

**REPORT ON:  
RISK ASSESSMENT FOR URBAN AREAS  
ABOVE THE MINE**

**PROJECT:  
HUNTLY EAST MINE CLOSURE ASSESSMENT**

CLIENT: WAIKATO DISTRICT COUNCIL

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## EXECUTIVE SUMMARY

The subsurface Huntly East Mine opened in 1978. The minimum depth of cover to the surface is approximately 100m, which is in the southern part of the mine. Throughout the period of active mining, coal seam gas was managed and extracted from the workings. In the same period the urban area of Huntly has developed on the surface above the mine. In early 1983 adverse surface subsidence was observed, and as a consequence mining practises were altered.

The mine was closed in 2015. The closure included the sealing of the mine entrances, which are to the east of the township. The monitoring of the seals to date suggest they have been effective in excluding the intrusion of air and promoting the increase of methane gas in the voids to a concentration that is not within an explosive limit. The approach taken in the design of the closure is to flood the mine, thereby equalising the pressures throughout the coal seams so that no further gas will be released from the coal matrix. However, there is a period between mine sealing and the eventual full flooding of the mine, which has been estimated to be in the order of 5 years (Solid Energy New Zealand, 2018).

Waikato District Council initiated this study to assess risk presented by the closed underground mine to the surface urban development over the coming years, relating particularly to:

- Surface settlement affecting the surface environment; and
- The migration of coal seam gas to the surface environment.

This study adopted the internationally recognised ISO 31000 approach to the assessment of risks. In developing this approach, the existing information relating to the mine was adopted as the basis of the assessment. Group workshops with participants who have diverse skills, experience, and direct knowledge of the circumstances of the Huntly area collectively undertook the assessment. The likelihood of various consequences to the surface environment were assessed in the context of a broad set of risks faced by modern urban environments.

The conclusions of the assessments are presented in two risk register matrices; one relates to new developments and the other addresses the circumstance of existing developments in the area. The assessment of risk suggests, in summary:

- The types of risks have been, and remain, those related to the effects of settlement and coal gas.
- The likelihood and possible consequences are influenced by the different mining methods used and the type of surface development.

- The risk to the surface environment of settlement is not materially altered from the time of mine operations. Ongoing surface settlement following closure of underground workings is a well-recognised phenomenon in other parts of the world.
- Physical mechanisms for transmitting coal gas from the closed mine to the surface environment were considered in workshops, but the likelihood of this occurring in the circumstances is considered to be very rare. Risks associated with gas migration from closed underground mines is not a phenomenon reported in commonly available statistics. In addition, instances of coal seam gas migration to surface environments have not been identified at Huntly or elsewhere.

In light of previous recommendations, the issue of monitoring for settlement and gas migration across the area was considered in the workshops. The conclusion is that currently there is frequent, but ad hoc, monitoring of the buried utility infrastructure in the area and this provides an extensive monitoring network for both:

- **Surface Settlement.** The condition of buried water pipes and sewerage pipes are an effective means of assessing settlement and differential settlement across a wide area. Condition assessments of these brittle long utilities are not currently identifying disproportionate damage or unusual settlement characteristics.
- **Gas migration to the surface across a wide area.** If methane gas (a component of coal seam gas) were to be hypothetically present in the near surface environment it would readily find its way into buried ducts and travel along the ducts. The utility operators always monitor voids for gas before entering them. To date the operators have not encountered elevated gas levels in the area. Nonetheless, should repeated instances of elevated methane gas levels occur in an area they would highlight a need for further investigation.

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## 1 INTRODUCTION

The Huntly East Mine opened in 1978 and closed in 2015. The seals across the mine entrances in the high wall of the abandoned Kimihia open cast mine have been monitored at intervals in the intervening period by Terra Firma. Since closure, two reports have been prepared by Ian R Brown Associates Ltd (IRBA) (2015 and 2018). The report in 2018 commented on possible further effects of the closed mine, in particular those associated with surface settlement and coal gas migration. IRBA (2018) in summary concludes that planning future developments in the area should consider:

- Solid Energy New Zealand (2018) suggested that flooding of the mine might take 2 to 5 years, but the flooding status of the mine cannot be monitored.
- Surface settlement is likely to continue but also likely to diminish as the mine floods. However, the magnitude of possible future settlement cannot be predicted.
- Coal gas will continue to desorb from the remaining coal seam into mine cavities until the mine is fully flooded. The two theoretical pathways for coal gas to migrate to the surface suggested by IRBA (2018) are through abandoned boreholes from the original mine investigations and the second through overlying geological strata.

