it is generally noted that groundwater within the catchment is typically within the upper 3 m of sediments. This groundwater is commonly associated with perched groundwater that forms above a low permeability layer (e.g., silts, clays). The low permeability layer impedes the vertical infiltration of the groundwater. These layers vary both in their lateral extents and their depth across the catchment. Where these layers intercept incised stormwater pathways (e.g., gullies), seepage can occur on the slopes and/or support baseflow to streams. Localized deepening of the modelled groundwater surface is observed in close proximity to the Waikato River and deeply incised gully systems. The localised deepening is attributed to a depression of groundwater due to groundwater drawdown associated with seepage and springs on gully slopes and floors. The current groundwater model does not include the southern portion of the Waitawhiriwhiri catchment outside of the city boundary. However, the groundwater in this area is expected to be close to ground level due to the poor drainage properties of the peat soils.

Due to the geological history of the area being a former braided river system, there are no well-defined or continuous aquifers. High yield aquifers are usually found within localised lenses or zones of higher permeability soils.

6.4 Catchment groundwater flow direction

Groundwater flow within the catchment is expected to follow the topography and flow from higher topographic relief areas in the south of the catchment towards lower topographic relief areas and the Waikato River in the north.

6.5 Conceptual hydrogeological model

Based on the available geological and hydrogeological information, a conceptual hydrogeological model has been developed for the catchment area as follows.

Recharge occurs in the form of rainfall which infiltrates into the ground and into shallow groundwater forming the aquifers. Excess runoff from rainfall flows into reticulated networks (e.g., in the built-up environment) or into nearby surface water bodies (e.g., streams).

The shallow groundwater, where close to gully and river systems, flows horizontally and out of the side slopes as seepages or springs. Seepages and spring flows contribute to the baseflows of the surface waters. Rainfall recharge to shallow groundwater and the travel time to discharge as baseflows to surface water bodies can be variable due to the geology and aquifer characteristics. This means that the time delay between rainfall events and the subsequent resulting change and amount in groundwater levels is variable between geomorphic zones. Away from gully and river systems, shallow groundwater progressively infiltrates deeper where it contributes to the deeper aquifers.

Given the local geology, the base of the gullies within the catchment are inferred to intersect or overlie lower permeability layers (e.g., silt, clay) which inhibit vertical infiltration of the surface water. Due to the low infiltration rates, ‘losing reaches’ are not expected and the water collects where it flows down gradient, eventually discharging into the into the Waikato River.

7 Geotechnical constraints

7.1 Seismic hazards

As presented in Section 3.3, no active faults are currently understood to be present below or very near to Hamilton City. Accordingly, direct fault rupture effects are not expected. However, ground shaking from regional earthquakes and their effects on the catchment will need to be considered, including liquefaction, lateral spreading and cyclic softening.

Future ground shaking expected for large regional earthquakes in NZ has been published in the updated 2022 National Seismic Hazard Model (NHSM)[6] (Figure 7.1) which shows that ground shaking hazard in Hamilton is generally lower (darker colours) compared to central and southern areas of NZ where the brighter colours indicate increasing hazard. While the NSHM will inform future design standards, it does not provide information that can be directly applied in design applications. Consequently, the current ground motion parameters required to be used in design scenarios for the Hamilton area are detailed in MBIE/NZGS Module 1 (MBIE, 2021). Important updates to Building Code compliance documents that will be informed by the NSHM are expected to be released in 2025.

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[6] GNS Science, National Seismic Hazard Model website: https://nshm.gns.cri.nz/

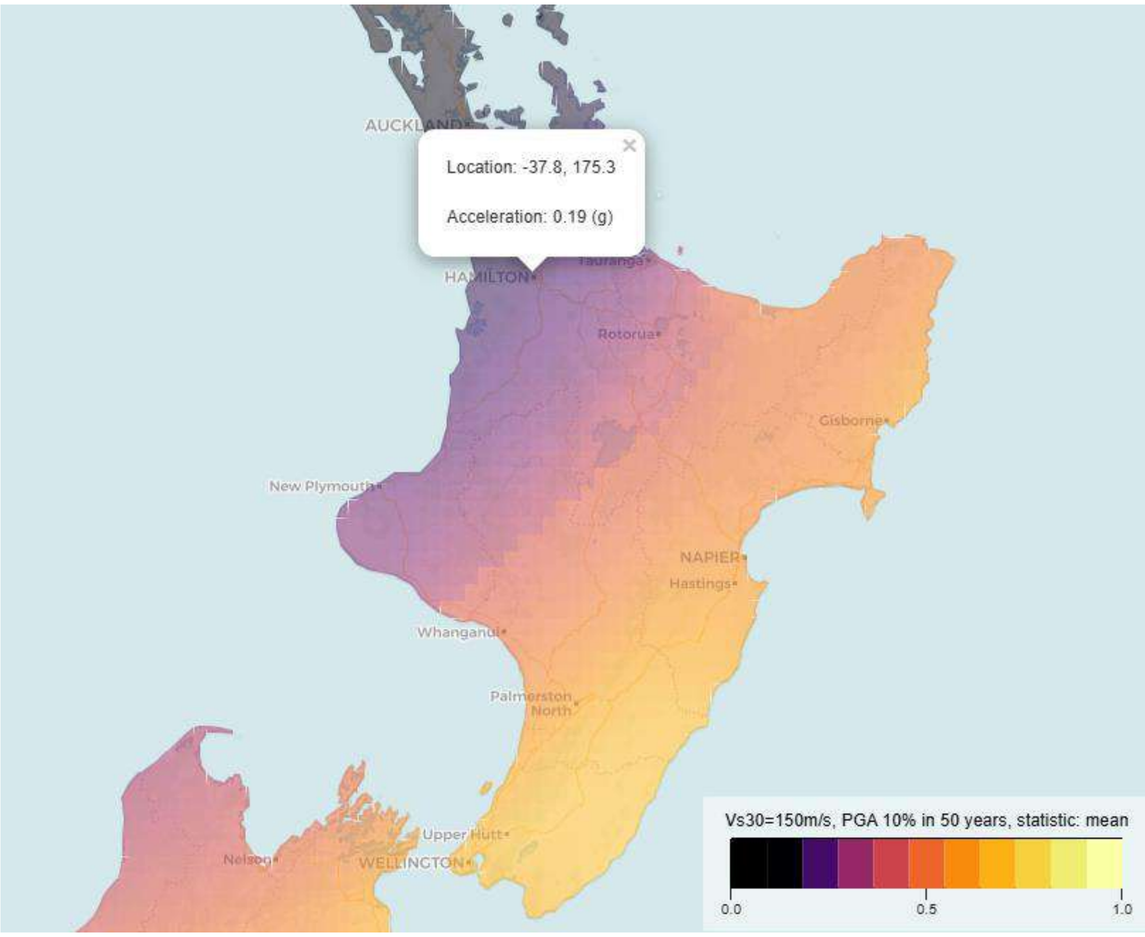

Figure 7.1: National Seismic Hazard Model 2022, Peak ground acceleration (PGA) for Hamilton during a one in 500-year event. (One in 500 equates to a 0.2 % Annual Exceedance Probability, or a 10 % year probability). Map colours denote peak ground acceleration values from 0 to 1 g.

7.1.1 Liquefaction

Liquefaction of soils can be induced during earthquake ground shaking causing damage to land, structures and infrastructure (refer Figure 7.2 and Figure 7.3).

Liquefaction occurs when saturated, loose sands or silts contract and densify in response to ground shaking, increasing pore water pressures and reducing effective stresses. The resultant effect may include water and sand ejecta, differential ground surface subsidence and bearing failure.

The effects of liquefaction at the surface depend on shaking intensity, depth to groundwater, thickness of liquifiable ground, presence of clay like soils and pre-existing density which together may form a non-liquefiable ‘crust’ to mitigate any deeper liquefaction.

