REPORT

Whangarei District Council

Mine Subsidence Hazard
Kamo Area, Whangarei

Tonkin & Taylor

ENVIRONMENTAL AND ENGINEERING CONSULTANTS

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Executive summary

WDC is currently reviewing the District Plan zoning with respect to an area centred on the Kamo commercial centre. Parts of the area under review are designated as Mining Hazard Zones[1] (MHZ) and therefore have certain development limitations not applicable to adjacent areas of otherwise similar character. WDC has commissioned Tonkin & Taylor (T&T) to undertake a review of the limitations on development and possible options for remediation from a geotechnical perspective.

Three MHZ are defined in the Operative District Plan. They represent areas of different subsidence hazard based on an assessment of the nature of the underground workings and the overburden thickness.

It is concluded here that the current MHZ's are appropriate and should remain in-place.

The Operative District Plan does not distinguish the three MHZs in terms of Policy or Rules. The practical implications of these policies and rules to the development of the MHZs are:

- That the subdivision and development of land within a MHZ is to be avoided unless the subsidence hazard can be remediated or mitigated;

- The construction or alteration of a building within a MHZ is permitted as long as the ground conditions and potential severity of subsidence are evaluated; that the structure is appropriate for the inferred level of hazard; and that construction will not increase the likelihood of subsidence occurring.

A considerable number of subdivision, land use and building consents have been issued by the WDC for the MHZs over recent years. This appears to be at odds with previous recommendations by T&T with respect to no further subdivision of MHZ1 and MHZ 2 (T&T, 2005a).

Property loss is the most likely outcome of crown-hole or trough subsidence. T&T (1984) concluded *"that the damage which results from mine subsidence... is not such that it would normally pose any threat of personal injury or loss of life".* Although an injurious or even fatal consequence from the emergence of a crown-hole cannot be ruled out, it would appear that the annualised risk of a person being adversely affected is significantly less than the multitude of other risks that residents face every year.

It is concluded however that the current level of risk within the MHZs is currently unknown.

The probability of a particular building being affected by subsidence within its design life is considered to be small, and potentially negligible. However damage to buildings has occurred in the past and should be expected to occur in the future. Any increase in the number of buildings through future subdivision of the MHZs will result in a corresponding increase the annual risk of property loss above current levels unless some mitigation of the hazard is undertaken.

There are a number of ways by which the mine subsidence hazard could be mitigated. Some have been used in the past to control mine instability and surface subsidence but are hugely expensive. It is likely that mine rehabilitation would require the mines to first be dewatered. Not only is this likely to be an expensive and difficult exercise in itself, lowering

[1] These are referred to as Mining Hazard Zones in the technical documentation and Mining Hazard Area in the District Plan

of the groundwater will increase the likelihood of subsidence occurring, at least until the mitigation work is complete.

It has been concluded that it is not practical or economically viable to mitigate the subsidence hazard by rehabilitating or remediating the mined land.

The design of structures to be resistant to the damaging effects of subsidence, or of a type that can be readily re-levelled (or both) is the most practical means of managing the property loss risk within the MHZ.

It is considered highly unlikely that that the mine subsidence hazard would be affected by the construction of a typical one or two storey structure. The construction of a large commercial or retail building could adversely affect the stability of mine workings, depending on site specific conditions. There is no uniform building density or foundation loading that could sensibly be applied to a broad area such as a MHZ. Large structures or developments would need to be assessed on a case by case basis. Unless workings are very shallow, it is unlikely that construction of buildings or earthworks will trigger mine collapse and surface subsidence.

Surface subsidence above the Kamo mine workings has been an issue from the time of mining operations through to relatively recent times. This hazard can be expected to continue into the foreseeable future. T&T believe that the ongoing subdivision and densification of the MHZ is being undertaken without a full understanding of the current level of risk. This does not infer however that some level of development above the current status is necessarily going to breach some threshold of unacceptability. Nor does this imply that depopulation or abandonment of the MHZs is a necessary or even sensible response.

Given the difficulties associated with determining the actual (quantitative) level of risk present within the MHZs, and how these compare to acceptable, tolerable or unacceptable thresholds, it is recommended that a cautious approach be adopted to the development of the MHZs, particularly MHZ 1 which has been the area most affected by previous subsidence.

Those areas of Kamo located within the MHZ's have the potential to contribute to the future development of the local community. It will be necessary however that future development is cognisant of the presence of the subsidence hazard and that this is reflected in appropriate measures with respect to population density, building types and layout.

1 Introduction

Kamo is a small community located approximately 5km north of the Whangarei CBD. Coal was discovered at Kamo in 1865, however it was not until 1876 that commercial extraction began. Underground mining was subsequently undertaken at a number of locations in and around Kamo between 1876 and 1955. Mining operations ceased when the last underground mine (New Kamo Mine) was closed due to flooding.

Surface subsidence above the Kamo mine workings is understood to have been an issue during the period of mining operations and it has continued into relatively recent times. Following a major subsidence incident in 1980, the Whangarei City Corporation (WCC)[2] commissioned an assessment of the mine subsidence hazard at Kamo (St George, 1981). This work resulted in three mining hazard zones (MHZ)[3] being defined on the basis of the inferred likelihood and severity of future mining related subsidence. Tonkin & Taylor Ltd (T&T) has provided technical and planning reviews on the MHZ for both the WCC and WDC between 1983 and 2005.

The location of the MHZs are shown on Figure 1.

WDC is currently reviewing the District Plan zoning with respect to an area centred on the Kamo commercial centre. Part of the area under review is designated as MHZ 1 and MHZ 2 and therefore has certain development limitations not applicable to adjacent areas of otherwise similar character. WDC has commissioned T&T to undertake a review of the limitations on development, and possible options for remediation, within the MHZ from a geotechnical perspective.

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[2] Incorporated into the Whangarei District Council in 1989.

[3] The term Mining Hazard Zone has been used in previous reports prepared for WDC. The WDC GIS website also refers to Mining Hazard Zones, whereas the District Plan refers to Mining Hazard Areas. The term Mining Hazard Zone is used here to maintain consistency with previous T&T reports.

2 Purpose and Scope of Work

The area under review by WDC is indicated on Figure 2. It comprises the central Kamo Commercial Area and the surrounding residential suburbs. The northern and eastern parts of the residential areas are underlain by historic mine workings and are designated MHZ 1 and MHZ 2. Apart from a very small section in the north, the commercial area lies outside of the MHZ.

The Operative Whangarei District Plan places certain requirements around the subdivision and development of land within the MHZs. In particular, subdivision of land should not occur unless the subsidence hazard is mitigated. Building consents can be granted provided that a geotechnical survey is undertaken; that the structure is appropriate for the site; and that the structure does not increase the hazard. A considerable number of subdivision, land use and building consents have nevertheless been issued by the WDC for the MHZs over recent years. This appears at odds with previous recommendations from T&T, particularly with respect to no further subdivision of MHZ1 and MHZ 2 (T&T, 2005a).

WDC is seeking advice on what limits on future development within the MHZs are appropriate from a geotechnical perspective. We understand that the current hazard zone boundaries would be retained. Advice is also being sort on whether the subsidence hazard can be mitigated, whether the land is able to be remediated and whether there is a conflict between the current consent issuing practices and T&T's previous advice.

The following tasks have been undertaken:

- Compile and review previous reports and the District Plan;
- Summarise the development of the MHZ;
- Develop a database of known subsidence events;
- Assess the potential impact of mine subsidence on surface structures;
- Assess the potential impact of surface development on future subsidence hazard;
- Review MHZs remediation options;
- Provide a broad-scale assessment of how development within the MHZ may result in changes in risk profile; and
- Prepare a detailed report presenting the results of the assessment.

The specific area requiring this geotechnical assessment was actually smaller than indicated on the figure supplied by WDC. It extended north of Wilkinson Avenue, east to the railway corridor/State Highway 1 and up to the north of Puriri Street (Figure 2).

3 Previous Work

In 1981, WCC commissioned mining engineer John St. George to undertake an assessment of the mine subsidence hazard at Kamo. The findings of this work was presented in a number of reports spanning 1981 and 1982 (St. George, 1981; 1982a,b,c,e,f). This work, together with that of Mansergh (1982) led to those areas of Kamo underlain by historic coal mine workings being subdivided into three Mining Hazard Zones (Figure 1). Each of these zones represented different levels of mine subsidence hazard. The WCC implemented building and subdivision policies for these MHZs in December 1982.

Since this time, T&T has been commissioned to undertake a number of reviews of the MHZs and the relevant Council policies. These reviews were as follows:

Tonkin & Taylor, 1983a. *Kamo Mine Subsidence Review*. Report to Whangarei City Corporation dated November 1983.

Tonkin & Taylor, 1984. *Old Mine Workings – Whangarei Subsidence Review*. Report to Whangarei City Corporation dated January 1984.

