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A PRELIMINARY ASSESSMENT OF GEOLOGICAL FACTORS INFLUENCING SLOPE STABILITY AND LANDSLIPPING IN AND AROUND TAURANGA CITY.

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SUMMARY

Tauranga City occupies parts of three promontories extending into Tauranga Harbour, a drowned Pleistocene river basin. The basement to the basin consists of a number of hard resistant volcanic rock units formed principally in the time interval 1 to 6 million years before the present day. The basin is partially infilled by soft, weakly consolidated fluviatile and estuarine sediments, the Tauranga Formation, overlain by weathered and unweathered volcanic ash.

Both deep-seated and shallow mass movements have occurred in the rock units infilling the basin. Deep-seated failures are confined to areas adjacent to the seacliff where the weathered, clay-rich older volcanic ashes are very thick or the Tauranga Formation is unusually clay rich. Superficial failures (1-2 m deep) are more widespread occurring on sloping ground especially when a thin cover of ash overlies coherent basement rock. Both types of failure are closely related to periods of high rainfall. Factors influencing deep-seated failures are soil conditions, cliff height, rainfall, marine erosion, and urban development. Factors influencing shallow failures are soil conditions and structure, slope, rainfall and excavations and road constructions. Storms of the intensity of the March 1979 rainstorm which caused widespread landslipping in the district have a return period of nearly 100 years which may be sufficiently long to exclude them from practical planning considerations. The effects of storms with a shorter return period are insufficiently well known at present.

Further work could include lines of investigation to quantify landslip risk and lines of action to minimise risk and damage and to monitor groundwater conditions. It is worth considering delaying any action on the latter until the findings of the Abbotsford Commission are released but if council desires a start could be made to further investigations to clarify landslip risk in the city.

1.0 INTRODUCTION

This report outlines the geology of Tauranga City and makes some initial conclusions concerning landslipping and slope stability. The contents are based on reconnaissance mapping by B.F. Houghton prior to completion of a 1:50 000 geological map of the area and data from warm water drill holes in Tauranga basin. A map showing possible and probable landslides existing within the city in 1959 has been prepared from vertical aerial photography by B.D. Hegan. Some specialised information is drawn from detailed investigation of similar landslipping involving the same stratigraphic units at Omokoroa. This work was performed jointly by B.F. Houghton and C.P. Gulliver of Tonkin and Taylor.

The report arises out of a request for advice from the City Engineer to B.F. Houghton.

1.1 Regional Setting

Tauranga is constructed on three adjacent promontories extending into southern Tauranga Harbour (Fig. 1). Tauranga Harbour forms part of an actively subsiding basin formed probably in the last one million years and now partially infilled by a sequence of terrestrial and estuarine sediments and overlying rhyolitic volcanic ashes. The basin was in the past occupied by a major river system and continued subsidence and migration of river channels together with glacial fluctuations of sea level have produced a complex variety of sedimentary rock types. The promontories extending in the harbour probably represent ridges between major channels active late in the sedimentary history of the basin.

1.2 Physiography

Most of Tauranga City lies above 10 m elevation and below 50 m. A discontinuous seacliff is present around most of the coastline ranging in height up to 25 m. Particularly steep cliffs occur on the western tip of Otumoetai peninsula (Matua), on both coastlines in the central portions of Tauranga peninsula and at the northern tip of Maungatapu Peninsula. The land surface slopes gently towards the ridge crests behind the seacliff on all three peninsulas. Remnants of a low (approximately 2 m) marine terrace are present around the coastline in places intervening between the former sea-cliff and the modern shoreline. South of Greerton and Welcome Bay steeper slopes are encountered particularly in the rolling Papamoa Hills.

2.0 STRATIGRAPHY

We can conveniently subdivide rock units of Tauranga Basin into two groups, a basement sequence of units which defines the basin and a cover sequence which partially infills the basin (Fig. 2). The basement consists of representatives of three distinct rock units; Coromandel Group, Minden Rhyolite, and Waiteariki and Papamoa Ignimbrites.