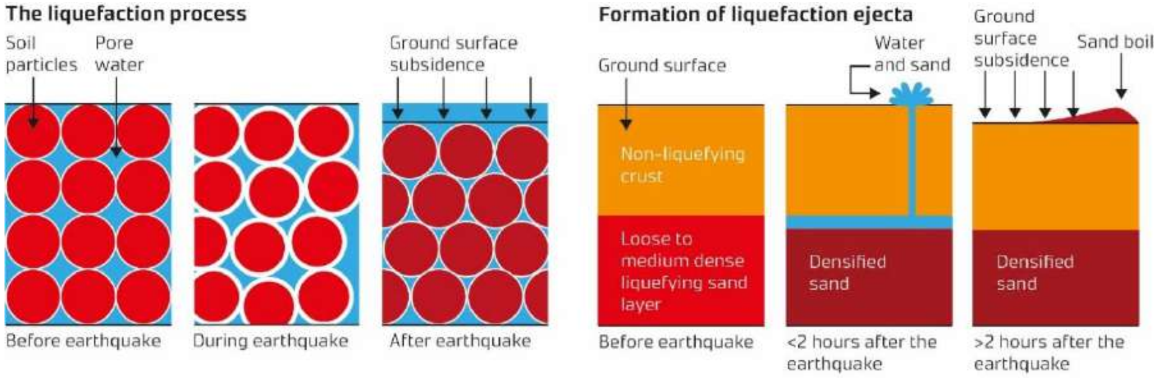

Figure 7.2: Process of liquefaction and the manifestation of liquefaction ejecta.

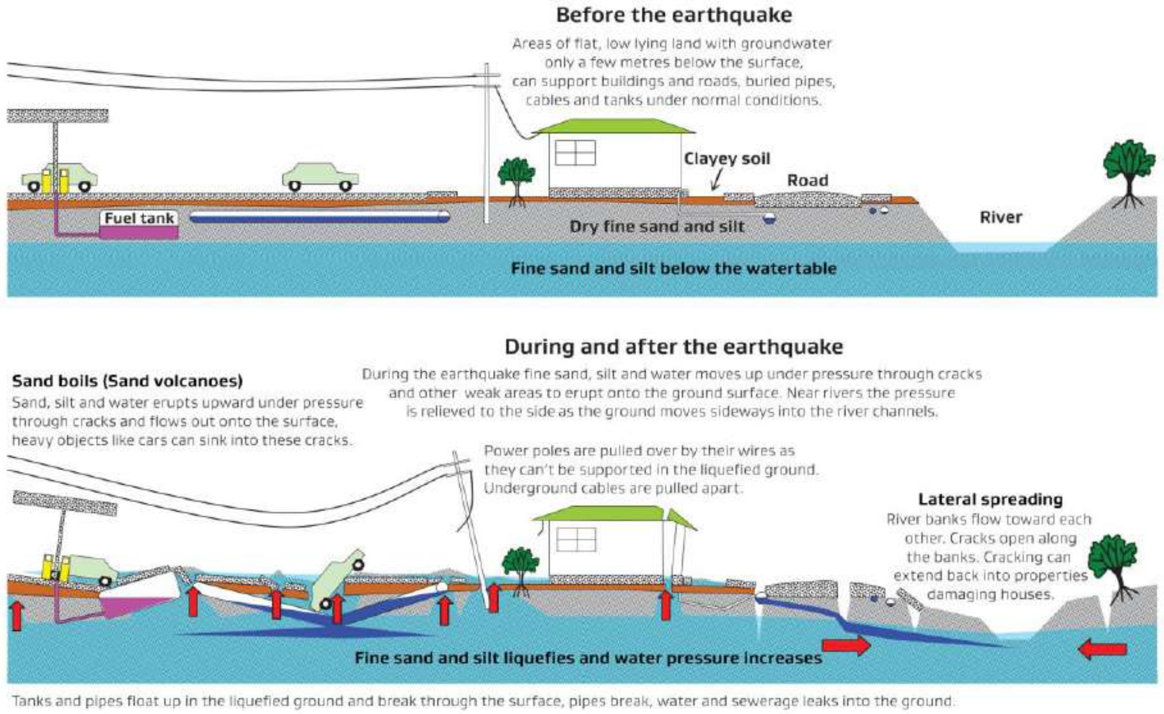

Figure 7.3: Liquefaction damage, (MBIE/MfE/EQC, 2017).

7.1.1.1 Liquefaction vulnerability

Liquefaction vulnerability has been assessed for Hamilton City (T+T, 2019) in general accordance with a Level A/B assessment under the Planning and Engineering Guidance for Potentially Liquefaction Prone Land (MBIE/MfE/EQC, 2017).

The study involved spatial analysis of an extensive Cone Penetration Test (CPT) dataset for liquefaction susceptibility based on the geomorphological and geological zones described in Section 3.

The results showed the following for the ICMP area (refer Figure 7.4):

- A decrease in the depth to groundwater (i.e., shallower groundwater) resulted in an increase in the expected liquefaction related land damage.
- The low hills were categorised as '*Liquefaction Category Is Undetermined*'.
- The river terraces/gullies, peat and alluvial plains were categorised as '*Liquefaction Damage Is Possible*'.

All zones had a large spread of liquefaction severity. However, overall trends in the data showed the highest vulnerability was generally found in the alluvial plains, followed by peat, gullies/river terraces, and the low hills. The low hills may have a lower liquefaction vulnerability than the other zones due to presence of clay like soils and inferred deeper groundwater - however, there was large uncertainty in groundwater depths at the time of the study and hence the susceptibility category was 'undetermined'. Peat was indicated to provide some resilience to liquefaction but depended on the peat thickness, fibrous nature of the peat and liquefaction susceptibility of the underlying soils.

Low hills versus recent groundwater modelling

Recent shallow groundwater modelling (refer Section 6.3) indicates a likely groundwater level of 3 to 5 m bgl for the low hills geomorphic zone. Accordingly, this may suggest that liquefaction vulnerability for the low hills may be low or very low, such that "Liquefaction Damage is Unlikely" may be a more suitable category. This assessment is currently undertaken by individual applicants at resource or building consent stage using observations from site specific investigations.

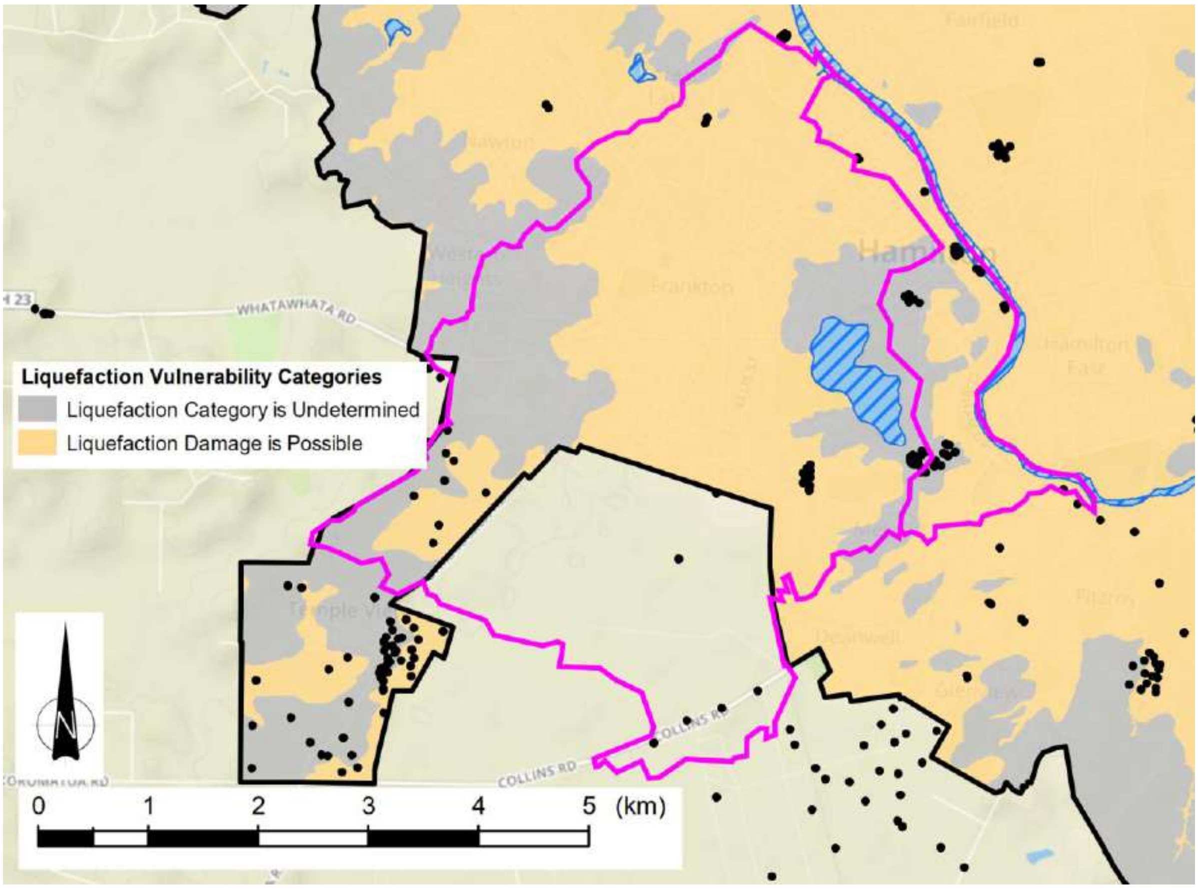

Figure 7.4: Liquefaction vulnerability, (T+T, 2019).