Tonkin & Taylor, 1999. *Kamo Mine Subsidence Review*. Report to Whangarei District Council dated October 1999.

Tonkin & Taylor, 2005a. *Mine Subsidence Hazard, Kamo Area, Whangarei*. Report to Whangarei District Council dated March 2005.

Tonkin & Taylor, 2005b. *Review and Usage of Mine Subsidence Hazard Zones for Kamo and Hikurangi.* Addendum to T&T (2005a). Letter report to Whangarei District Council dated 5 December 2005.

4 Coal Mining at Kamo

4.1 Geology

The geology of the Kamo area can be divided into the following three distinct elements:

- Surficial Tertiary to Quaternary basalt flows of the Puhipahi-Whangarei Field;
- Sediments of a largely marine origin that dominate the geology in the eastern parts of Kamo. The sediments consist of Eocene to Oligocene aged limestones, sandstones and coal measures. Thrust over these are older (Cretaceous to Oligocene) sediments of the Northland Allochthon. The entire sedimentary stratigraphy dips to the east at approximately 8°;
- A faulted basement formed from greywacke of the Jurassic Waipapa Terrane.

The relevant section of the published geology map for Whangarei urban area (White and Perrin, 2003) is presented as Figure 3. This indicates that the vast majority of the study area is underlain by basalt lava, with a minor occurrence of Whangarei Limestone occurring to in the east. A schematic section showing the stratigraphic relationship of these geological units within the study area is presented as Figure 4.

The coal measures are shallowest immediately to the east of the Kamo commercial area, where they are overlain by basalt. They increase in depth towards the east in response to the dip of the beds as well as the effects of faulting. Higher stratigraphic units are increasingly exposed to the east as a result.

The number and thickness of the coal seams varies widely throughout the Kamo coal field. Some limited data on the coal seams, as reported by Kelsey (1980) are presented in Table 1. A stratigraphic sequence presented in Kear (1959) indicates that the upper coal seam at Kamo ranged in thickness from 0 to 8m, whereas the lower coal seam was normally just over 1m thick, although it too could reach 8m in thickness.

4.2 Mining Methodology

All of the coal mined in Kamo was recovered by the room and pillar method. Tunnels (known as rooms or roadways) were mined through the coal as a series of straight and parallel drives. A second series of parallel drives (cross cuts) were mined at right angles to the original roadways. The coal located between the two sets of drives (i.e. the pillars) was left in place to support the roof of the mine. In most cases, the volume of coal present within the pillars was well in excess of that recovered by excavation of the rooms. Once the pattern of rooms and pillars had been fully developed, the miners would either abandon that section of the mine with the pillars left in place, or they would mine the pillars, either partially or fully, as they withdrew.

Mining was generally undertaken within one seam only. Where two seams were present, typically only the upper seam was worked, although some areas saw two seams mined (Table 1).

Table 1: Coal Seams and Extraction Methods used in the Kamo Coal Field

Mine	Coal Seams	Extraction Method
Ruatangata	Two seams worked The upper seam was 3.1m thick and lower seam 2.4m thick	Pillar extraction was practiced
Kamo	Two seams were worked in at least a portion of the mine	A portion of the mine had pillars removed
New Kamo	Divided into mines 1 to 4 and 6 Two seams are present but generally only the top seam was mined Mine 3 has some limited mining of two seams Mine 2 involved working a section of the old Kamo mine	Pillar extraction occurred in portions of mines 1 and 4 No pillars were extracted in Mine 2 Pillar extraction in Mine 3 lead to flooding of the mine in 1955
Harrison's	One seam present, ranging from 0.4 to 3.1m thick	Pillars were extracted

5 Nature of Mine Subsidence

5.1 Incidents of Subsidence

Records indicate that surface subsidence has occurred on numerous occasions in the Kamo area (T&T, 1999). Some incidents were concurrent with mining, whereas others occurred several years or even decades after mining ceased. Few details of the older incidents of subsidence are available. T&T (1983) identified a number of crown-holes[4] from aerial photographs taken in 1942. These were particularly prevalent in the vicinity of Kamo High School. An aerial photograph from 1959 apparently did not indicate any obvious signs of additional subsidence (T&T, 1983).

Since cessation of mining in 1955, the known incidents of subsidence are limited to the following:

- 1976: a crown-hole developed at 14 Wakelin Street. The depth to the mine at this location was approximately 23m (T&T, 1983). This crown-hole was filled in but is reported to have reactivated in 1977;
- 1980: a 200m wide circular area of subsistence developed, centred on Grant and Boswell streets. The depth to the mine at this location was approximately 33m. This trough subsidence affected 11 properties (T&T, 1983);
- 2001: several crown-holes are reported to have developed near the dwelling at 30 Puriri Street. It was reported by Kennedy & Associates (2001) that several crown-holes had been filled “several years ago” but they had continued to sink.

The approximate location of previous subsidence events is shown on Figure 5. It should be noted that:

- The locations of the crown-holes in the vicinity of Kamo High School and the trough subsidence of 1980 are taken from Figure 3 of T&T (1999);
- The location of the crown-hole subsidence at 14 Wakelin Street is taken from Drawing No. 6036-3 of T&T(1999); and
- T&T does not possess a plan showing details of the crown-hole subsidence reported by Kennedy and Associates (2001) to have affected 30 Puriri Street in 2001. An inferred general location of this subsidence is indicated on Figure 5.

T&T (1999) reported that the number of crown-holes in MHZ 1 was “less than 20”. Clearly, only some of the crown-holes that have occurred in the Kamo area as a result of mining since 1876 are indicated on Figure 5. Nevertheless it can be seen that subsidence is most closely associated with the western part of the coal field i.e. MHZ1, where the old mine workings are closest to the ground surface. Whilst this is not unexpected, the predominance of subsidence within an area covered by basalt probably is (White and Perrin, 2003). This supports the contention made in T&T (1984) that the thickness of overburden is more important than material strength in determining the development of crown-holes.

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[4] A circular collapse structure that results from the vertical migration of a void at mine level.

5.2 Mechanism of Subsidence

Surface subsidence results from the collapse or sagging of the mine roof into the workings. This may be bought about either directly from the collapse of an unsupported section of roof or it may result from the collapse of one or more pillars. Where pillars were fully removed during mining, roof collapse and subsidence occurred essentially immediately. However where pillars were left undersized, pillar collapse may occur any time after mining, possibly years or even decades later as the conditions of the pillars deteriorate. Subsidence occurring decades to centuries after mining ceases is not uncommon in coal mines of this type.

The collapse of one pillar can result in adjacent ones failing as stresses are transferred from one to another. In some cases undersized pillars do not collapse but punch down into the “fireclays” that typically underlie the coal seams. Where subsidence involves the loss of one or more pillars, the resulting surface expression is more likely to be a shallow but broad depression or trough subsidence of approximately circular shape.

The localised collapse of a section of roof can cause a chimneying effect, in which the roof void migrates vertically upwards. If the void is able to migrate to the surface it appears as a crown-hole. The development of crown-holes is dependent on a number of factors including the strength of the overburden materials, the bulking characteristics of the overburden and the volume of the void into which the overburden material could fall. Crown-holes are the most common form of subsidence at Kamo.

The development and characteristics of both crown-holes and trough subsidence are summarised in Table 2.

Although the strength or competence of the rock above the coal seams (overburden) affects the development of subsidence, it is the thickness of the overburden that is probably of greatest importance in determining whether mine instability will result in surface subsidence. The time, amount and extent of subsidence cannot be predicted with accuracy. Subsidence should be considered a possibly as long as voids are present, unless ground conditions are highly favourable.

Table 2: Development and Characteristics of Mine Subsidence at Kamo

Subsidence Type	Characteristics	Occurrence
Crown-Hole	• Local depressions or holes resulting from the failure of the mine roof and collapse of overburden into the mine opening • Generally small diameter (<10m) and circular, although can be much larger • Have clearly defined physical boundaries • Physically effects a relatively limited area	• Typically develop where the cover is thin • Limited by competent strata above the coal seam • Tend to occur where the cover is <5 times the extracted seam. • Limit on development is often considered to be 10 times the seam thickness, depending on rock structure • Depths of subsidence depends on bulking and void volume etc • Dominant form of subsidence in areas of thin cover
Trough Subsidence	• Shallow and broad dish-shaped depression • Indistinct physical boundaries • Great variation in size • Affects much greater area than crown-holes • Maximum depth is approximately half the thickness of the mined coal seam	• Develops when overburden sags or collapses into the mine workings • Results from the crushing or removal of pillars, pillars sinking or punching into the mine floor • Pillar strength is affected by weathering and groundwater • Failure of one pillar will over stress others • Less common that crown-holes

6 Defining the Kamo Mining Hazard Zones

The Whangarei District Plan identifies three Mining Hazard Zones[5]: Zones 1, 2 and 3. These are qualitatively associated with a high, medium and low "risk"[6] of mining subsidence respectively. The first Kamo MHZs were defined by St George (1981) based on a number of physical parameters and their associated effects on mine stability and subsidence occurrence. The three MHZs were defined as follows:

<u>MHZ 1: High risk of subsidence</u>

- Areas of shallowest mine workings;
- Nature of risk: possibility of crown-holing and major subsidence;
- Defining criteria: areas where the thickness of the cover over the workings (D) is less than 10 times the thickness of the worked coal seam (t) i.e. D <10t;
- Suggested building controls: area to be free of buildings or limited to those buildings designed to take major settlement. No residential development permitted.