Further investigation cannot eliminate uncertainty in the assessment of the consequences from the identified hazards. Consequently, this study takes the following approach:

- All available historical information and reports are adopted within the context with which it was prepared.
- Many activities have inherent uncertainty and those associated with the closed mine can be placed within the context of other risks mitigated or accepted by individuals, communities and the wider society.
- A risk-based approach provides a means of understanding and rationalising uncertainty. A risk assessment should be based on a robust methodology that is internationally recognised.
- The assessment process can be used to develop planning policies and rules for future developments and provide a basis for communication to the community where this might be necessary.

RDCL was engaged in June 2019 to manage the development of the risk assessment. The study developed in the following sequence:

- Define likelihood and consequences for review, comment and eventual adoption by Waikato District Council for this project.
- Develop a risk register and risk matrix structure from the system proposed for natural disaster events (GNS, 2016), which in turn is based on the approach of the AS / NZS ISO 31000.
- Undertake workshops to explore the settlement and gas hazards, mechanisms, risks and mitigation measures. These included a variety of attendees, primarily from the Waikato District Council, with extensive experience of the area and the requirements for urban developments.
- Population of a risk register; for the assessment of future development. These incorporate the assessment of risk and mitigation measures. The register is presented as a locked Excel spreadsheet.
- Undertake supplementary discussions to provide context when developing Policies and Rules for the Draft Waikato District Plan for future development in the Huntly East Mine area.
- The drafting of this report to record and summarise the risk assessment.

## 2 RISK ASSESSMENT METHODOLOGY

The risk assessment was planned and undertaken in accordance with the international standard AS/NZS ISO 31000 : 2018 Risk Management standard. This assessment approach was adopted because it is well recognised, and:

- Is structured and comprehensive.
- Can be customised to reflect particular circumstances.
- Is inclusive of many facets of a situation.

The methodology adopted in this assessment incorporates the steps for establishing the context, identifying risks, analysing risks, risk evaluation and mitigation as suggested by AS/NZS ISO 31000 (Figure 1).