Southern Waitawhiriwhiri

The 2019 T+T assessment did not include the southern portion of the Waitawhiriwhiri catchment area (refer Figure 7.4). The WRC hazards portal[7] includes liquefaction vulnerability mapping across the Waikato but also excludes the southern Waitawhiriwhiri, and this part of the IMCP area remains un-assessed.

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[7] WRC Hazards Portal - https://www.waikatoregion.govt.nz/services/regional-hazards-and-emergency-management/regional-hazards-portal/

As the southern portion of the Waitawhiriwhiri falls within the peat geomorphic zone, liquefaction vulnerability in this zone would likely be consistent with ‘Liquefaction Damage is Possible’ in accordance with the 2019 T+T study, however, this would need to be confirmed by further liquefaction vulnerability studies. The thickness of the peat in this location will have an influence on the liquefaction vulnerability category in this area, however, the presence of a significant thickness of peat will also pose additional geotechnical challenges should development of this area be considered.

As well as uncertainty in groundwater levels, the MBIE/NZGS Module 1 (MBIE, 2021) seismic hazard parameters used in the 2019 study were updated in 2021 (see section 7.1) resulting in higher ground motion parameters. Subsequent to this, the 2022 National Seismic Hazard Model has been published which will likely result in a lowering of the MBIE/NZGS Module 1 seismic hazard within the Hamilton Basin.

7.1.1.2 Liquefaction national guidance

MBIE provides guidance (MBIE/MfE/EQC, 2017) on the level of detail for investigation and assessment required to support a range of development stages and scenarios across a spectrum of increasing liquefaction susceptibility. These show that as land development progresses through plan change, to resource and building consent, the level of detail required to support each development scenario increases.

In this context, the 2019 T+T study provides assessment at ‘Level B’ (Calibrated Desktop Assessment) which is suitable to support regional and district planning and plan changes for urban and commercial intensification. Assessment at ‘Level C’ (Detailed area-wide assessment) or ‘Level D’ (site-specific assessment) is generally undertaken to support subdivision consent or building consent applications respectively where liquefaction is possible.

7.1.2 Lateral spreading

Liquefaction which occurs adjacent to an ‘open face’ such as a gully, riverbank, channel or swale may result in the soil moving horizontally or laterally toward the free face in a displacement known as lateral spreading, and may result in large, often damaging, ground movements. This can result in substantial damage to any structures or infrastructure built on or in the soil, refer Figure 7.3.

As described in the 2019 liquefaction vulnerability study for Hamilton, particular attention should be given to the potential for lateral spreading to occur on land within and directly adjacent to the river terraces/gullies geomorphic zone.

7.1.2.1 Lateral spreading guidance

The MBIE guidance (MBIE/MfE/EQC, 2017) recommends that particular attention should be given to land that is susceptible to liquefaction within 100 m of a free face less than 2 m high, or within 200 m of a free face greater than 2 m high.

7.1.3 Cyclic softening

Although clay like soils are generally considered to be non-liquefiable, such soils can experience weakening during ground shaking events which may cause damage to land and structures.

The cyclic loading and unloading of the soil from earthquake ground shaking can cause progressive shear strength reduction which may lead to bearing failure or slope failure.

Cyclic softening is dependent on existing undrained shear strength, plasticity and ground shaking intensity.

As clay like soils are generally found in the low hills geomorphic zone (refer Section 3.2), cyclic softening should be considered in that zone, particularly where weak, low plasticity clay is identified during site specific investigations.

7.1.3.1 Cyclic softening guidance

Cyclic softening guidance is provided in (MBIE, 2021) module 3 and suggests that assessment and design should be carried out in accordance with Boulanger & Idriss, (Boulanger & Idriss, 2007).

In practice, clay soils which are soft (e.g., < 50 kPa) and likely prone to cyclic softening would generally be captured during site specific slope stability and foundation assessments.

7.2 Slope Stability

Landslides may occur where sufficiently steep/high slopes are present and can result in damage to land, structures and infrastructure either by loss of land or by inundation with landslide debris.

Landslide debris may also negatively impact sensitive receiving environments, e.g., silt and sediment in streams, altered water quality, and mobilisation of contaminants in soil. Furthermore, where landslides have occurred, ongoing erosion is possible which may lead to ongoing soil mobilisation, or even further landslides and inundation.

Along with overall slope angles and slope heights, slope stability effects are influenced by geological and groundwater conditions. Generally, susceptible slopes may experience landslides in response to loading of the slopes (from building or earthworks) or unloading of the toe (due to earthworks), saturation of the slope (from groundwater and/or infiltration), removal of vegetation (leading to erosion and slope saturation), or during a strong earthquake.

7.2.1 Slope stability risks in the ICMP

As discussed in Section 3, moderate to very steep slopes are found within the gullies of the Waitawhiriwhiri and hospital tributaries and banks of the Waikato River. Accordingly, it is these areas which may be prone to land instability. A summary of some known issues is discussed as follows:

- The Natural Hazards Commission (NHC) Natural Hazards Portal[8] indicates a strong correlation exists between known landslip claims and the gully landforms in Hamilton, including the gullies of the Hospital Tributaries and Waitawhiriwhiri stream.
- Ongoing slope instability is documented in the steep slopes of the Hospital tributaries east of the Waikato Hospital where slope monitoring has been carried out by T+T since 2014 (T+T Hospital, 2014 - 2023).
- The Willoughby closed landfill forms a significant portion of the eastern Waitawhiriwhiri gully bank within the Beetham Park recreational reserve which is prone to land instability. Assessment in 2024 (T+T Closed Landfill, 2024) notes:
  - The landfill does not have a low permeability engineered cap but instead has variable thickness cover fill (sand and silt soils) which are relatively permeable to water infiltration.
  - The closed landfill does not have a low permeability engineered base liner or measures to control leachate.

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[8] https://www.naturalhazardsportal.govt.nz/s/claims-map

- Refuse is exposed at the toe of the landfill slope, and streambank, adjacent to Waitawhiriwhiri Stream. Suggesting that at least some parts of this slope comprise landfill refuse.
- Evidence of recent and historical slope instability on the landfill gully slopes and stream banks, particularly where the landfill slope has been over steepened from lower access track formation and where stream banks are being eroded by the meandering Waitawhiriwhiri stream.
- Where landfill material is near the streamside slope, landslides may result in soil and refuse debris inundation entering the waterway. The landfill aftercare management plan (AMP) requires HCC to address instability of the landfill slopes where these pose imminent risk to the integrity of the landfill.
- The main driver of the instability was oversteepening of the slope, however, secondary impacts from stormwater infiltration/seepage and overland flow were noted.
- The report recommended some proactive mitigation measures to address slope stability risks, including slope and streambank stabilisation and prevention of stormwater infiltration and overland flow diversion.
  - We understand that HCC will implement some stability and overland flow control mitigation measures in mid-2025.

Other slopes present in the ICMP generally include man-made features such as cut or fill embankments, drainage channels, etc. These slopes may also be prone to instability if inadequate design or construction has been carried out.

Further discussion of landslide issues, effects and potential management considerations for the ICMP are provided in Section 9.

7.2.2 Waikato Riverbank and Gully Hazard

HCC delineate a Waikato Riverbank & Gully Hazard Area (GHA) in the district plan maps[9] this is shown in Figure 7.5 below in the current ICMP context.

The HCC Operative District Plan[10] (ODP) General Standard 4.4.6 Building Setback requires a 6 m setback from the GHA. This setback applies to buildings and swimming pools and any earthworks ancillary to these. According to the ODP, Volume 2, Section 1.2.2.10, a Site Management Plan (SMP) must be provided for any development within the GHA and the setback.