<u>MHZ 2: Moderate risk of subsidence</u>

- Workings less than 100m or deeper sections of mine with two extracted seams and areas of pillar removal;
- Nature of risk: possible surface settlement with horizontal strains and subsidence fracturing;
- Defining criteria: areas where D>10t;
- Suggested building controls: no new residential development. Commercial or industrial buildings designed for subsidence.

<u>MHZ 3: Low risk of subsidence</u>

- Areas where cover is greater than 100m and with single seam mining and low percentage of coal extraction. Large stable pillars;
- Nature of risk: Possible minor subsidence;
- Defining criteria: areas where D>100m;
- Suggested building controls: Residential development discouraged.

In reviewing the development of the MHZ, T&T (1983) agreed with the basis on which they had been defined by John St George, but felt that some consideration needed to be given to the effects of subsidence on those areas not located directly above old workings. T&T (1983) subsequently expanded the area enclosed by each hazard zone by:

- Extending the risk zones a distance of 0.7D beyond the underlying the footprint of the mine for shallow workings. This is equivalent to a zone of influence of 35° from the vertical;

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[5] Referred to as Mining Hazard Areas on the District Plan maps
[6] The likelihood or probability of subsidence occurring is hazard, not risk. The term risk has been retained where it has been used in reference documents.

- In deep areas of the New Kamo Mine, areas of multiple seam mining and pillar extraction had a buffer zone added at mine level which was projected vertically to the ground surface.

Subsequent reviews of the MHZs (T&T, 1999; T&T, 2005) concluded that there was no new information that would lead to the zones being modified. The MHZs, as defined by T&T (1983) were subsequently included in the Operative Whangarei District Plan. The Operative District Plan defined the MHZs as follows (Part B – Introduction – Meaning of the Words):

Mining Hazard Area
Means an area which is subject to possible subsidence due to past coal mining activities undertaken on the land

Mining Hazard Area 1
Indicates the area where there is a possibility of crown-holing and major subsidence due to their being less than 10t cover (t being seam thickness)

Mining Hazard Area 2
Indicates:

a) Areas where there is up to 100m of cover and “medium” subsidence is possible; and
b) Areas where there has been 2 seam pillaring and greater than 100m of cover exists.

Mining Hazard Area 3
Indicates areas where there is greater than 100 metres of cover. Although this is a low risk zone, it is possible for buildings to be affected by mining.

The locations of the MHZs and known incidences of subsidence within the area subject to this review are shown on Figure 4. It shows that the area covered by this study consists predominantly of MHZ 1 and MHZ 2. There is no land designated as MHZ 3 within the study area.

7 WDC Policy and Rules for MHZs

7.1 Policy History

WCC adopted polices and rules for the issuing of Building and Subdivision Consents for the MHZ in 1982. New Council policies and rules were adopted in 1995, and amended in 2000. The policy and rules were modified again for inclusion in the District Plan which became operative in 2007. These various policy updates were in response to a number of changes in relevant legislation, particularly the Resource Management Act 1991, the Building Act 1991 and the Building Act 2004.

A detailed history of the Council policy and the legislative framework up to and including the 2000 amendments was presented in T&T (2005a,b).

7.2 Current Policy and Rules

Although mine subsidence is a consequence of man-made activity, it is considered to be a natural hazard for the purposes of the Whangarei District Plan. Council Policies and Rules relevant to the subdivision and development of the MHZ are contained in the following sections of the District Plan:

Part C: Policies

Section 8 – Subdivision and Development

Section 19 – Natural Hazards

Part D: Environmental Rules

Part 36 – Living 1, 2, and 3 Environmental Rules

Part E: Resource Areas

Section 56 – Natural Hazards

Part F: Subdivision Rules

Section 71 – Living 1, 2 and 3 Environments

The relevant extracts from the District Plan are presented in Table 4.

The practical implications of these policies and rules to the development of the MHZs are:

- That the subdivision and development of land within a MHZ[7] is to be avoided unless the subsidence hazard can be remediated or mitigated;
- The construction or alteration of a building within a MHZ is permitted as long as the ground conditions and potential severity of subsidence are evaluated; that the structure is appropriate for the inferred level of hazard; and that construction will not increase the likelihood of subsidence occurring; and
- Earthworks are permitted if a geotechnical survey of the site and its surrounds is undertaken and a report/certificate provided showing that the site is suitable for the proposed earthworks.

[7] As one form of natural hazard. These rules would apply to all natural hazards.

Table 4: Relevant Sections of Whangarei District Plan Relating to Natural Hazard Policy

District Plan Section	**Objectives**	**Policies**
Part C: Polices		
Section 8 – Subdivision and Development	Section 8.3.6 *"The avoidance of subdivision and development in areas where the existing and potential adverse effects, in particular of, noise and natural hazards, cannot be mitigated."*	Section 8.4.13 *"To avoid subdivision and development in areas where natural hazards, including... subsidence ...may occur, unless adverse effects on health, safety and property can be avoided, as far as practicable, or otherwise, remediated or mitigated".*
Section 19 – Natural Hazards	Section 19.3.1 *"The adverse effects of natural hazards on people, property and environment are avoided, as far as practicable, or otherwise remedied or mitigated."* Section 19.3.2 *"Explanation and Reasons: Natural hazards can rarely be fully understood or controlled by humans. The avoidance and mitigation of the effects of natural hazards are the better management approaches, with avoidance being preferred to reduce the risk to property and the health and safety of people."*	Section 19.4.1 *"Certain uses and development may initiate or intensify the adverse effects of natural hazards on the site and beyond. The activity will be restricted if the effects cannot be mitigated to an acceptable level. This will be assessed on a case by case basis."* Section 19.4.2 *"To avoid subdivision, use and development in identified natural hazard areas where the natural hazard is likely to impact adversely upon human health and safety, property and infrastructure."* *"Explanation and Reasons: The difficulty of managing the adverse effects of natural hazards highlights the need to avoid development in identified hazard prone areas where substantial potential risk to human life exists. If mitigation of the natural hazard can be proved to reduce the potential risk to human health and safety to an acceptable level, activities may be considered. Natural hazards have the potential to cause damage, by a range of degrees, to property and infrastructure. Activities may be acceptable if mitigation of the natural hazard reduces risk to human life and property to an acceptable level. This will be assessed on a case-by-case basis."*
Part D: Environmental Rules	**Rules**	
Section 36 – Living 1, 2 and 3 Environment Rules	Section 36.4.1 *"The net site area associated with each residential unit is at least 500.0m² in the Living 1 Environment"* Section 36.4.3 *"Construction or alteration of a building is a permitted activity if building coverage on the site does not exceed: a) 35% in the Living 1 Environment"*	
Part E: Resource Areas	Section 56.2.4 "*Construction or alteration (excluding internal modifications) of a building or earthworks within a Mining Hazard Area is a permitted activity if:* *a) A geotechnical survey of the ground under, and in the immediate vicinity of the site, is undertaken and* *b) A report or certificate, which has been prepared by a suitably qualified and experienced professional, is provided to the Council which indicates that:* *i) Where the site is to accommodate a residential unit, there is an identified building area of at least 100m² where a residential unit can be built so that there is compliance as a permitted activity with the rules in this plan; and* *ii) The site is suitable for the activity or structure, and* *iii) The structure is of an appropriate design and the building materials are appropriate in the circumstances; and* *c) The risk of subsidence is not increased by construction, alteration or excavation"* Section 56.3 *"The risk to properties situated above these old coal mining tunnels, and to human life, can be minimised by ensuring that any earthworks or structure is suitable and does not increase the likelihood of subsidence. This can be achieved by controlling the design and building materials of structures that can be built in these areas."*	

Part F: Subdivision	Section 71, Living 1, 2 and 3 Living Environment Subdivision Rules, Rule 71.3.4 Building Area *"Subdivision is a **controlled** activity if:* *a) Every allotment in the subdivision contains an identified building area of at least 100.0m² on which a residential unit can be built so that there is compliance as a permitted activity with the rules in this Plan.* ***Control is reserved over:*** *i) The need for earthworks;* *ii) Provision for parking, loading manoeuvring and access;* *iii) Effects of natural hazards;* *iv) Bulk, height, location, foundations, and floor level of any structures of allotments;* *v) Protection of land from natural hazards;* *vi) Protection of residential units from road noise;* *vii) The additional matters listed in Chapter 70.3"*

It is noted that although three MHZs are differentiated on the District Plan maps, neither the Policies nor the Rules differentiate between these three areas in terms of restrictions or requirements to be satisfied in order for development to proceed. This is in contrast to the original formulation of the MHZs which specifically recommended different levels of development in each of the MHZs to reflect the different levels of “subsidence risk” within each. This differentiation was adopted in the Council Policies of 1982 and 1995. The amendments of 2000 considered MHZ 1 and MHZ 2 west of MHZ 3 the same and MHZ 3 and those areas of MHZ 2 enclosed within it as the same. In effect this created two zones with respect to Council policy, which is as follows:

“That areas in zones two and three indicated in the Tonkin & Taylor report (Figure 1, Zone 3 and 2 within 3) need not have building consents issued in terms of 36(2) and may be issued in terms of Section 35 of the Building Act.