2.1 Basement Sequence

2.1.1 Coromandel Group

The Coromandel Group, formerly known as Beeson's Island Andesites, is an assemblage of andesitic to dacitic lavas, breccias, and minor related terrestrial sedimentary rocks. The group is exposed in the Kaimai Range west and south of the city and in the Papamoa Hills south-east of Tauranga. The andesites also form Motiti Island and an isolated rock on the harbour side of Matakana Island, suggesting they underlie the basin at depth.

The Coromandel Group is the oldest stratigraphic unit exposed in the Tauranga area and was erupted approximately twenty to six million years ago, during a period of widespread volcanic activity of the type now seen in Tongariro National Park.

2.1.2 Minden Rhyolite

A number of bodies of rhyolitic lava were erupted at the surface in the Tauranga basin towards the end of the deposition of the

Coromandel Group. These form the rounded hills on the Tauranga skyline; Mt. Maunganui, Kairua, Kopukairoa, and Mount Minden. Other rhyolite bodies were subsequently buried by the Tauranga Formation or by eruption of ignimbrites and their presence is inferred only from drill holes. The rhyolitic bodies are principally volcanic domes - steep-sided, rounded masses of lava extruded from underlying vents although lava flows, elongate tongues of solidified lava, are associated with the larger bodies. Many of the Minden Rhyolite bodies are now partially buried by younger deposits, e.g., the Mt. Minden body is known, from drill holes, to extend northwards beneath Te Puna at depths up to several hundred metres.

2.1.3 Ignimbrites

Large volcanic eruptions from undetermined sources between 1.0 and 0.75 m.y. ago produced extensive sheet-like deposits of volcanic rock in parts of the Tauranga Basin. The deposits consist of large particles of pumice and dense volcanic rock (up to 30 cm in diameter) set in sand- and silt-sized volcanic ash. The ignimbrites are soft and unconsolidated in their upper parts but retained sufficient magmatic heat for particles in the bases of the units to weld together to form a strong, coherent rock. Two ignimbrites are exposed close to Tauranga City. The Waiteariki Ignimbrite forms the Whakamarima Plateau and dips gently eastward beneath the basin. It has been found at depths of 130 m to 200 m in drillholes at Te Puna and Otumoetai. The Papamoa Ignimbrite is exposed south of Welcome Bay Road in all the river valleys between Kaitemaiko Road and Reids Road.

The Waiteariki Ignimbrite is a dark grey to pink rock containing strongly flattened grey pumice fragments in a lighter coloured matrix. Much of the soft, easily weathered top has been stripped from this unit leaving the considerably harder base.

The Papamoa Ignimbrite is a soft, welded unit containing dark grey to black pumice particles in a brown ash matrix.

2.1.4 Relationship of basement units to landslipping

The Coromandel Group, the Minden Rhyolites and the ignimbrites are all strong coherent rock units and are generally not involved in the superficial mass failures in the Tauranga area. Where the Tauranga Formation is absent and the cover consists of a thin (1-5 m) sequence of weathered and unweathered volcanic ash the contact between the ashes and the coherent underlying basement frequently acts as a plane of failure. Many of the failures in March 1979, particularly in the Papamoa Hills, were of this type. This will be discussed in more detail in subsequent sections.

2.2 Cover Sequence

The cover sequence which partially infills the Tauranga Basin consists of four units:

(1) Tauranga Formation,
(2) Old (pre 42 000 year) weathered rhyolitic ashes,
(3) Rotoehu and younger (post 42 000 year) unweathered rhyolitic ashes,
(4) post-glacial terraces deposits.