For gully areas, the 6 m setback is a generic approach that does not consider slope height, slope angle, slope geology or groundwater on a site-specific basis. For the riverbank, the setback is the Riverbank Stability line (viewable in the DP viewer), which is based on the BECA 2006[11] riverbank stability hazard assessment.

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[9] https://hamilton.isoplan.co.nz/eplan/property/1806556/1792480/5825267/5806724/0/82

[10] Hamilton City Council, Operative District Plan, 4 April 2024.

[11] Beca, 2006, Bank Stability Hazard Assessment (Appendix D of Waikato River Bed Degradation Investigation Stages III & IV).

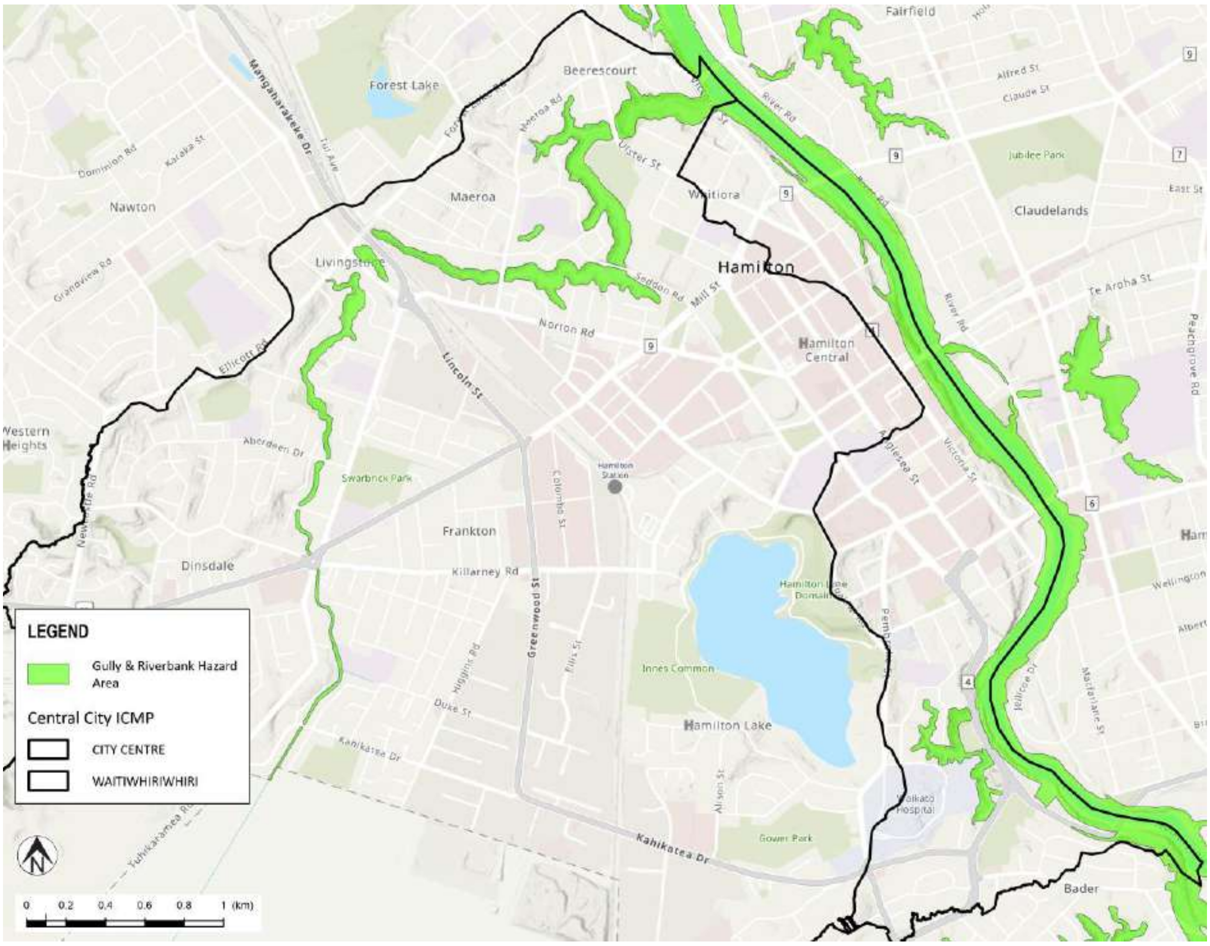

Figure 7.5: Waikato Riverbank and Gully Hazard Area within the ICMP catchments.

7.2.3 Gully setback assessment

T+T has recently assessed the GHA setback for the gullies associated with the Waitawhiriwhiri stream and hospital tributaries (T+T Slope, 2024). The purpose of the assessment was to delineate areas where further assessment of slope stability would be recommended to support a building or resource consent application within the Waitawhiriwhiri and Central City Catchments over and above the existing 6 m setback. The Waikato Riverbank was not included in this assessment.

The assessment involved geoprocessing 2019 LiDAR to establish the toe of the gully slope from where a 2H:1V regression line could be considered and compared to the existing 6 m set-back from the GHA. A new combined slope assessment line was produced, taking the furthest of either the regression line, GHA buffer, or gully crest line. This is illustrated in the example given in Figure 7.6 below.

It was recommended that the model be used to advise where further assessment should be sought to determine site specific ground conditions and a subsequent setback from the gully slopes.

Figure 7.6: Gully setback analysis results; detail near Main Trunk railway, Waitawhiriwhiri Gully (T+T Slope, 2024).

7.3 Peat

The following section discusses the presence of peat in the ICMP area which can pose a number of engineering and environmental threats but also provide some opportunities for enhancement.

Further discussion of peat issues, effects and potential management considerations for the ICMP are provided in Section 9.

7.3.1 Peat review

Recent review of peat within the Hamilton City boundary was carried out by T+T (T+T Peat, 2024) to help HCC understand potential issues linked to areas underlain by peat soils. The study reviewed existing datasets and literature about peat soils in Hamilton City and the wider Waikato region and production of a GIS layer for predicted peat extents in the city. Overall, peat soils were indicated to cover around about 24 % of Hamilton City's area. The study notes that with urban expansion and population growth in Hamilton, increasing development on peat soil presents several engineering and environmental risks, including:

- Low shear strengths, high water content and low bearing capacity, high susceptibility to decomposition and compression leading to subsidence/settlement.
- Exposure of peat soil to oxygen through lowering of ground water level can lead to oxidation and potential acidification of soil and groundwater in some cases (refer acid sulfate discussion in Section 7.4).
- The drainage of peatlands also increases decomposition of organic matter and produces CO_2 emissions. In Aotearoa-NZ, drained peatlands account for up to 8 % of net Green House Gas (GHG) emissions (Pronger, 2024) so can be expected to contribute to HCC's net GHG emissions.

- Understanding peat distribution can inform better environmental management and planning decisions to preserve peatland groundwater levels.

A 2018 report (WSP Opus, 2018) discusses settlement issues for a localised area of saturated highly compressible organic soils (peat) in the vicinity of Bryce Street and the adjacent rail cutting (visible in Figure 7.7). The report notes the following:

- The site has been subject to ground movements dating back to 2012 which has culminated in multiple extensive cracking to the road pavement and footpath together with settlement of the grass verge.
- Observed ground movements appear to be related to settlement of the thick deposit of the organic silt underlying the road which has been exacerbated by the load of the trees and their effect of water drawdown leading to potential tertiary settlement.
- It was recommended that removal of trees along the slope crest as well as ongoing monitoring of settlements be carried out. It is our understanding that the tree removal has been undertaken

7.3.2 Peat in the ICMP catchment

The peat extent GIS layer discussed in Section 7.3.1 was updated for inclusion into this ICMP report and (refer Figure 7.7) and indicates the following:

- Peat is indicated to cover at least the southern half of the Waitawhiriwhiri catchment area (historic Rukuhia swamp).
- Peat was not indicated to be present in the City Centre catchment.