That every five years or less, a review of the survey and measurements taken in these mine zone areas, be reviewed by Council/engineers.

1) *That areas in zones one and two indicated in the Tonkin and Taylor report (figure 1 zones 1 and 2 to the west of zone 3) will require buildings consents be granted under Section 36(2) with the appropriate engineer’s report, unless the engineer can show Council (subject to expert review by Council’s consultant) that Section 36 is not applicable or that the hazard can be mitigated; and*

   Further, subdivision and landuse requests associated with building development, will require an appropriate engineer’s report, subject to expert review with regard to the Tonkin and Taylor report.

2) *That no building will be permitted within 20 m of a mine shaft, crown hole or mine entrance unless it can be demonstrated that the hazard can be mitigated or that building damage can be prevented.*

3) *That in all areas which are undermined (zones 1, 2 and 3) building design and construction must make allowances for potential subsidence.*

The Appendix in T&T (2005), which updates Council’s policy with the 2000 amendment does not contain point 1 above. This should have been included under the Zone 3 provisions.

At the time of T&T’s last review of the mine subsidence hazard (T&T, 2005a), Building Consents could be granted for

- The repair of, and minor extension to, existing buildings;
- Erection of single storey accessory buildings not exceeding 50m^2;
- Single storey housing that can be transported intact, constructed using light weight building materials.

Building Consents would be issued under Section 36(2) of the Building Act unless the engineer can show that either Section 36 was not applicable or that the hazard could be mitigated. The building design and construction had to make allowances for potential subsidence. The construction or alteration of a building may also trigger a landuse resource consent under the Resource Management Act 1991, if conditions in Part E Resource Areas, Section 56.2.4 Mining Subsidence are not met. Rule 56.2.4 Mining Subsidence will also apply at the time of subdivision , requiring a geotechnical survey of the site, a report certifying the site is suitable, the materials and design of the structure are appropriate and the risk of subsidence will not be increased by construction, alteration or excavation. All subdivision requires resource consent – there is no permitted activity subdivisions.

T&T (2005a) concluded that these building controls were appropriate. T&T (2005a) also concluded that WDC should be able to grant building consents for the MHZ without resorting to Section 72 of the Building Act 2004, which had then come into force. With respect to the subdivision of land, T&T (2005a) did however recommend that no further subdivision of land within MHZ 1 or MHZ 2 be permitted, and that the extent of subdivision in MHZ 3 be restricted. The Operative District Plan does however allow subdivision of the MHZs provided that the hazard can be remediated or mitigated.

A significant number of Building, Subdivision and Landuse consents have been issued by WDC since 2005. Most of these consents have been granted in the MHZ 2 and MHZ3 areas, although some have been granted in MHZ1 (Figure 5). As the mining subsidence hazard at Kamo remains unaltered and the land unremediated, we must infer that development proponents have been able to provide evidence to Council that the potential adverse effects have effectively been mitigated through the construction of subsidence resistant structures, services etc.

8 Discussion

Significant development of the MHZs has taken place over recent years and there is potential for a significant further increase in subdivision and population depending upon the policy adopted by WDC in the future. This section presents a discussion on the nature of the subsidence hazard and the risks that arise from it; the potential for mitigating the hazard; the potential limits on development; and the implications of such development occurring

8.1 Risks Associated with Mine Subsidence

In the following discussion, reference is made to previous documents that use the term "subsidence risk" or "High Risk" when it would typically be more correct to use the term hazard. For the purposes of the following discussion, the original terminology is retained i.e. hazard and risk both refer primarily to the likelihood or probability of subsidence occurring. Where a distinction is required, this is specifically stated.

8.1.1 Definition of Risk

In developing the mine subsidence hazard zoning system in 1981, John St George assigned the terms High Risk, Medium Risk and Low Risk to MHZ 1, MHZ 2 and MHZ 3 respectively. These risk levels reflected available information on the nature of the mine workings below each zone and the thickness of overburden. They were however only qualitative in nature, as no probability of occurrence was assigned to either crown-hole or trough subsidence and no annualised loss of life or property loss risks were calculated.

In their subsequent reassessments of the Kamo mining subsidence hazard, both T&T (1984) and T&T (1999) refer to hazards zones that are only defined on the basis of the thickness of cover (overburden) relative to seam thickness (as developed by St George (1981)). No risk terminology is assigned to these MHZs, although it is clearly implied that the subsidence hazard/risk is higher for MHZ 1 than the other two zones. Council policy of the time also refers to MHZ 1, 2 and 3 without referring to any particular level of hazard or risk.

T&T 2005b refer to *"high, moderate and low risk of subsidence"* in their review of the Council policy changes between 1995 and 2000. The use of such terms was inconsistent with the previous two T&T reports. Although the Operative District Plan does not assign risks levels to the MHZs, it is noted however than the WDC GIS Website Legend[8] does describe MHZ 1, 2 and 3 as *"High Risk, Medium Risk and Low Risk"* respectively.

Because the MHZs are defined according to any established quantitative hazard or risk classification system, it is more appropriate for the purposes of this discussion to consider MHZ 1 having a higher subsidence hazard than MHZ 2, which is turn has a higher subsidence hazard than MHZ 3. Whether any of these zones have a high, moderate or low risk in absolute terms has not been determined. The very limited quantity of data available for both the ground conditions and the frequency of subsidence events makes the statistical determination of such qualitative values difficult and potentially unhelpful.

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[8] http://www.wdc.govt.nz/BuildingandProperty/GISMaps/Documents/GIS-Website-Map-Legend.pdf

8.1.2 Loss of Life Risk

In assessing the potential for subsidence to adversely impact people, T&T (1984) concluded the following:

> *"that the damage which results from mine subsidence of the types just described* [crown-hole and trough subsidence] *is not such that it would normally pose any threat of personal injury or loss of life".*

This statement was paraphrased in both T&T (1999) and T&T (2005). Although an injurious or even fatal consequence from the emergence of a crown-hole cannot be ruled out, it would appear, based on the fact that such events usually occur years apart; that the crown-holes are only a few metres in diameter; that the void does not extend to any significant depth below the surface expression; and they affect only a tiny portion of the MHZ at any one time, that the annualised risk of a particular property or person being adversely affected is significantly less than the multitude of other risks that residents face every year e.g. driving. A far greater mining-related danger would be any on-going presence of open shafts.

As stated above, none of the previous hazard assessments for Kamo have attempted to calculate what the annualised loss of life or injury risk is in any of the MHZ. Whether the current loss of life risk to residents, particularly those located within MHZ 1, can be considered unacceptable, tolerable or acceptable is unknown. The determination of these values lies outside of the scope of this report.

It is important to note than regardless of what the current risk level is in absolute terms, any increase in the resident population of the MHZs will result in a corresponding increase in risk. This is because the annual probability of an injury or death occurring increases simply because there are more people available to be affected. In risk terminology the ongoing development and densification of the MHZs increases the "elements at risk". That is not to say however that the risk has or will breach any particular threshold of acceptance or tolerance.

It is concluded therefore that the current level of risk within the MHZs is currently unknown. Further subdivision and development of the MHZs will further increase the loss of life risk above current levels unless some for mitigation of the hazard is undertaken. Opportunities for the mitigation of the mine subsidence hazard are discussed in Section 8.3.

8.1.3 Property Loss Risk

Property loss, either partial or complete is the most likely outcome of crown-hole or trough subsidence. Historic evidence suggests that crown-holes are much more likely to occur than trough subsidence. Crown-holes are more likely to affect a single property and because of their size, may very well not directly affect a structure. Trough subsidence will in contrast affect a much greater area and potentially several properties at once. The 1980 trough subsidence event affected 11 properties. There is also a greater probability that if a dwelling is present on a property affected by trough subsidence, that the structure itself will be impacted.