2.2.1 Tauranga Formation

A sequence of terrestrial and estuarine sediments partially infills Tauranga Basin reaching a maximum thickness of greater than 200 m. The sediments overlie the ignimbrite basement and lap onto and partially bury the Minden Rhyolite lava domes. The sequence, which accumulated under conditions of lowered sea level when a major river system occupied Tauranga Harbour, shows great variability. The wide range of lithologies present includes sorted, often cross-bedded sandstones and conglomerates (river channel deposits), carbonaceous and diatomaceous sandy siltstones (river over bank, lacustrine and estuarine deposits), well sorted sands rich in shell fragments (beach deposits), peat and white clay-stones (swamp and lacustrine deposits), and reworked volcanic ash. Many of the particles making up the sediments consist of pumice or related crystal fragments. The rock types are consistent with an ancient river/estuary system affected by an influx of volcanic detritus following each major explosive eruption in the Rotorua-Taupo region.

The vertical succession of rock types at each place was affected by:

(1) migration of river channels across the basin with time, and

(2) sea level changes with time, in response to glaciation.

The wide range of lithology in the Tauranga Formation is reflected in the ranges of physical properties particularly strength and permeability. Permeability of the formation in areas where it is dominated by sandstone and conglomerate is high in other areas where original grainsize is smaller or degree of weathering greater permeability is low.

2.2.2 Older ashes

A sequence of partly eroded and highly weathered airfall rhyolitic volcanic ashes from a source(s) outside the Tauranga Basin overlies the Tauranga Formation. Thicknesses of up to 15 m have been measured. A complex history of weathering and partial redistribution by erosion, accompanied their formation so that at many sites a large proportion of the original sequence is missing. The ashes were probably originally of sand to silt size but extensive weathering has now converted the majority of the ash particles to clay minerals. The principal clay species present is halloysite, a mineral with limited swelling properties.

2.2.3 Rotoehu and younger ashes

A sequence of young, unweathered rhyolitic ashes between two and four metres thick occurs beneath the modern soil over much of the Tauranga Basin. These ash units are the products of violent explosive eruptions from Haroharo and Tarawera volcanoes over the last 42 000 years. The most prominent unit is the 42 000 year old Rotoehu Ash formed during eruptions which laid down the fan-like Rotoiti Breccia between Lake Rotoiti and the Bay of Plenty coast. The ashes were transported for long periods through air and were well sorted during transportation. Field evidence suggests that the younger ashes are highly permeable and therefore have a major effect on surface hydrology in the basin.

2.2.4 Post-glacial terrace deposits

Remnants of a low (2-4 m) marine terrace occur around the shoreline of Tauranga Harbour. The terrace deposits consist of silt and sandy silt, rich in marine fossils, which overlies fresh rhyolitic ash (that probably correlates with the younger ashes). The deposits probably formed during a post-glacial highstand of sea level. Their low elevation means they are not involved in landslipping and they are not considered further.

2.2.5 Relationship of landslipping to cover units

Almost all landslip failures in the Tauranga Basin have occurred within the older ashes, in clay-rich portions of the underlying Tauranga Formation or in fill material probably derived from these units. Results of investigation of Omokoroa landslips of August 1979 suggest the lower, older ashes in Tauranga Basin are a loosely bound aggregate of small clay particles with large void spaces and a high water content (I. Smailley, pers. comm.). Inter-particle forces are very weak and on disturbance the structure collapses catastrophically and the ashes liquify. The ratio of undisturbed strength to strength on remoulding is very high for this material and for clay-rich portions of the Tauranga Formation such that they could be classified as 'quickclays'. Failure is sudden and strength loss after failure is very great. Where the older ash sequence is thick the lower older ashes are probably below the water table for much of the year, and therefore water-saturated. Quite small changes in groundwater levels could initiate failure under these conditions. Landslip failures in Tauranga during 1979 span a continuous spectrum of types but it is convenient to consider two types of failure. One type consists of shallow failures where a thin soil fails on a more resistant plane within the subsoil or basement. The second type is the deep-seated failure within the lower older ashes or Tauranga Formation in areas with a high seacliff as seen below Te Hono Street Maungatapu and Omokoroa.