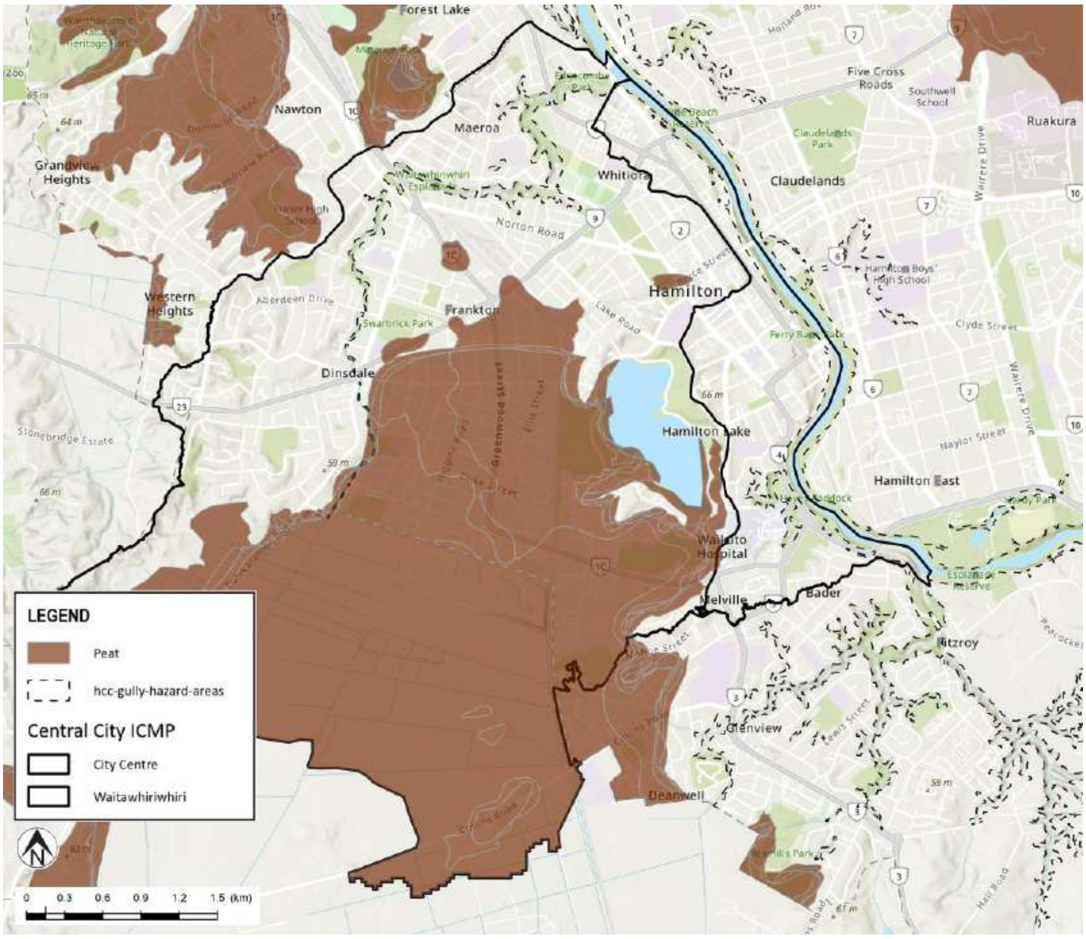

Figure 7.7: Peat extents for the ICMP, (T+T Peat, 2024).

7.3.3 HCC peat guidance

There are no specific engineering controls for peat in the HCC ODP other than where these intersect with any wetlands or peat lakes, which require:

- Policy objective to preserve peat lake/wetland environments, including maintaining groundwater to mitigate ‘differential shrinkage’ (HCC ODP 20.2.4).
- 50 m offset to buildings from peat lake/wetland environments (ODP 20.4.1).

Where engineering considerations of the peat are concerned, e.g., soft soil, bearing, elevated water, liquefaction and settlement, these will generally be captured during geotechnical assessment and design during either resource or building consents or via engineering approval. As there has been no environmental controls for general peatland areas, a common approach in Hamilton has been to remove peat as an effective method to address the associated geotechnical risks associated with land development. We note that this approach is not consistent with some key environmental opportunities where peatland is conserved, refer Section 7.3.1.

7.4 Acid sulfate soils

Acid sulfate soils are naturally occurring soils and sediments which contain sulfide minerals that have the potential to cause water and soil to acidify when they oxidise (Roberts & McConchie, 2017).

Acid sulfate soils are commonly found in organic rich, warm, low energy, waterlogged environments such as swamps and estuarine areas. These soils have been identified in Northland, Auckland and Hauraki, and potential acid sulfate soils may be present within the Waikato due to the large number of swamps and peat deposits present in the region. Oxidisation of these soils can occur when the groundwater is lowered through excavation and drainage of potential acid sulfate soils.

The Waikato Regional Council (WRC) has noted adverse environmental impacts that have been attributed to the presence of acid sulfate soils. These impacts include infrastructure damage (e.g., acid degradation of concrete structures), fluctuations in surface water pH, increased metal leaching and localised fish kills (GHD, 2023).

It should be noted that peat and associated groundwater typically has a lower than normal pH owing to natural organic acidity. For example, the upper Waitawhiriwhiri Stream catchment (which drains peatland) is typically acidic with a median of around pH 6 or occasionally lower (this is discussed further in the ICMP Receiving Environment Report). The GHD study indicates a pH of between five and six (weakly acidic) for the single sampling location within the ICMP, refer Section 7.4.2. Accordingly, acid degradation of infrastructure within peat soils should be considered irrespective of potential or actual acid sulfate soils.

7.4.1 Acid sulfate potential in the Waikato region

GHD carried out an acid sulfate soils preliminary risk assessment in 2023 for WRC (GHD, 2023). The assessment provides a draft map showing probability of acid sulfate occurrence throughout the Waikato region. The assessment considered a number of contributing factors including topography, geology, depositional environment, pedology and vegetation. The study suggests that wetland environments including peat and gley[12] (reduced waterlogged soils) are strongly associated with formation of acid sulfate soils.

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[12] Landcare research describes gley as follows: Gley Soils, together with Organic Soils, represent the original extent of New Zealand wetlands, which have been greatly restricted in area by drainage. Gley Soils are strongly affected by waterlogging and have been chemically reduced. They have light grey subsoils, usually with reddish brown or brown mottles. The grey colours usually extend to more than 100 cm depth. Waterlogging occurs in winter and spring, and some soils remain wet all year.

The GHD study excluded potential volcanogenic sources of inorganic sulfide such as volcanic ash which they note, ‘may supplement the soil with sulfur-rich content’, due to the uncertainty of extent and thickness. Furthermore, the study included generally sparse sampling and laboratory testing and, therefore, it was recommended that site specific investigations be carried out for high risk areas where development activities may take place.

The study indicates that Australian guidance (WQA, 2018) on the management of acid sulfate soils could be adopted in the absence of any formal national of regional guidance in New Zealand. Including the following relevant activities:

- Road/rail construction.
- Alteration of surface water or groundwater and flows, drainage projects, dewatering, or pumping which may reduce groundwater levels.
- Agriculture which may disturb or drain.
- Laying utilities, dam construction, foundations.
- Filling of ground which may result in changes to groundwater conditions, displacement and heave.
- Stockpiling, management and re-use of acid sulfate soils.

7.4.2 Acid sulfate potential in the ICMP area

The GIS layer created by GHD for the Acid Sulfate Soils Survey has been compared to the current ICMP area, geomorphic zones described in Section 3.1 and is shown in Figure 7.8. The GIS layer indicates the following:

- High potential for acid sulfates was located in the central and southern areas of the Waitawhiriwhiri catchment (consistent with the peat geomorphic zone).
- Medium potential for acid sulfates was located in the Waitawhiriwhiri and hospital tributary gullies, as well as within the Waikato Riverbanks (gullies/river terrace geomorphic zone).
- Low potential for acid sulfates was located in the north of the Waitawhiriwhiri and most of the City Centre catchment (alluvial plains geomorphic zone).
- Negligible potential for acid sulfates was located within the elevated low hills (low hills geomorphic zone).

It is important to consider the limitations of the study as these apply to the ICMP (refer discussion in Section 7.4.1). A single ground truthing test location[13] at Innes Common (peat soil) tested lower than the adopted threshold for chromium reducible sulfur (CrS), with GHD stating that ‘the sample was not considered immediately as potential acid sulfate soil’ but was overall still considered to be within the high potential category based on its swamp/peat environment. Furthermore, the same sample did not meet the threshold for being highly acidic or ‘actual acid sulfate soil’ – suggesting that the sample was not an acid sulfate soil. However, following table 2.1 of the Australian Guidance, the Rukuhia Swamp does represent an area where acid sulfate soils are commonly found and further sampling and testing would be required to properly assess if they are present or not.