Although the probability of a particular building being affected by subsidence within its design life (say 50 years) is small, and potentially negligible, damage to buildings has occurred in the past and should be expected to occur in the future.

It is concluded therefore that that damage can be expected to affect some buildings located in the MHZs, particularly MHZ 1 in the future. Exceptions would be those newer buildings designed and constructed specifically to be subsidence resistant. Any increase in the number of buildings through future subdivision of the MHZs will result in a corresponding increase the annual risk of property loss above current levels unless some mitigation of the hazard is undertaken.

8.2 Mitigation of the Hazard

The Operative District Plan allows development within the MHZs if the hazard and potential for adverse effects to people and property (i.e. the consequences) is avoided, remedied or mitigated. This section provides an assessment on the options and opportunities for hazard mitigation.

The mine subsidence hazard zoning system adopted for Kamo reflects the relative likelihood or probability that a subsidence event will occur. The hazard, which originates within mined-out coal seams can only be mitigated by the prevention of collapse or further deterioration of the workings[9]. This effectively means the hazard mitigation requires the filling or stabilisation of the existing mine void.

T&T (1984) provided a detailed assessment of the various means by which the mine subsidence hazard could be mitigated. The mine void filling options included hydraulic backfilling, pneumatic backfilling, grouting, over-excavation with back filling, blasting, dynamic compaction and the construction of piles or piers to support the mine roof.

Whilst the backfilling and excavation methods have been used in the past to control mine instability and surface subsidence, they are hugely expensive. Also, the current flooded state of the historic workings makes the process of backfilling problematic. It is likely that backfilling would require the mines to first be dewatered. This would certainly be the case for the construction of roof support piers.

Although likely to be an expensive and difficult exercise in itself, lowering of the groundwater within the mines will reduce effective roof support and increase the likelihood of subsidence occurring before backfilling operations are completed. The hazard mitigation process would therefore be expected to increase the likelihood of subsidence occurring, at least until the works were completed.

T&T (2005a) concluded that it was not practical or economically viable to mitigate the subsidence hazard by rehabilitating or remediating the mined land. This is also the conclusion reached here.

8.3 Mitigation of Risk

If the mine subsidence hazard cannot be mitigated, then either the hazard (and its associated risks) are accepted or steps are taken to reduce the consequences of mine subsidence to some lower “tolerable” level. This approach is the management of risk, as the hazard remains unchanged.

Risk mitigation can be achieved through a number of different approaches. These include:

- Avoidance of the hazard
- Managing the elements at risk;
- Ground Improvement;
- Resistant design of structures;
- Not increasing the hazard.

[9] Those other methods that reduced the consequences of subsidence (e.g. settlement resistant construction etc) modify the level of risk, not the hazard.

8.3.1 Hazard Avoidance

With the MHZs already being developed into residential areas, avoidance of the mine subsidence hazard is impractical.

8.3.2 Managing the Elements at Risk

Although it is not reasonable to expect a reversal of the development that has taken place in the past, it is possible however to manage the future risk by determining the level of development that can take place. Policies on the future development of the MHZs should be made from an informed position with respect to the current level of risk. Currently however the level of risk associated with each of the mining zones is unknown. Whether the current level of risk can be considered acceptable, tolerable or unacceptable is also currently undetermined. What is clear however is that regardless of where the risk currently lies with respect to these thresholds, further subdivision and development brings the community closer to them.

Because of the current uncertainties around the level of subsidence risk, T&T recommends that a cautious approach be adopted to the subdivision of the MHZs, particularly MHZ 1 which has been the area most affected by previous subsidence until such time as:

- The level of risk present is quantified;
- The level of risk corresponding to acceptable, tolerable and unacceptable are defined; and
- The capacity of the MHZs to sustain further development without the subsidence-related risks increasing to unacceptable levels.

Given the practical difficulties in quantitatively determining the Loss of Life and Property Loss risks for land above historic mine workings, WDC’s policies on the development of the MHZs will necessarily need to continue to be based on qualitative assessments that take into account the uncertainties associated with this hazard and its potential impacts. This does not imply that those areas underlain by historic workings (MHZ 1 in particular) need to be abandoned, reduced in population or degraded in some manner. The current inferred level of risk to both people and property from subsidence does not appear to justify such conservative actions. Nevertheless, the high probability of additional subsidence events occurring at some time in the future needs to be taken into account when considering future development options.

8.3.3 Ground Improvement

Ground improvement is a process by which the strengthening of the ground is used to effectively isolate the near surface soils from the effects of mine instability occurring at depth. T&T (1984) looked at the issue of ground improvement in some detail. Methods included grout columns, drilled piers and piles. T&T (1984) concluded that ground improvement methods:

- Reduce, but do not eliminate future subsidence movements;
- Are expensive and capital intensive, requiring the cost to be spread over a relatively short time interval;
- Require careful planning and thorough investigations prior to construction; and
- For Kamo, it is improbable that any of the ground improvement would be economically attractive

We concur with those views although the use of deep piles may be feasible for large buildings located over shallow workings. This would need to be assessed on a case-by-case basis as both the site-specific ground conditions and the nature of the building needs to be taken into account.

8.3.4 Resistant Design of Structures

The design of structures to be resistant to the damaging effects of subsidence, or of a type that can be readily re-levelled (or both) is the most practical means of managing the property loss risk within the MHZ. This is effectively the basis on which current development of the MHZ is taking place.

The goal with resistant design is to minimise the damage, as complete damage prevention is often not cost effective. T&T (1984) assessed the options around subsidence resistance design and concluded:

- Wooden framed structures lightly connected to their floor stab are ideal for housing;
- The traditional method of isolated piles or jack studs has proven to be effective in isolating buildings from substantial ground movements. Such building techniques are rarely used today however;
- Rigid structures with a thick slab or raft stiffened by shear walls are another possibility. Such structures can be jacked level in the event of subsidence occurring;
- Buildings with concrete block walls and rigid cladding should be avoided as they are vulnerable to damage

There are a range of modern techniques that structural engineers and architects could potentially adopted to make future buildings subsidence resistant.

8.3.5 Not Increasing the Hazard

Mining subsidence is typically thought of as mine instability affecting surface structures. There is potential however for surface developments, be it buildings, earthworks or other structures, to increase the incidence or severity of mine subsidence. It is a requirement of the Operative District Plan that *"any earthworks or structure....does not increase the likelihood of subsidence"*[10]. This section discusses the potential for man-made activities to result in an increase in both hazard and risk.

8.3.5.1 Mine Dewatering

The abandoned mine workings at Kamo are currently flooded. The presence of water within the mining voids effectively aids stability by:

- providing buoyant support to the roof;
- Reducing the effective vertical stress within the pillars and overburden;
- Reduces the deterioration of the pillars through oxidation, wetting and drying cycles and spalling.

Dewatering of the mine workings will significantly increase the effective stresses acting on those remaining pillars that support the workings. This is potentially the single most important source of increased risk for the MHZs.

[10] District Plan Part E: Resources, Section 56.3

8.3.5.2 Imposed Loads

The construction of a building or the placement of earth fill will increase the vertical load imposed on the ground. This has the potential to materially affect the stability of any mine working located below by overstressing marginally stable pillars or sections of unsupported roof.

The extent that a surface development could have a material effect on the stability of the mine workings depends on the scale of the development and the imposed load. If it is assumed that potentially unstable mine workings exist at a depth of 20m below ground surface (the likely minimum depth to any workings in Kamo), the *in-situ* vertical stress at mine level is approximately 230kPa. Assuming that a typical single story house imposes a load at foundation level of 10kPa, the resulting increase in effective vertical stress at mine level is approximately 2kPa. This represented an increase in effective vertical stress on the very shallow mine workings of less than 1%.

Conservatively assuming that a two storey house of the same footprint imposes a 20kPa load at foundation level, the increase in effective vertical stress at mine level is only 4kPa, or less than 2% of the *in-situ* value. The increase in effective vertical stress from an imposed load such as a residential dwelling tends towards the negligible for mine workings deeper than approximately 20m. Such increases in effective vertical stress are in the same magnitude as those regularly brought about by seasonal fluctuations in groundwater levels. It is expected therefore that mine subsidence hazard is highly unlikely to be affected by the construction of a typical one or two storey structure.

The construction of a large commercial or retail building could however imposed significantly greater loads on the mine workings. This is not only because of the higher imposed loads generated by these structures, but their much larger footprint means that the vertical stress “bulb” extends much deeper. The result is that larger effective vertical stresses are imposed on shallow workings and the smaller imposed loads can extend to the deeper workings.