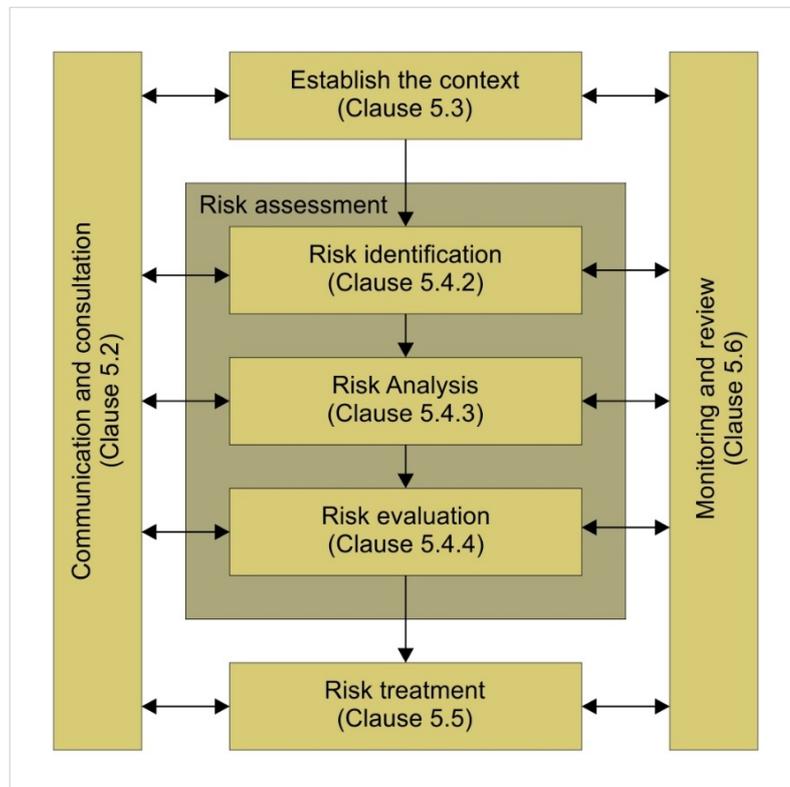
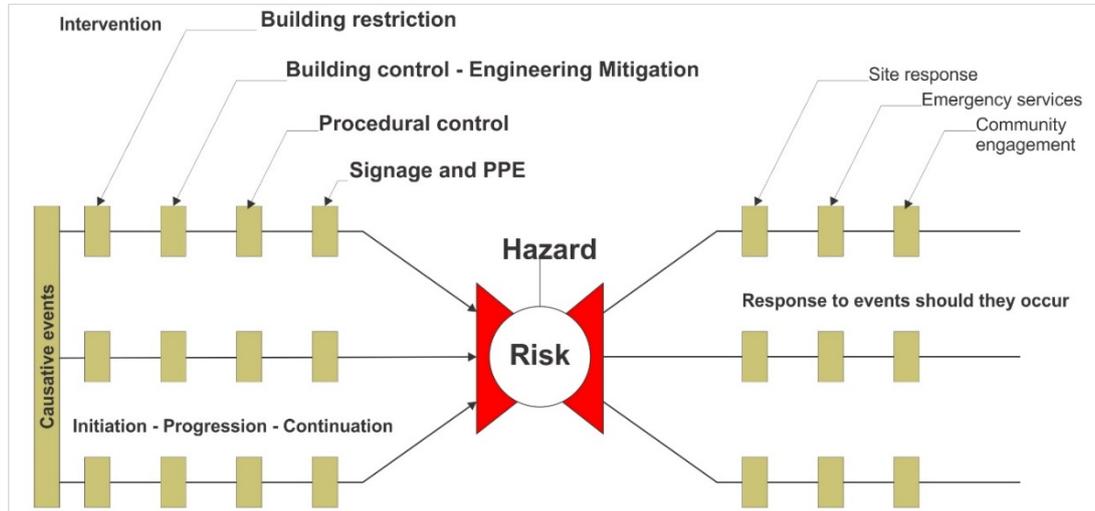


FIGURE 1 – ISO 31000 RISK ASSESSMENT PROCESS

**Risk Assessment for Urban Development Areas – Huntly East Mine**

The workshops adopted the Bow Tie process which is commonly used for assessing risks and their mitigation (Figure 2). The two causative events of interest are; settlement processes in the mine and the collection of coal seam gas in mine voids. The effects on the surface environment and the likelihood of their occurrence can be assessed from these events and the mechanisms involved.



**FIGURE 2 – BOW TIE ASSESSMENT METHODOLOGY**

The evaluation of risk adopts the scheme presented by GNS (2015), which is a 5 by 5 matrix of likelihood and consequence to assess the risk’s severity (Figure 3).

**Assessment Matrix Guidelines**

		Consequences				
		Negligible 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	Almost Certain (5)	Blue	Yellow	Orange	Red	Red
	Likely (4)	Green	Blue	Yellow	Orange	Red
	Possible (3)	Green	Blue	Blue	Yellow	Orange
	Unlikely (2)	Green	Green	Blue	Blue	Yellow
	Rare (1)	Green	Green	Green	Green	Blue

**FIGURE 3 – GNS (2015) EVALUATION AND ASSESSMENT OF RISK**

Where mitigation measures are necessary and appropriate these are incorporated into the risk register and the risk is re-evaluated using the same assessment matrix.

### 3 WORKSHOPS

Workshops and telephone discussions supported the development of the risk assessment. The workshops covered different aspects and topics:

- 24<sup>th</sup> July 2019 – Huntly Power Station conference room. **Future developments** in the area. The large venue accommodated 12 participants, allowed for presentations and areas for discussion.
- 16<sup>th</sup> August 2019 – Telephone conference. **Existing urban environment**. This workshop took approximately two hours and followed roughly the same format as the initial workshop on possible future developments.