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[13] Location 64B (Peat profile at Innes common). Potential acid sulfate: @ 2 m depth CrS = <10 mole H+/t, below the threshold of 18 mole H+/t. Actual acid sulfate: @ 1 m depth, pH = 6 and @ 2 m depth pH = 5.7, both below the threshold of actual acid sulfate (pH<5) or highly acidic (pH<4).

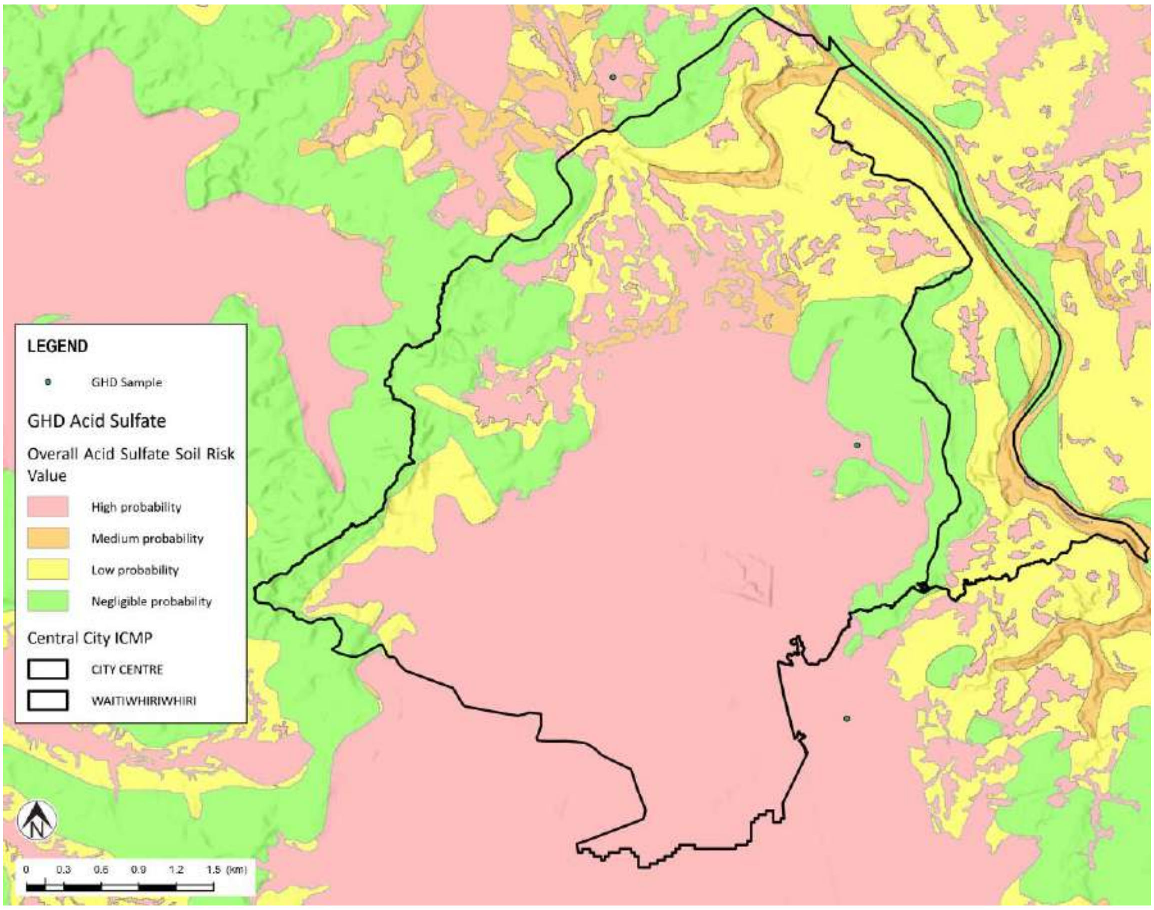

Figure 7.8: GHD acid sulfate soil risk, GIS data supplied by WRC.

7.4.3 Acid sulfate management

In the absence of any formal NZ acid sulfate policy, WRC have provided interim guidance on disturbance of acid sulfate soils during earthworks (WRC Doc #25137403[14]). The guidance covers identification, investigation and management of acid sulfate soils. Suggested controls include:

- Containing spoil, runoff and groundwater discharges.
- Preventing discharges to waterways or other receiving environments.
- Neutralization with lime.

Consideration of other Australian guidelines may also be appropriate, including:

- National Acid Sulfate Soils Guidance and Identification Manual (WQA, 2018).

Further discussion of acid sulfate issues, effects and potential management considerations for the ICMP are provided in Section 9.

7.5 Expansive soils

Expansive soils are those which may undergo significant volume change (e.g., shrink/swell) in response to variations in moisture content leading to potential damage of structures founded in these soils.

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[14] WRC, Guidance for acid sulfate soil disturbance during earth works activities. WRC Doc #25137403

Expansive soils (also termed reactive soils) typically include highly plastic clay dominated soils, particularly those rich in montmorillonite or smectite clay minerals (BRANZ, 2008), (Roberts, Ge, Du, & Khalili, 2019). The reactive depth of the soils generally includes the upper few metres of the soil profile which experience variable moisture conditions in response to environmental and climatic/seasonal conditions. The reactive depth ends where moisture conditions become constant.

The factors contributing factors to expansive soils include:

- Clay composition (mineralogy).
- Proportion of clay.
- Amount of moisture change.
- Loading and lateral restraint.

As discussed in Section 3.2, thick sequences of clay (weathered tephra) are found in the low hills landforms of the ICMP catchment (Hamilton Ash, and Kouroa Ash). The tephra sequences are indicated to be rhyolitic in origin and dominated by clay comprised of halloysite and subordinate amounts of allophane (Lowe & Percival, 1993).

Research undertaken by the University of Waikato (Moon V. , 2016) suggests that halloysite has a low plasticity index reflecting a low shrink/swell potential.

The authors are unaware of any documented issues within Hamilton City that have been attributed to the presence of expansive soils.

8 Groundwater and stormwater management considerations

Management of activities associated with groundwater and stormwater within the catchment requires consideration as some activities may have potential impacts on land, structures and infrastructure.

The suitability of the discharge of stormwater via soakage will require different considerations depending on the underlying geology and sediments. While soakage generally has positive effects in terms of recharge to the underlying groundwater system and reduced loading on infrastructure, the concentration of soakage in certain areas (e.g., gullies, slopes) may have potential effects on other areas within the catchment.

Dewatering of groundwater within the catchment can have an effect on the hydrogeologic properties of sediments within the catchment. The magnitude of the effect coincides with the duration, types of soils and the reduced level.

The catchment lies primarily within the ‘Hamilton Basin – West” aquifer management area defined in the Waikato Regional Council aquifer maps[15] and has a defined management level of 37,500,000 m^3/annum.

8.1.1 Peat soils

Peat soils can be negatively impacted by reductions in groundwater levels. Increases in impermeable surfaces can limit rainfall infiltration and result in a lowering of the groundwater level within the peat soil. By reducing the water level oxidation and degradation of peat soils can be triggered. This can in turn result in settlement of the ground, generation of acidic minerals within the peat and release greenhouse gases. Similarly, dewatering of peat (e.g., drainage swales, construction activities) can have similar effects with the magnitude governed by the duration and level of

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[15] Waikato Regional Council, 2024. Waikato Regional Plan. Module 3 – Water Module, Section 3.3 Waikato Regional Plans - Waikato Regional Plans.

dewatering. These soils are commonly found in areas with shallow groundwater which support wetland and ecological habitats.

Management of peat soils should include an initial understanding of the groundwater levels through monitoring in areas of development so that a neutral (or even increase) effect on groundwater levels can be achieved. This may be achieved through level controls in the drainage network and adoption of stormwater soakage to offset the impacts of intercepted rainfall from increased impervious areas as well as avoidance of prolonged dewatering activities. Where dewatering may be required to facilitate future development (i.e., underground infrastructure), maintaining groundwater levels away from the dewatered location should be targeted and mitigations used to limit any of the impacts (e.g., circulate water back into/on to the ground, limiting area of works).