Whether the construction of a large building could adversely affect the stability of mine workings will depend on site specific details such as the impose load and the condition of the mine. It is doubtful that any meaningful assessment of mine stability could be achieved through even an extensive geotechnical investigation. Some knowledge of the depth to any workings, the nature of the overburden and the size of the imposed load would however enable an informed engineering decision to be made regarding the suitability of such a proposal. It is not possible however to define a particular stress level that will not adversely increase the likelihood of subsidence over a broader area, such as a MHZ. The elevated risk to larger structures is however much more likely to be a function of them having a larger footprint and potentially greater vulnerability to settlement, than the larger imposed load leading directly to void collapse and surface deformation.

The stress imposed on the ground by earthworks is typically many times that of a comparable structure. Significant earthworks above shallow mine workings should be viewed with caution.

9 Conclusions and Recommendations

A review of the Whangarei District Plan and previous report on the Kamo Mining Hazard Zones has been undertaken. The purpose of the review was to assess the potential limitations on development within the MHZs from a geotechnical perspective. The following conclusions have been made:

- There is a long history of mining-related subsidence at Kamo. This hazard can be expected to continue into the foreseeable future;
- The current MHZs are based on an extensive assessment of the nature of the underground workings at Kamo and those parameters, such as overburden thickness, that influence the onset of subsidence. It is concluded that these MHZ's are appropriate and should remain in-place;
- The terms High Risk, Moderate Risk and Low Risk have been periodically assigned to the three MHZs. The use of these terms is somewhat arbitrary, qualitative and inconsistent. Their use should be discontinued;
- The Operative District Plan takes a position that:
  - the subdivision and development of land within a MHZ is to be avoided unless the subsidence hazard can be remediated or mitigated;
  - the construction or alteration of a building within a MHZ is permitted as long as the ground conditions and potential severity of subsidence are evaluated; that the structure is appropriate for the inferred level of hazard; and that construction will not increase the likelihood of subsidence occurring.
- T&T has previously concluded that the Council building controls were appropriate. This is reaffirmed here;
- T&T has previously recommended that no further subdivision of land within MHZ 1 or MHZ 2 be permitted, and that the extent of subdivision in MHZ 3 be restricted. Substantial subdivision has however taken place within the MHZs;
- Until such time as the level of risk present is quantified and the level of risk corresponding to acceptable, tolerable and unacceptable are defined, it is recommended that a cautious approach be adopted to the development of the MHZs, particularly MHZ 1 which has been the area most affected by previous subsidence;
- Although the risk to people and property is (and is likely to remain) unquantified, the nature of the subsidence events observed to date do not appear to justify depopulation or abandonment of the MHZs. Intensification of development will result in a corresponding increase in Loss of Life or Property Loss Risk, although it is noted that this does not imply that any intolerable or unacceptable limit has or will be breached;
- Property loss risk is the most significant risk arising from the presence of mine subsidence. Loss of life risk from the sudden development of crown-holes is likely to be comparable, or less than, many other routinely accepted risks such as driving;
- It is impractical to mitigate the mine subsidence hazard. Some measures such as resistant building design and limiting the density of development can however lead to reduced risks, either by reducing vulnerability and/or limiting the number of elements at risk;

- It is unlikely that any but the largest structures or earthworks could potentially impact the stability of the mine workings. The potential influence of domestic dwellings is considered insignificant;
- There is no uniform building density or foundation loading that could sensibly be applied to a broad area such as a MHZ. Large structures or developments would need to be assessed on a case by case basis;
- WDC's policies on the development of the MHZs should reflect the significant uncertainties present with respect to the extent and potential impact of the subsidence hazard; and
- Management of the hazard and associated risks should be able to be managed through adopting suitable limits on population density, building footprint size and the construction of subsidence-resistant building types and layouts.

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11 Applicability

This report has been prepared for the benefit of Whangarei District 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 without our prior review and agreement.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Kevin J. Hind	Nick Rogers
Engineering Geologist, Principal	Project Director

kjh

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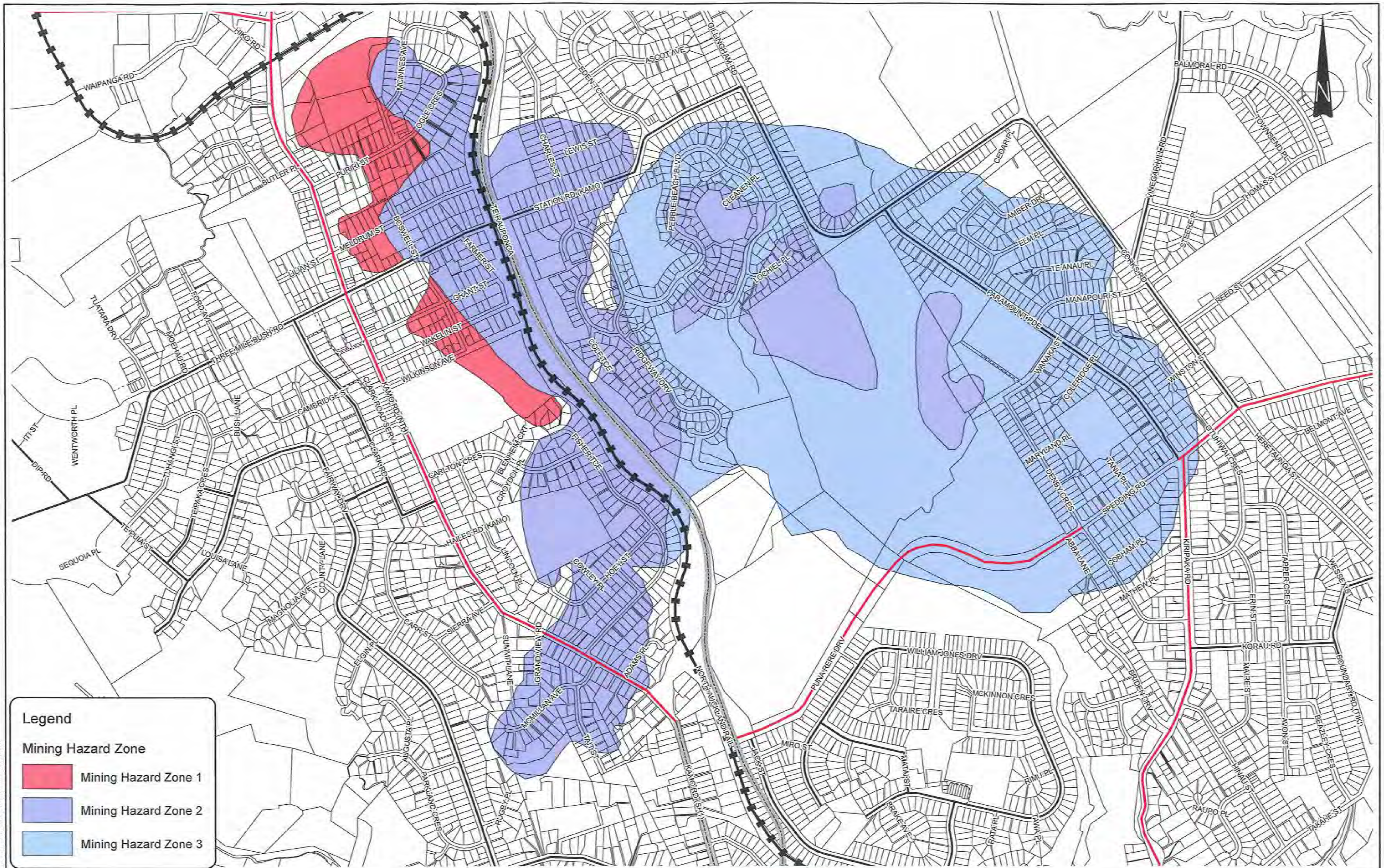
Appendix A: Figures



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Whangarei District Council
Kamo, Settlement Hazard Mine
Mine Hazard Zone - General Area

FIGURE No. Figure 1.