The attendees included a broad range of individuals from various groups in Waikato District Council, including; Regulation management, District planning and policy, Consents, Resource management, Building control, Utility asset management and operation as well as communications. In addition to Waikato District Council representation, the workshop on 24<sup>th</sup> July was also attended by Ian Brown, an independent consultant from IRBA. The workshops were conducted by RDCL (Cam Wylie and Jeremy Eldridge) and focused on:

- Establishing the historical context of the mine development and the urban setting.
- Establishing risks and probabilities within the context of the recorded risks in other common activities and circumstances.
- Exploring possible mechanisms for the progression of the hazards from the mine to the surface environment.
- Exploring the qualitative understanding of likelihood that these mechanisms might occur.
- Developing possible measures to mitigate unacceptable risks.

## 4 LIKELIHOOD

The assessment of likelihood is set in the context of the hazards and risks encountered frequently and infrequently by the public, in different occupations and activities. In the 1990s The Health and Safety Executive (HSE) of the United Kingdom undertook an extensive study of the risks to the public as individuals and what risks are accepted by society.

HSE (1992) proposed the threshold for acceptability is a likelihood of occurrence in any one year of 1 : 10,000. If a serious event is more likely than this, then a society would mitigate the possibility or reduce the effects of an event. This threshold is now widely accepted across many developed countries in the governance of significant hazards.

In New Zealand this criterion is evident in determining the design criteria for large water retaining dams. This 1:10,000 Annual Exceedance Probability event is described as:

“The condition or event has not been observed, and no plausible scenario could be identified, even after considerable effort.” (ANCOLD 2003, after Barneich 1996)

The significance of the threshold in the context of other common activities is illustrated in Table 1. The data is taken from HSE (1992, 2001) and other sources. These statistics tend to change over time and from country to country. They are presented here to provide context for the discussion of likelihood. During compilation, no statistics were identified that specifically relate to risks from gas migration from abandoned underground coal mines. The absence of such statistics suggest that such risks are small or negligible when compared with other typical risks experienced by communities.

**TABLE 1 – LIKELIHOOD OF COMMON ACTIVITIES**

Activity	Likelihood (Probability in any year- AEP)
Fatality in mountain climbing 5 hours every weekend	1 : 100
Fatality in offshore oil; and gas industry	1 : 600
Fatality in deep sea fishing	1 : 750
Fatality in mineral extraction (mining)	1 : 3,900
Threshold – Theoretically possible but not at all expected	1 : 10,000
Fatality in gas incident (fire explosion, carbon dioxide poisoning averaged over UK population)	1 : 1.1 million
Fatality from a lighting strike	1 : 10 million

From Various sources since the 1990s

The definitions for understanding likelihood used in this risk assessment were developed in association with Waikato District Council (Figure 4).

**Risk Assessment for Urban Development Areas – Huntly East Mine**

<b>Level and</b>	<b>Definition</b>	<b>Experience</b>	<b>Estimated Frequency</b>
<b>Likely 5</b>	Expected to occur in most years.	An almost inevitable event	AEP 1 : 1
<b>Possible 4</b>	Expected to occur possibly in any one year.	Events that will probably happen in common circumstances	AEP 1 : 10
<b>Unlikely 3</b>	Expected to occur in period of a few years.	Events that could happen at some time	AEP 1 : 20
<b>Rare 2</b>	Expected to occur in a generation.	Conceivable but highly unlikely	AEP 1 : 200
<b>Very Rare 1</b>	It is an unlikely experience by an individual in a lifetime.	Theoretically possible but not at all expected	AEP 1 : 10,000

**FIGURE 4 – LIKELIHOOD DEFINITION FOR THIS RISK ASSESSMENT**

## 5 CONSEQUENCE

The list of consequences is focused on specific effects that might be observed in the surface environment. These are related to the different configurations of:

- Residential developments. Including; all residences where people may sleep, thus both individual homes, hostels, retirement homes and the like. This group includes considerations of associated buildings or facilities such as building extensions and swimming pools.
- Non-residential developments. Including; commercial buildings where people are not resident, such as offices, warehouses, and supermarkets. These buildings do not have people sleeping in them i.e. those locations where people are conscious while in occupation.
- Above ground infrastructure. Including; footpaths, roads, road furniture, retaining walls, power cables, telephone cables, earthworks and embankments.
- Below ground infrastructure. Including; water supply, wastewater, gas supply, buried telecommunications (including fibre optics cables).