3.0 LAND INSTABILITY

3.1 Deep-seated failures

The deep-seated failures of the type experienced at Maungatapu in March 1979 and Omokoroa in August 1979 result from sudden catastrophic transformation of a soil layer into a liquid of highly sensitive material at some depth beneath the land surface. The transformation is probably initiated by excess pore water pressure. Overlying coherent material then fails under tension in a more brittle fashion as it is rafted downslope on the thin layer of liquidified material. There are few, if any, precursory indications of the failure and movement is complete in minutes. The failed material forms a flat tongue-like deposit at the base of the cliff and leaves an arcuate scarp on the cliff-face. The flows combine features of flow slides (sudden failure, high velocity, flat profile of deposit) and translational or rotational slides (ordered deposits, limited disturbance of grass soles and shrubs on top of the failed mass). This type of failure is very different from the slower type of bedding-plane failure, as seen at Abbotsford where initiation of failure is slow, movement of the failed mass may occur over several days, and precursory signs are common.

The role of shallow groundwater levels is critical to these deep-seated failures initiated by excess pore water pressure. Failure may be related to exceptionally high intensity rainstorms or to high cumulative rainfall over an extended period of several months or to any other factor which raises the groundwater level. The probability of deep-seated failure at a site may be assessed if ground water levels are monitored and liquid limits of the soil materials known.

3.2 Superficial failures

The majority of the failures at Tauranga in 1979 were of shallow origin produced when a portion of the regolith became water saturated and failed at the contact with an underlying more coherent or less permeable zone. The depth of such failures is generally less than 2 m even on steep cliffed slopes where failures may superficially appear to be deep-seated. The failures typically have a 'tear drop' form but the mechanism of failure varies with physical properties of the failed material - from flow slides in highly weathered clay-rich horizons to slumps and rotational slides. This type of failure is generally directly related to a high intensity rainstorm and there are no monitoring measures to predict such failures in advance. The extremely high intensity storm of March 1979 produced a monthly rainfall total exceeded only once since 1898 inducing failures in areas stable under conditions of moderate to high rainfall. Events with this frequency i.e. 50-100 years may be too rare to be given major consideration in planning procedures.

Superficial failures are extremely sensitive to any disturbance of the soil or any practise altering soil strength. Removal of trees, alteration of surface drainage and excavations at the foot of a slope are all hazardous on steeply sloping land.

4.0 AERIAL PHOTOGRAPH LANDSLIDE APPRAISAL

Vertical aerial photographs, taken during 1959, giving stereo coverage of Tauranga City at a scale of approximately 1:16 000, were studied; possible and probable deep-seated landslide scarps were identified and marked onto a 1:16 200 base map (Fig. 3). These inferred landslides were recognised by their topography; usually an arcuate main scarp at the head of the slide was the most obvious feature, although at some localities the hummocky topography of the slumped material was recognisable. Many of the landslides are masked by vegetation and modified by erosion or land development.

Subdivision of the inferred landslides into two categories, 'possible' and 'probable' is based on a subjective assessment of the topographic evidence for the landslide. As there have been no field checks carried out the reliability of the analysis is unknown. Further investigations are necessary before any of these features can be positively identified as landslides.

4.1 Distribution of the Inferred Landslides

Nearly all of the inferred landslides are either sited on the seacliff which surrounds most of Tauranga City, or within valleys eroded in land from the seacliff. In fact, an impression gained from viewing the aerial photographs is that landsliding appears to be part of a natural process of extending the head of most of the streams.

The accompanying map of Tauranga city shows the distribution of the inferred landslides. In the suburbs of Matua, Maungatapu and Tauranga Central, the inferred landslides are all sited on the steep seacliff. Elsewhere the inferred landslides are sited inland.