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SCALES (AT A4 SIZE) AS SHOWN		
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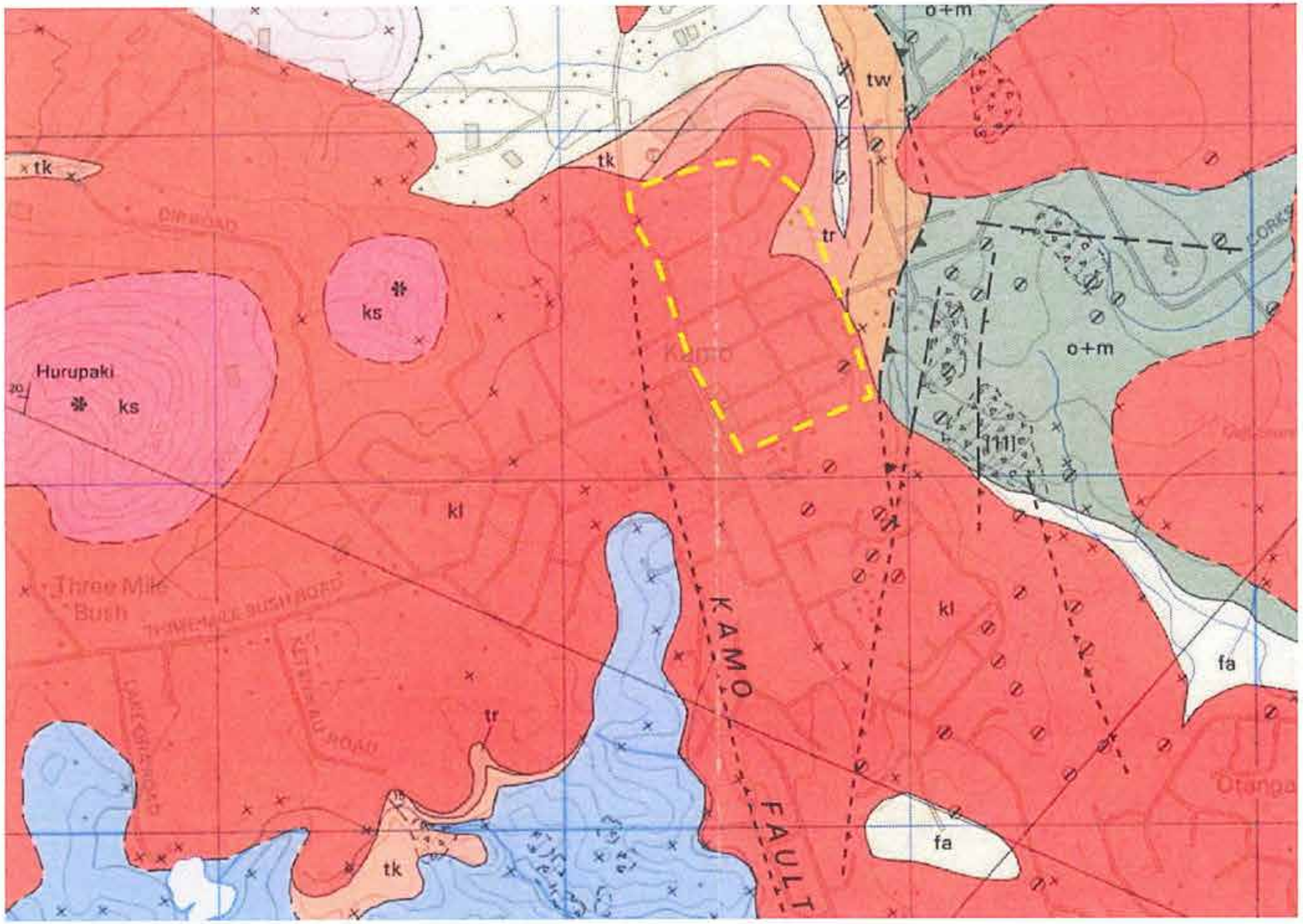
105 Carlton Gore Road, Newmarket, Auckland

WHANGAREI DISTRICT COUNCIL
KAMO MINE SUBSIDENCE HAZARD

Project Location Plan

FIG. No. Figure 2

REV. 0



Source: White and Perrin (2003)

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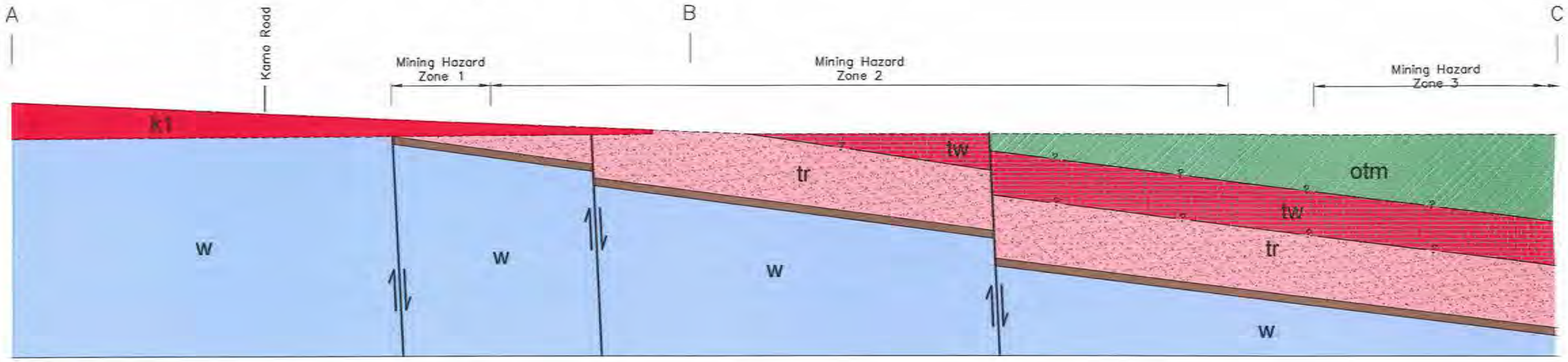
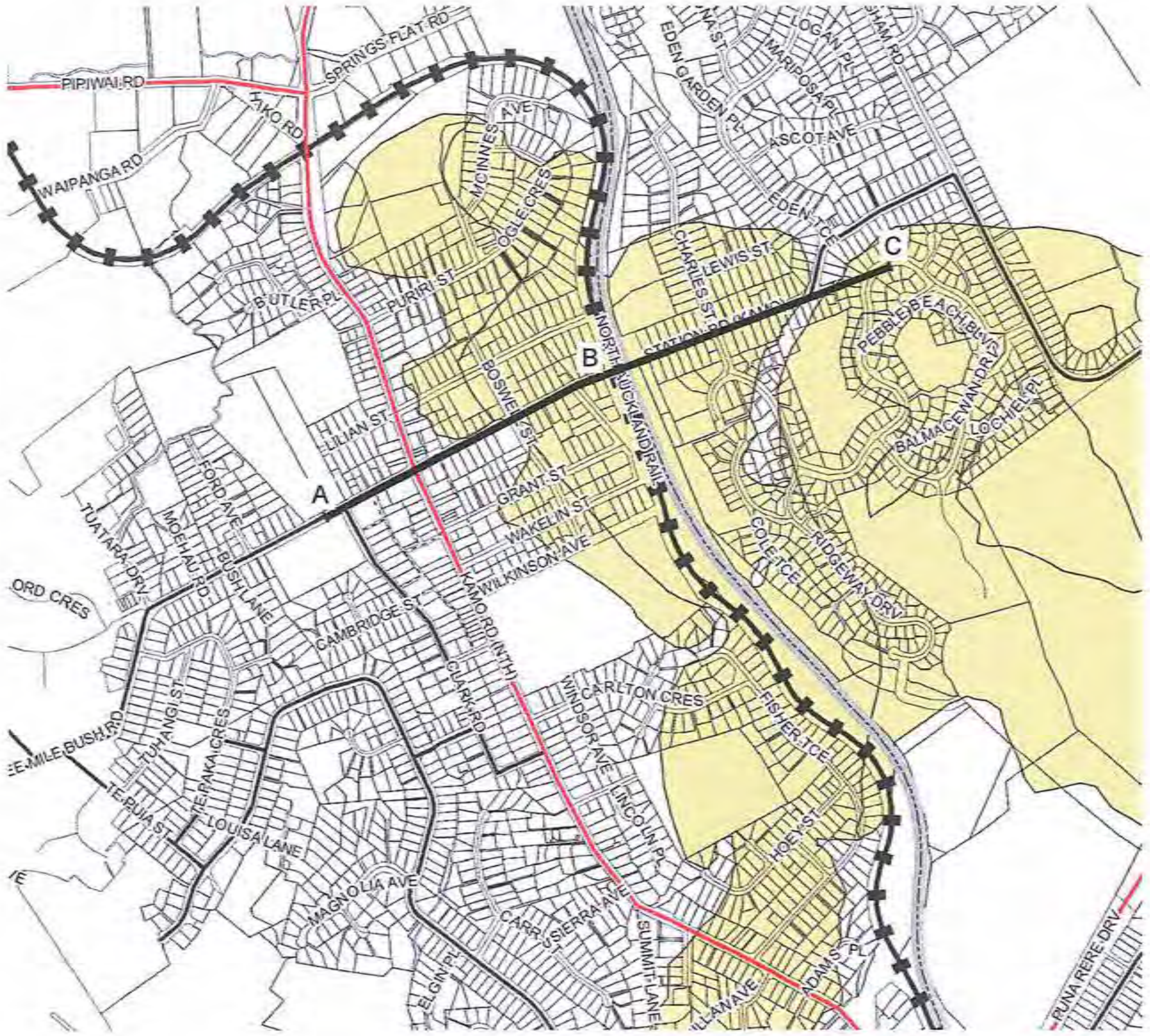
	PROJECT No. 29269	FIG. No. Figure 3	REV. 0