The significance of an event is dependent on the impact severity of the possible effects in categories of Health and Safety, Monetary loss, Infrastructure damage, Legal or regulatory breach, Reputation and media coverage, Environment and sustainability consequence.

These categories generate a matrix with the severity of the impact of the consequence categories; Insignificant, Minor, Moderate, Major, and Catastrophic. The type of effects is related to key factors affecting individuals, communities or organisations (public and private) (Figure 5). To meet an impact category severity criterion only one of the effects needs to be met, not all.

**Risk Assessment for Urban Development Areas – Huntly East Mine**

Severity of impact	Hazard Types				
	Monetary loss	Health & Safety	Infrastructure	Legal / Regulatory Breach	Environmental / Sustainability
<b>Catastrophic</b> (5)	> NZ \$2 Million	Multiple fatalities or severe permanent disabilities / Loss of operational facility	Loss of a significant commercial or residential neighbourhood	Criminal convictions, financially material judgement, very serious litigation (including class actions)	Very serious, long term eco-system or social function impairment
<b>Major</b> (4)	NZ \$0.2 - 2 Million	Extensive or severe injuries that require hospitalization >48 hours / Significant damage of operational facility	Loss of: A commercial building A few houses	Temporary suspension, litigation, major judicial order or commercial dispute	Serious incident with medium term social or eco-system effects
<b>Moderate</b> (3)	NZ \$100k - 200k	Injuries requiring hospitalisation ≤48 hours / Extensive damage	Disruption to significant underground infrastructure Gas pipe lines Electrical power lines Telecommunications	Non compliance with Regulations, Codes or rules, significant judicial order or commercial dispute	Local event with short to medium term social or environmental effects
<b>Minor</b> (2)	NZ \$50K - 100K	Lost time injury (LTI) / Minor damage	Disruption to safety infrastructure requiring a rapid response - eg road signals	Non conformance with regulations, minor legal claims or commercial dispute	Localized incident, moderate, short term effects, non eco-system
<b>Insignificant</b> (1)	Up to NZ \$50K	First aid minor medical or no injury / No damage	Minor cracks in surface infrastructure - repairs can be delayed	Small claims legal or commercial dispute	Minor biological environmental & social events

**FIGURE 5 – CONSEQUENCE DEFINITION FOR THIS RISK ASSESSMENT**

## 6 CAUSATIVE MECHANISMS

The mechanism that lead to consequences are dependent on the root causes. The causes identified for the closed Huntly East Mine relate to:

- Surface settlement; and
- Coal gas migration.

### 6.1 SETTLEMENT - INITIATION AND PROPAGATION

The surface settlement over the mine is a consequence of the collapse of the void formed by coal extraction. However, the type and magnitude of settlement is depending on factors such as:

- The mining method; small pillars methods (Zone A) promote greater settlement than either large pillar method (Zone B) or the longwall method (Zone C). The areas over the mine roadways (Mine Roadways) are unlikely to exhibit any appreciable settlement due to their inherent cavern stability. (Figure 6)
- The geological structure over the mine. The brittle mudstone of the Te Kuiti Group (Figure 7) immediately above the mine workings did, at times, collapse into the workings. However, the deep soft, saturated soils above the mudstone has not permitted an open hole to develop to the ground surface (a crown hole). The presence of the soft alluvium of the Tauranga Group probably inhibits the development of crown holes.
- The depth of the coal workings below ground. Shallower mining working are likely to exhibit more pronounced settlement, with greater differential settlements. The shallowest mine workings are in the southern areas, where the depth of the workings is approximately 100m.