Where economical, removal and replacement of the peat soils could be considered for isolated/small scale structures, however removal of the peat soils may also trigger oxidation and generation of greenhouse gas emissions.

Dewatering of peat soils either directly or indirectly requires careful consideration and assessment by geo-professionals, hydrogeologists and/or ecologists to understand the potential magnitude and extent of the effects.

8.1.2 Hinuera Formation soils/alluvial plains

The alluvial plains comprise stratified layers of soils which have variable soakage potential. Higher permeability layers (e.g., sands, gravels) can have suitable soakage properties but can be separated by lower permeability layers (e.g., silts, clays) which inhibit vertical infiltration of groundwater.

Due to these properties the suitability of soakage can vary considerably over short distances. Care should be exercised where soakage is proposed above existing slopes. Water that is discharged into the ground can flow horizontally along more permeable layers to where they daylight at side slopes. Where volumes of water are increased or concentrated (i.e., soakage device), seepage can occur on the slope face. This seepage can erode the surficial soils, triggering instability (e.g., landslides) and increase sediment loads within streams. Similarly, the concentrated discharge of water onto slopes directly can trigger similar effects.

Management of these soils should include an assessment by a suitably qualified and experienced professional to confirm of the suitability of the sediments for soakage capacity. Where soakage is considered above or near gullies or slopes, the effects of soakage on the stability and erodibility of the slope should be assessed. Where applicable controls should be implemented to manage these effects. Some controls may include soakage exclusion zones, limiting the rate of soakage (i.e., attenuation) near to gullies, diversion of stormwater to reticulated networks, or discharging directly to the base of the slope. Direct discharge to the base of a slope may have additional effects on receiving surface water body (e.g., stream) such as water quality impacts, erosion, etc. Away from slopes, the sediments are generally considered to be favourable to stormwater soakage. Due to the inherent variability of the sediments, specific testing is required to confirm the design of soakage devices.

Dewatering activities may have wide zones of influence depending on the duration and rate of water abstraction. Control on dewatering activities is via the regional plan and associated groundwater take rules.

8.1.3 Walton Subgroup/low hills

The surficial soils of the low hills typically comprise soils with low soakage potential (e.g., Silts, Clays). The use of stormwater soakage systems within these soils is not likely to be favourable. Alternatively, management devices may need to consider lower discharge rates. These characteristics are favourable with respect to excavations and groundwater management during construction as inflow rates would be expected to be low.

9 Development controls and considerations

Table 9.1 & Table 9.2 are presented below and discuss development controls and considerations for the ICMP. Table 9.1 summarises existing issues, effects and existing development controls for the ICMP based on our understanding of constraints which are discussed in Sections 7 and 8. Table 9.2 presents a summary of proposed management considerations for the ICMP development.

Table 9.1: Summary of issues, effects and existing development controls for the ICMP

Issue	Relevant geomorphic zone	Effect	Existing development controls
Saturated, susceptible soils subject to sufficient earthquake shaking can lead to liquefaction, lateral spreading and cyclic softening.	Possible in all zones. Highest vulnerability found in the alluvial plains, followed by peat, gullies/river terraces, and the low hills.	Damage to: - Infrastructure. - Buildings. - Land.	The HCC Operative District Plan (ODP) does not currently provide a hazard zone for liquefaction or lateral spreading vulnerability under Chapter 22 (natural hazards). Subdivision natural hazard provisions of RMA s106[16]. Building Regulations B1[17].
The creation of free-faces for the purposes of swale or wetland construction can exacerbate lateral spreading risk.			
The river slope and gully slopes of the Waitawhiriwhiri stream and hospital tributaries are susceptible to landslides and this can be exacerbated by saturation of slopes, earthworks, vegetation clearance, erosion at the toe, uncontrolled stormwater discharge.	Gullies / River terraces.	Damage to: - Infrastructure. - Buildings. - Land. - Closed landfills. Landslide debris inundation leading to: - Loss of amenity. - Effects on receiving environment. - Stream/culvert blockage and flood effects.	ODP Gully Hazard Zone (GHA). - ODP General Standard 4.4.6 Building Setback requires a 6 m setback from GHA. - Site management plan (SMP) must be provided for any development within the Waikato Riverbank and Gully Hazard Area and 6m setback. The SMP must be prepared by an appropriately experienced and qualified practitioner and consider 'land instability'. Willoughby Street Closed Landfill Aftercare Management Plan (AMP)[18]. Building regulations B1[17].
		Exacerbation of hazard through increased erosion.	
		Exacerbation of hazard from aging (leaky) infrastructure.	
Peat soils are susceptible to settlement in response to loading or the lowering of groundwater.	Peat.	Damage to: - Infrastructure. - Buildings. - Land.	There are no specific engineering controls for peat in the HCC ODP other than where these intersect with any wetlands or peat lakes, which require: - Policy objective to preserve peat lake/wetland environments, including maintaining groundwater to mitigate 'differential shrinkage' (ODP 20.2.4) - 50 m offset to buildings from peat lake/wetland environments (ODP 20.4.1) WDC Operational District Plan (WDC ODP) does contain some controls for peat soils: - Policy objective to protect peat soils (WDC ODP 15.3.5.4) - Discretion over use of peat soils in the rural zone to maintain sustainability (WDC ODP 21.1.4.33). WRC Regional Plan (WRC RP) contains a policy objective to: - 'Manage the adverse effects of activities resulting from use and development of peat soils, including by slowing the rate of subsidence and the loss of carbon by oxidation from peat soils' (LF-P10-Peat soils). Waikato Regional Infrastructure Technical Specifications (RITS, 2018) provides some basic design guidance for peat stormwater recharge (4.2.15.1). Building regulations B1.
Peatlands are the largest natural terrestrial carbon store. Lowering of groundwater leads to aerobic conditions.		Increase in councils net GHG emissions.	

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[16] Section 106 of the RMA allows a territorial authority to deny or impose consent conditions for subdivision land development to prevent or mitigate the potential adverse effects of natural hazards on people and property.

[17] The NZ Building Regulations: 'B1 Structure clause' ensures that people who use a building can do so safely and without injury. The regulation requires that all structures must be built to withstand potential forces they could be subject to, including potential impacts to foundations (e.g. liquefaction and lateral spreading) or other natural hazards (e.g. landslides).

[18] The AMP (Rev. 6, dated April 2024) provides guidance on how the site will be managed to ensure compliance with resource consent conditions, and to minimise the effects of discharges from the site on the environment. It focuses on risk management and the processes involved in ensuring that activities carried out on the landfill do not have unacceptable effects on the environment or on the public. In particular, "*If erosion or instability of the gully slope or the stream bank is observed, the effects of this on the integrity of the landfill shall be assessed. If the integrity of the landfill is considered to be at imminent risk, then steps shall be taken by HCC to reduce this risk and minimise effects on potential receptors*".

Issue	Relevant geomorphic zone	Effect	Existing development controls
Potential acid sulfate soils can acidify groundwater when oxidised due to dewatering.		Damage to infrastructure. Effects on receiving environment. Localised fish kills.	No existing specific acid sulfate controls in the HCC ODP, WDC OPD or WRC RP However, some related peat or wetland policy objectives and controls in the WDC ODP, and WRC RP (refer above). WRC provides some interim guidance on the management of acid sulfate soils (WRC Doc #25137403, and on their website[19]). Building regulations B2[20].
Stormwater Infrastructure/management devices that are under designed due to insufficient capacity/soakage.	All zones.	Damage to: - Infrastructure. - Buildings. - Land. Flooding and increased pressure on Council network. Increased overall flow and velocities.	Building Code E1[21]. Regional Infrastructure Technical Specifications (RITS, 2018). Waikato Regional Council - Waikato stormwater management guideline (May 2020). Review of stormwater designs by HCC Development Engineers. HCC's Comprehensive Stormwater Discharge Consent (CSDC).