SCHEMATIC STRATIGRAPHIC SECTION AND MINING HAZARD ZONES
SCALE 1: 10,000 (HORIZONTAL), (NO VERTICAL SCALE)

LEGEND

kt	Basalt (Puhipahi – Whangarei field)
otm	Motatau and Mangakahia complexes (Northland Allochthon)
tw	Whangarei Limestone
tr	Rautangata Sandstone
	Coal Measures
w	Waipapa Terrane (Greywacke)
	Mining Hazard Zones



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SCALES (AT A3 SIZE) NTS		
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WHANGAREI DISTRICT COUNCIL
KAMO MINE SUBSIDENCE HAZARD

Schematic Stratigraphy and Hazrd Zones

FIG. No. Figure 4

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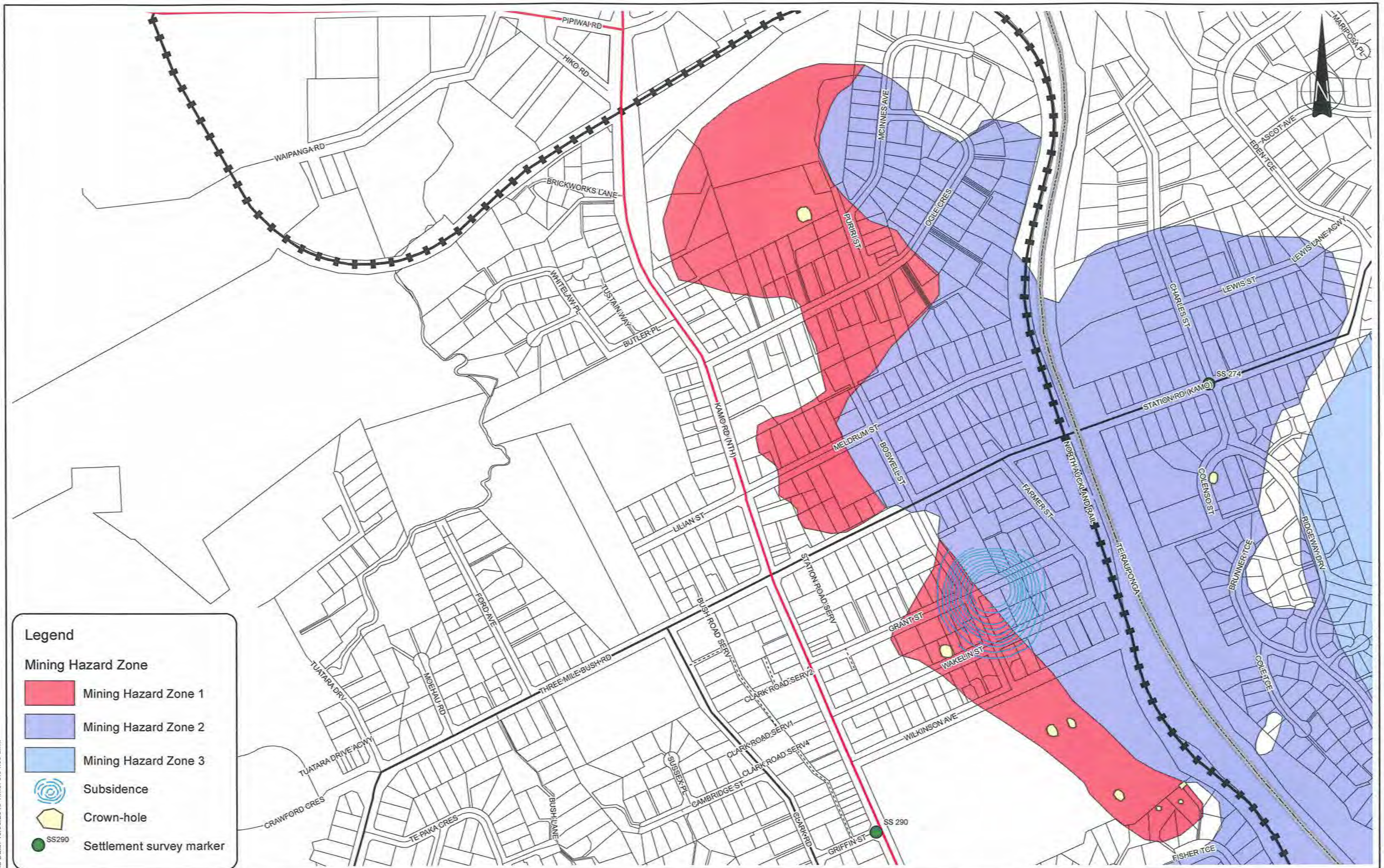

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Notes: Location and extent of crown-hole subsidence is indicative only

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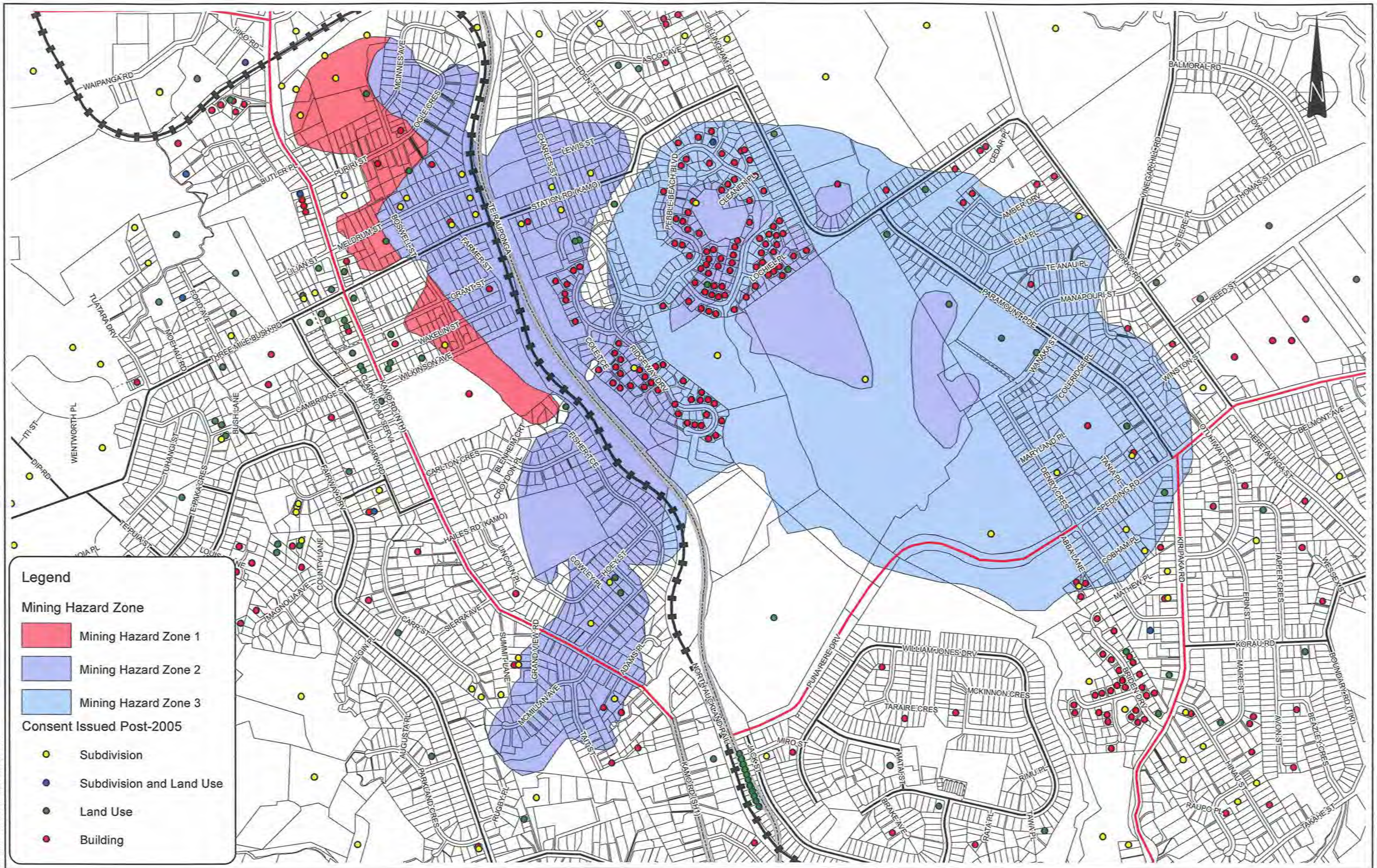
Whangarei District Council
Kamo, Settlement Hazard Mine Recorded Subsidence

FIGURE No. Figure 5.

Rev. 0



Notes:

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Whangarei District Council
Kamo, Settlement Hazard Mine
Consents Issued Post - 2005

FIGURE No. Figure 6.

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