In most of the well established suburbs (Otumoetai, Bellevue, Brookfield, Judea, Tauranga South, Gate Pa, and Greerton) the steep valley sides have formed a natural barrier to urban land development. As a consequence few house properties are sited near landslide scarps. However, in Maungatapu and Welcome Bay more recent subdivisions have been developed on land which has been involved in landslides in the past.

It is difficult, at this stage, to isolate particular factors which may have initiated these inferred landslides. However it is important to recognise that the geological conditions at these old, dormant landslide sites remain constant and it may only require a change in loading or groundwater level to reactivate them. This is supported by the fact that most of the slips that occurred during the March 1979 rainstorm were sited on or near landslides recognised on the 1959 aerial photographs.

5.0 FACTORS INFLUENCING LAND STABILITY

5.1 Deep seated failures

Factors influencing deep-seated failures are:

(1) Geology and soil conditions,
(2) Cliff height,
(3) Rainfall,
(4) Marine erosion,
(5) Urban land development.

5.1.1 Geology and soil conditions

The presence of highly sensitive, halloysite-rich layers in the older ashes and Tauranga Formation is the principal reason for deep-seated slope failures at Tauranga. The delicate structure of these units and their high water content means they experience catastrophic strength loss on disturbance. It should be possible to delineate areas within Tauranga City, where the older ashes are unusually thick and/or the Tauranga Formation relatively clay-rich, as areas of high risk. In these areas the various other factors discussed below may influence slope stability in a variety of ways.

5.1.2 Cli[redacted]

All failures of the deep-seated type have occurred on steep slopes, almost invariably on the seacliff which forms parts of the Tauranga coastline. In any area where other factors suggest a high risk of deep-seated landslips the risk increases with proximity to a seacliff. Analysis of 17 deep-seated failures at Omokoroa reveals there is a close approximation to a height/depth ratio of 2:1. Any formula to delineate a zone of high risk adjacent to the coastline can make use of this relationship and clearly the width of a buffer zone or reserve to protect properties within further subdivisions will increase proportionally with cliff height.

5.1.3 Rainfall

Rainfall, percolating through the relatively permeable younger ashes and infiltrating the clay-rich and less permeable older ashes increases the weight of the material overlying the highly sensitive units and decreases the effective cohesive strength of the latter. When water tables are high a relatively small rainstorm may be sufficient to initiate landslipping as occurred at Omokoroa in August 1979. The history of deep-seated failures in the greater Tauranga area has not been investigated but at Omokoroa the three major periods of landslipping in the last twenty years were preceded by the three highest six-monthly rainfall totals in that period. It would be possible to predict periods of high risk by recording groundwater data and rainfall figures on a long term basis.

5.1.4 Marine erosion

Marine erosion is proceeding at high rates along portions of the Bay of Plenty coast. Where erosion occurs at the base of high sea-cliffs it has two effects. Undercutting by wave action lowers the stability of material adjacent to the cliff and removal of landslip debris means older failures have a limited opportunity to stabilise. Assessment of the rates of marine erosion adjacent to Tauranga City was not possible for this report but such an investigation could be made and may in fact be partly covered by the Bay of Plenty coastal erosion survey made by University of Waikato.

5.1.5 Land subdivision

Subdivision of Tauranga City has had a number of direct and indirect effects on the stability of the peninsula. The most significant effects will be changes to the groundwater hydrology of the area. Domestic waste water is discharged partly by a reticulated sewage scheme and partly by soakhole seepage from septic tanks. Waste water in the area of soakhole discharge increases the total amount of water entering the groundwater regime and also concentrates it locally generally at the level of the older ashes. An evaluation of use of water in the last year would indicate if this is a significant contribution to groundwater relative to average annual rainfall. Experience at Omokoroa indicates in general it is not of significance (equivalent to and less than 10% average annual rainfall) but locally usage rose as high as 25% of annual rainfall. If similar anomalous high values are recorded in areas of Tauranga with a high risk of deep-seated landslipping there is probably a case for voluntary restrictions, at times of extreme risk, until sewage reticulation is completed.