Historically the most significant settlement event occurred in the southern area early in the 1980s. This area is characterised by the small pillar mining method and is the area of the shallowest mine workings. Yet, even in these circumstances an open crown hole did not develop.

The longwall mining method promotes consistent settlement across the surface as the longwall advances. Differential settlement tends to advance as a slow wave at the same pace as the longwall mining. However, residual ongoing settlement after a mine is closed is not a characteristic of this mining method.

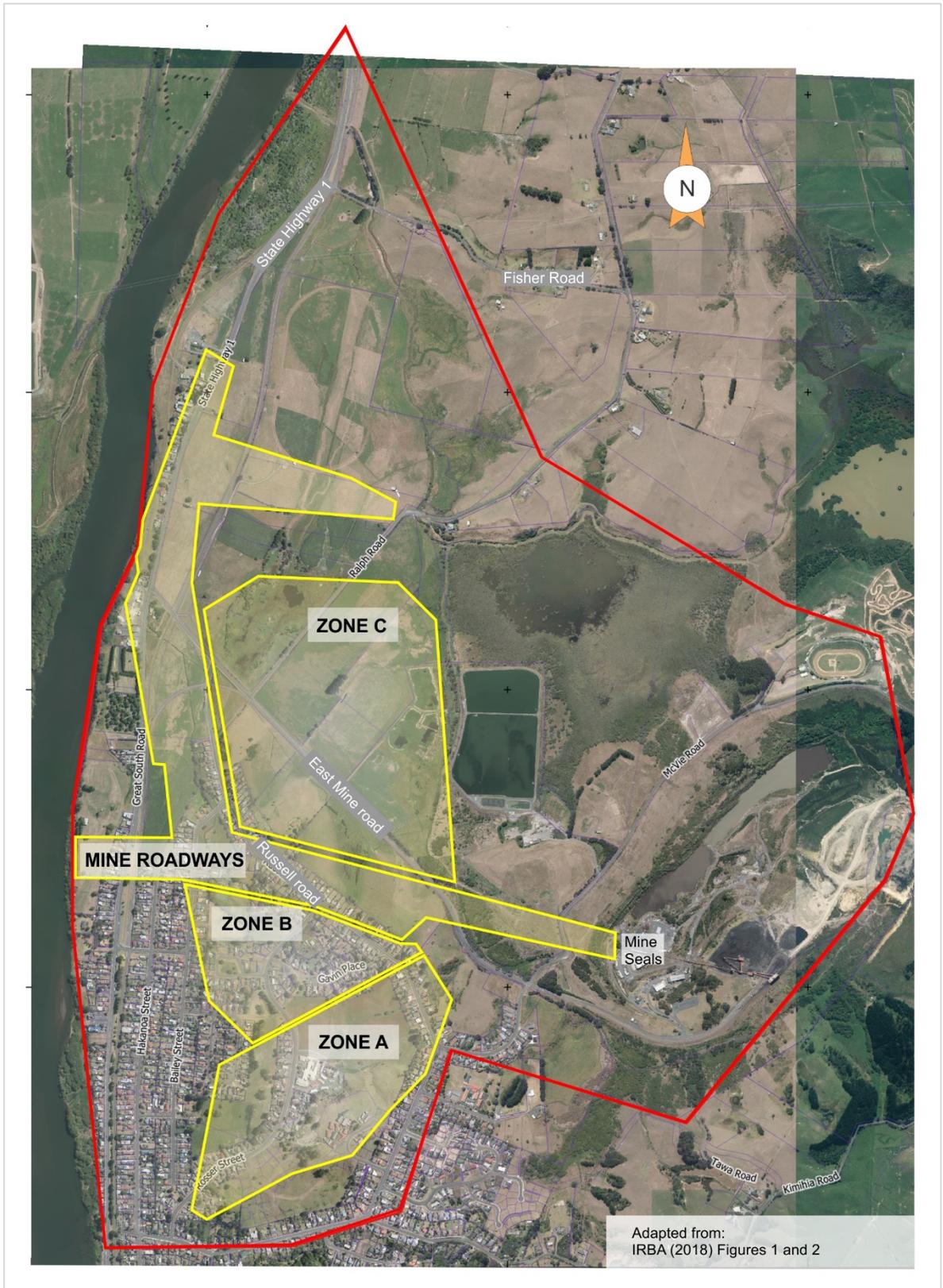


FIGURE 6 – ZONE LOCATIONS

## 6.2 GAS MIGRATION - INITIATION AND PROPAGATION

The constituents of consequence in coal seam gas is methane and when mixed with oxygen at specific concentrations can be ignited (between 5% and 15% by volume in air). Coal seam gas emerges from the remaining coal on the seam when there is less pressure in a void than in the coal measure. Likewise, the gas will theoretically move from a void with high pressure to another location of lower pressure. On closure the mine was sealed and the monitoring since indicates that, as intended, the methane concentration in the mine void is too high for combustion.

Once the mine is fully flooded, the pressure is equalised throughout the coal measure and is equal to the hydrostatic pressure of the groundwater above. At that time there is no further possibility of gas emerging from the coal. In the interim period, to be a credible risk to the surface environment, the gas must first reach the surface. Two mechanisms have been postulated (IRBA, 2018), but not proven:

- Gas travelling in water through the overlying groundwater regime to the near ground surface.
- Gas migrating up abandoned ground investigation boreholes installed as part of the initial mine investigations.

Regarding the first mechanism; methane is not very soluble in water at low pressures. However, elsewhere around the world it is detected in shallow groundwater (for example Bell 2017 and USGS 2006). The sources of methane in these groundwaters are various, including; near surface biogenic methane and methane of geological age. Edwards (1991) notes that methane is not very soluble at low pressure but become more soluble at high pressure. Edwards also notes that water can release methane if water containing methane travels from a location of high pressure to a low pressure environment, e.g. the ground surface. Methane can also be transported as a mixture with water in a high flow environment, for example flow in a sewerage pipe where water, air and methane mixtures flow in a turbulent environment.

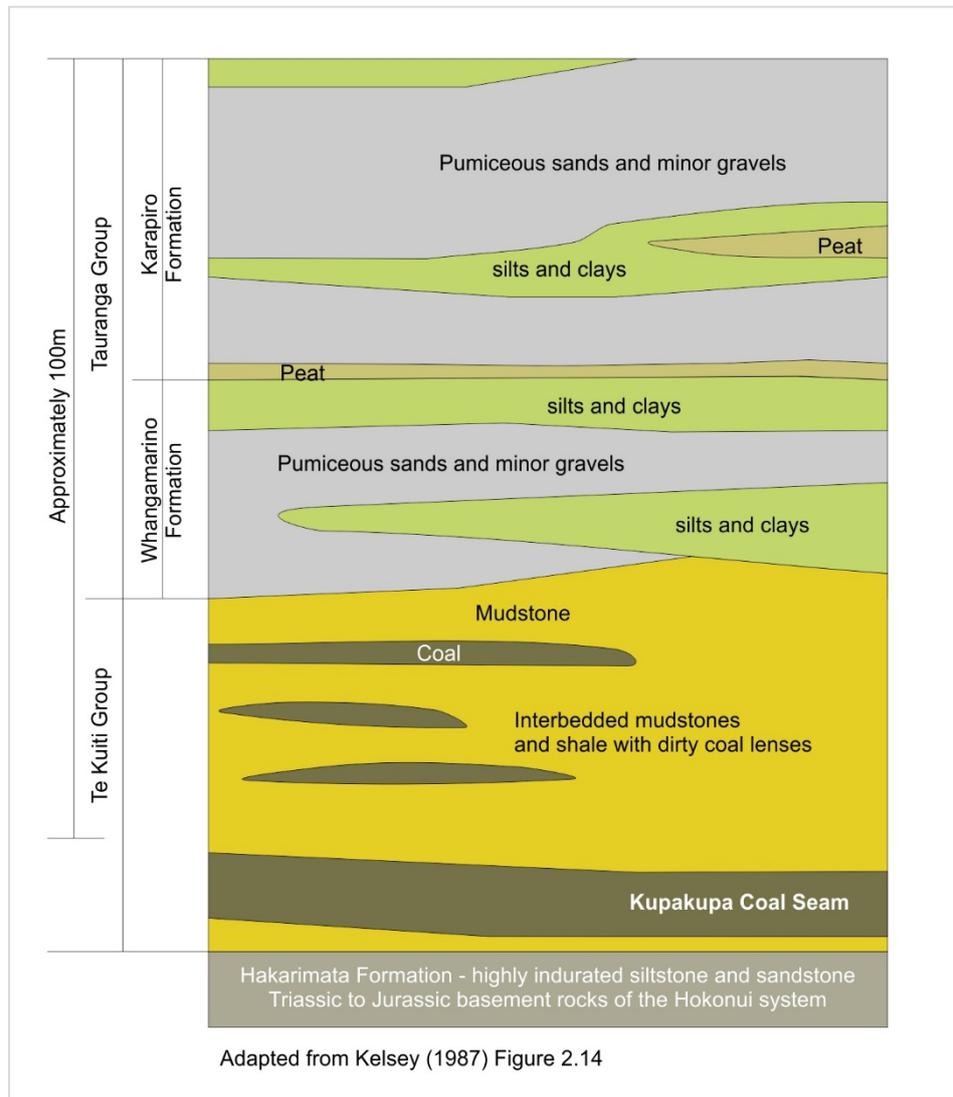
However, the transport of both methane in solution or as a mixture require flow of water to transport the gas. There is no evidence nor a credible mechanism for water to flow from the mine workings to the ground surface through the overlying saturated low permeability alluvial deposits of the Tauranga Group (Figure 7).