Table 9.2: : Summary of issues, mitigations and implementations for the ICMP

Issue	Potential mitigation options	Potential implementation options
Saturated, susceptible soils subject to sufficient earthquake shaking can lead to liquefaction, lateral spreading and cyclic softening.	Liquefaction vulnerability assessment undertaken to the appropriate level of detail in accordance with MBIE 2017 to support resource consents and building consents. Particular focus on infrastructure which may not require a building consent, e.g., underground services. Reduce areas requiring detailed liquefaction assessments by undertaking higher level of liquefaction vulnerability assessment	Development control: - Current: Liquefaction assessment to be required at the time of resource and building consent applications. Other action: - Update to the Hamilton liquefaction vulnerability assessment to include updated investigation data, groundwater information and seismic hazard updates to potentially remove some parts of the catchment from requiring detailed liquefaction assessments. Updates to liquefaction data will have benefit to many parties within HCC including, development engineers, planning, building services and the civil defence team. Estimated costs for updates could range from $50,000 to $150,000 depending on scope.
The creation of free-faces for the purposes of swale or wetland construction can exacerbate lateral spreading risk.	Lateral spreading assessment undertaken to the appropriate level of detail in accordance with MBIE 2017 to support resource consents.	Development control: - Current: Lateral spreading assessment to be required at the time of resource and building consent where discretion allows, for scenarios where free faces are to be constructed.
The river slope and gully slopes of the Waitawhiriwhiri stream and hospital tributaries are susceptible to landslides and this can be exacerbated by saturation of slopes, earthworks, vegetation clearance, erosion at the toe, uncontrolled stormwater discharge (e.g. where stormwater is being discharged on, or near to, the slope without appropriate design or control).	Earthworks and building subject to specific assessment by a geotechnical engineer where proposed within the Combined Slope Assessment Line (as defined in section 7.2.3). Stormwater soakage devices subject to specific assessment by a geotechnical engineer where proposed within the Combined Slope Assessment Line (as defined in section 7.2.3). Overland flow paths to gully slopes subject to engineering assessment. Mitigations in response to the Willoughby Street Closed Landfill Aftercare Management Plan (AMP) – Note: addressing slope stability concerns would improve the landfill integrity, reduce potential mobilisation of soil contaminants, and reduce leachate generation (if stormwater infiltration mitigations are included).	Development control: - Slope stability and overland flow assessments proposed to be required at the time of resource and building consent for all earthworks, buildings and stormwater disposal devices proposed within the Combined Slope Assessment Line where discretion allows (refer other action). Council programmes: - Current LTP funded project to carry out all necessary slope stability mitigations for the Willoughby Street Closed Landfill as part of ongoing AMP works. Other action: - HCC to consider adopting the Combined Slope Assessment Line as an alternative to the GHA. - Community gully replanting projects.

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[19] https://www.waikatoregion.govt.nz/environment/land-and-soil/managing-land-and-soil/managing-acid-sulfate-soils/

[20] The NZ Building Regulations: 'B2 Durability clause' requires that all structures must be built to satisfy the performance requirements of the code throughout its intended life, commonly referred to as the durability period. For example, acid sulfate soils may present aggressivity risks to concrete or steel within foundation structures.

[21] The NZ Building code clause 'E1 Surface Water' requires buildings to be constructed to protect people and other property from the adverse effects of surface water and that disposal methods do not compromise the integrity of any other property. E1 also provides performance standards for stormwater disposal and overland flow provisions if capacity is exceeded.

Issue	Potential mitigation options	Potential implementation options
	Prioritisation of erosion control measures in affected areas using stormwater master plan viewer and RGEA stream walkovers/gully reach stability assessments to identify risk areas.	Council programmes: - Budget provisions be made in the LTP to construct erosion protection measures as part of the City-Wide Waters programme. Identification and prioritisation of measures to be based on RGEA walkovers/gully reach stability assessments and erosion hotspot data. Note: projects and costs estimates are identified in the T+T Receiving Environment Report. - Current RGEA monitoring and assessment of gully reach stability being undertaken in tandem with erosion hotspot mapping. Review of methodology and workflow to address identified issues also being carried out.
	Use of stormwater viewer to prioritise asset maintenance issues in Long Term Plan.	Council programmes: - Budget provisions be made in the LTP to maintain aging infrastructure construct erosion protection measures as part of the City-Wide Waters programme. - Identification of issues based on ageing or damaged water infrastructure adjacent to gully and riverbank areas as part of the current Infrastructure Programme
Peat soils are susceptible to settlement in response to loading or the lowering of groundwater.	Specific development controls where a site is underlain by peat soils as defined in section 7.3.2: - Earthworks filling operations subject to settlement assessment including cross boundary effects. - Cuts limited to the unsaturated zone. - Infrastructure subject to specific engineering design. - Any activities that may either temporarily or permanently lower the groundwater level subject to dewatering settlement assessment. - On-lot soakage required to recharge peat. <u>Wider management through HCC District Plan Provisions amendments</u> - Reclassification of Rukuhia peat swamp as wetland or peat lake environment. - Inclusion of limits on earthworks in wetland and peat lakes. - Development of specific peat controls.	Development control: - Geotechnical investigation to assess nature and extent of peat soils and depth to groundwater to be required at time of resource consent and building consent where discretion allows. - Require all development to maintain post-development groundwater at pre-development levels Other action: - Consider requirement for a peat management plan (PMP), or similar, to be required at the time of resource and building consent where discretion allows, to include assessment and design considerations for earthworks, groundwater, filling, settlement and structures within peat soils areas. - Consider reclassification of the Rukuhia peat swamp (where it extends into the ICMP) as wetland or peat lake environment (or new 'peat environment' for example) through a plan change process (change to overlay). This may require Waipa DC and HCC consensus/uniformity. - Consider developing specific peat controls similar to Waipa DC in the HCC proposed DP. - Programmes for wetland/peatland restoration and rehabilitation, including potential land acquisition.
Peatlands are the largest natural terrestrial carbon store. Lowering of groundwater leads to aerobic conditions and release of carbon to the atmosphere		
Potential acid sulfate soils can acidify groundwater when oxidised due to dewatering.	Sub-catchment-wide testing programme to better understand risks outlined by WRC Acid Sulfate Soils assessment. On lot assessment of effects on groundwater levels in areas of potential acid sulfate soils as defined in section 7.4.2. Follow WRC interim guidance (WRC Doc #25137403, and WRC website[19]) or subsequent update plus specific assessment in general accordance with WQA 2018 of potential acid sulfate soils where lowering of groundwater is expected. On lot management plan for impact of actual acid sulfate soils where confirmed via laboratory testing and groundwater level assessment.	Development control: - Geotechnical/geoenvironmental investigation to be required at time of resource and building consent where discretion allows. - Require all development to maintain post-development groundwater at pre-development levels Other action: - Consider requirement for a peat management plan (PMP), or similar, to be required at the time of consent where discretion allows, to include assessment and design considerations for earthworks, groundwater, filling, settlement and structures within peat soils areas. - Consider reclassification of the Rukuhia peat swamp (where it extends into the ICMP) as wetland or peat lake environment (or new 'peat environment' for example) through a plan change process (change to overlay). This may require Waipa DC and HCC consensus/uniformity. - Consider developing specific peat controls similar to Waipa DC. - Consider undertaking a wider programme of sampling and testing to ground truth WRC Acid Sulfate Soil assessment with the intention of narrowing the areas requiring detailed assessment at the time of consent. However, residual uncertainty may mean that site specific testing could be required in any case. - Request that WRC publish their assessment data as a GIS layer. - Adopt and promote WRC guidance for the management of Acid Sulfate Soils

Issue	Potential mitigation options	Potential implementation options
Stormwater Infrastructure/management devices that are under designed due to insufficient capacity/soakage.	Allowance for seasonal variation and use of winter groundwater levels. Soakage design to consider the final levels and soakage potential of the soils present post-earthworks. Stormwater soakage devices subject to specific assessment by a geotechnical engineer where placed within the Combined Slope Assessment Line as defined in section 7.2.3.	Development controls - Geotechnical investigation to be required at the time of building consent, particularly where devices are proposed within the Combined Assessment Line, or where peat soils are present - where discretion allows. Particular focus should be on suitable soakage testing, placement and design. Other action - Request update to Regional Infrastructure Technical Specification (RITS, 2018) to incorporate more detailed guidelines on soakage testing and placement of soakage devices, particularly where peat soils are concerned. - Consider update of Hamilton groundwater modelling to take seasonal variation into account, depending on scope and availability of data this may cost in the order of $20,000 to $60,000.

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11 Applicability

This report has been prepared for the exclusive use of our client Hamilton City Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

We understand and agree that this report will be used by Waikato Regional Council in undertaking its regulatory functions in connection with HCC's comprehensive stormwater discharge consent.

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