Stormwater from city roads, roofs and private pathways is discharged partly by soakage and partly by stormwater drains and easements. Stormwater discharged by drains to sea level has a beneficial effect of effectively removing a substantial amount of water which would otherwise enter the groundwater budget. Discharge by soakholes does not have a major effect on the quantity of rainwater entering the soil but does rapidly concentrate water at the level of the soakhole, generally within the sensitive older ashes. In areas where landslip erosion risk is high and stormwater discharge from private properties and city roads is by soakholes it is well worth considering installation of a stormwater drain system. The proportion of rainwater removed from the groundwater regime is equivalent to the proportion of total area covered by roadways, roofs and pavement, probably 10-15% of the total. This proportion is possibly a significant factor in inhibiting landslip erosion.

Other effects involve practises used in the land subdivision. Several of the failures in March 1979 occurred either entirely or largely in fill material emplaced during subdivision. Much of the fill material appears to be locally-derived clay-rich material either derived from or closely resembling the older ashes. Disturbance during emplacement and compaction probably means shear strength is appreciably less than the undisturbed older ashes.

Removal of trees from the seacliffs during subdivision has probably also decreased soil strength by reducing water loss by evaporation/transpiration and by destroying root systems which contributed to overall strength of the regolith.

5.2 Superficial Failures

Factors influencing shallow failures are:

(1) soil conditions and structure,
(2) slope angle,
(3) rainfall,
(4) excavations and road construction.

5.2.1 Soil conditions and structure

The principal requirement to initiate shallow failures is soil layers of contrasting properties close to the surface, with either an incoherent layer overlying a more coherent one, or a permeable horizon above a relatively impermeable one. Given this structure and a suitable slope, failure may be triggered by:

(1) a sudden increase in load, e.g. by water infiltration,
(2) a decrease in soil strength due to an increase in pore water pressure, or
(3) removal of support from the toe of a slope.

A suitable soil structure for such superficial failure exists throughout most of the Tauranga Basin. Failure may and has occurred either in the cover sequence, at the permeable younger ashes/impermeable older ashes contact, at several planes of inhomogenity within the older ashes or at the contact between the incoherent older ashes and coherent basement rocks.

5.2.2 Slope angle

Soil on most of the slopes of the Papamoa Hills behind Tauranga and on other hilly areas near the city are stable under dry conditions and during light to moderate rainstorms, but become unstable during extremely heavy rainstorms (such as was experienced in March 1979). Critical slope angles above which failure may occur could be determined by back analysis of existing failures or by reference to aerial photographs taken before and after the rainstorm event.
It may be possible to delineate zones of low to high risk on the basis of slope angle from such a study.

5.2.3 Rainfall

Rainfall plays an obvious and critical role in initiating most superficial mass failures and shallow failures can generally be closely related to specific high intensity rainstorms. Infiltrating rainwater greatly increases both the weight of soil and the pore water pressure and may cause loading past effective strength limits of the soil.

5.2.4 Excavations and road construction

Urban land development may have a number of effects on slope stability. Excavations at the foot of a slope close to the critical slope angle increase the loading on the soil mass up-slope from the excavation. Slipping which occurred immediately above Welcome Bay Road and adjacent to farm tracks leading off Welcome Bay Road were probably influenced by this effect.

Earth movements during land development may also affect the natural patterns of movement of surface water producing ponding and unusual loading. Removal of deep-rooting plant species and replacement with grass and other plants with shallow root systems also decreases soil strength and may render a marginally stable slope unstable.

6.0 DISCUSSION

At this stage investigations to quantify landslip risk and monitor conditions in Tauranga City are necessary. It is probably prudent to delay any modification of city bylaws and regulations, until the findings of the Abbotsford Commission are available. The recommendations of this commission may have far-reaching implications for local bodies. It is possible however to commence detailed investigations to give a clearer picture of landslip risk in Tauranga to use as the basis for further action.

6.1 <u>Further Investigations</u>

This report has outlined the geology of Tauranga City and has commented on possible causes of the landslides within the city. An appraisal of the number and locations of pre-1959 landslides has been made by studying vertical aerial photographs. However a number of points still remain to be examined or quantified to give a clear picture of landslip risk in Tauranga City. Lines of investigation are:

(1) compilation of a history of landslipping prior to 1979,
(2) verification of the inferred landslides identified in this report by field inspection,
(3) reconnaissance study of all landslips produced during March 1979 to determine a representative selection for further detailed investigation,
(4) compilation of data on (i) return period of rainstorms, (ii) the effect of stormwater and domestic waste water on the groundwater budget,
(5) compilation of data on the history of land subdivision and subdivision practices.

It is suggested that (1), (4), and (5) could be undertaken by council staff under direction of a council engineer. However (2) and (3) should be undertaken by either an engineering geologist or geotechnical engineer. This could then be used to establish detailed terms of reference for an investigation by an engineering geologist analysing mechanisms of landslip failure, defining areas of highest risk, and providing proposals for remedial work, monitoring and guidelines for future subdivisions.

7.0 POSSIBLE COURSES OF ACTION

A detailed list of recommendations can only be drawn up after a fuller investigation. However there are some possible lines of action which are already clear. These can be considered in two categories for existing subdivisions and new subdivisions respectively.

7.1 Existing subdivisions

7.1.1 Building Restrictions

The coastal reserves adjacent to seacliffs in some existing subdivisions are insufficiently wide to prevent deep-seated landslip affecting residential properties. In areas where a history of deep-seated failures is established (e.g. [illegible]), a coastal zone where land is vulnerable to such landslipping, can be defined on the basis of cliff height/slip depth ratios. Where building permits have not been granted it could be stipulated that dwellings must be constructed outside this zone. Recent subdivisions in Welcome Bay should be examined by a geotechnical engineer, as the area contains many inferred landslides which may be reactivated by urban development.

7.1.2 Improvement to drainage and stormwater systems

Where a substantial number of houses lie within a zone of high risk of deep-seated failure and storm water disposal is by soakhole, priority could be given for alteration to an alternative method of disposal either by the existing city scheme or additions to it or by piped discharge down the seacliff to high tide level.

With time extensions to the reticulated sewage scheme in Tauranga will also reduce the amount of water entering the groundwater regime and lessen the risk of landslip erosion.

7.1.3 Remedial works

Many of the shallow failures in the district are short-lived features and limited planting on the slip face will help stabilise the landslips. Geotechnical engineering advice should be sought on the stabilisation of the cliffs prone to deep-seated failures such as seen at Maungatapu. Horizontal relief drains designed to lower pore pressure and control groundwater levels may prove effective.

A concerted planting programme on seriously affected cliff faces under the council's control may increase soil strength, increase evaporation/transpiration rates and limit surface erosion. Topping and pruning at regular intervals to prevent weakening of soil through overloading and wind action would be necessary.

7.1.4 Monitoring

Groundwater levels should be monitored in areas of high risk possibly using drillholes completed in the investigation stages. Levels should be recorded regularly on a long term basis and more frequently after high intensity rain storms for comparison with rainfall data. This data would be invaluable in modelling potential failures and identifying areas of high risk.

7.2 New Subdivisions

Land subdivisions adjacent to the seacliff in areas of high risk from deep-seated failure should be planned so as to leave a coastal reserve equivalent in width to the zone of high risk (to be determined by further investigations). Hill slope subdivisions where a potential for landslipping is known should require a written assessment by a competent engineering geologist or geotechnical engineer.

REFERENCES

Gulliver, C.P.; Houghton, B.F. (1980): Omokoroa Point Land Stability Investigation. Unpublished Report to Tauranga County Council.

Henderson, J.; Bartrum, J.A. (1913): The geology of the Aroha Subdivision, Hauraki, Auckland. New Zealand Geological Survey Bulletin 16.