The second of the postulated mechanisms is the travel of gas up an abandoned open site borehole which would have been drilled in the late 1970s as part of the investigation for the mine. Typically, diameter of this type of borehole would probably have been between 4” and 5” (96mm - 125mm). They would have required a steel casing to prevent the surrounding

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soft alluvium from filling the advancing hole before reaching the sandstones and the coal measures of interest. Once the hole is completed and the necessary samples have been retrieved, the casing is withdrawn to be used on another investigation hole. The casing is used to keep the borehole open during an investigation. Following the withdrawal of the casing it is common and expected that the surrounding alluvium would move into the hole and fully close the hole. The hole’s site would then act as a barrier to gas migration in a similar way to the surrounding alluvium.

Consequently, based on the discussions above, both mechanisms are considered by the workshops participants to be less likely than “theoretically possible but not at all expected”.



**FIGURE 7 – SCHEMATIC ENGINEERING GEOLOGICAL PROFILE (KELSEY 1987)**

## 7 FUTURE URBAN DEVELOPMENT

The area of interest has the potential for both commercial and residential development, with the attendant above and below ground infrastructure. In developing the risk assessment the following is assumed:

- The presence of the mine is acknowledged and appreciated in planning any development.
- The area is relatively flat requiring no large-scale earthworks to facilitate development, particularly deep excavations.
- The developments will not include high rise buildings and therefore no deep foundations, such as piles, are anticipated.

### 7.1 RISKS

The possibility of risks differs depending on the mining method and therefore the zone being considered. The risk is also influenced by the resilience of the structure being considered, and the damage that might occur to that structure under the same circumstances. The assessment of the risks for different types of development in each zone are recorded in the risk register (dated 2<sup>nd</sup> October 2019). The general points are:

Settlement occurrence:

- The development of crown holes in Zone A is likely to be **rare** and **very rare** across the other areas. No crown holes have developed in the area in the past.
- Differential settlement exceeding 25mm across 6m (MBIE (2014) B1/VM4 Appendix B Section B1.0.2) is **likely to possible** in Zones A and B. There have been similar experiences of settlement in area A in the past. In the other zones the possibility of settlement being more extreme than is otherwise expected in the Building Code is **rare to very rare**.

Gas migration occurrence:

- The likelihood that coal gas might migrate to the surface in the period from the closure of the mine working to the time when the mine is fully flooded was assessed as **very rare**. This assessment is based on the consideration that mechanisms for gas migration from the coal measures to the surface might be theoretically possible, but they are not expected. For this reason, consideration of gas migration to the surface are not considered further in this report.

## 7.2 MITIGATION

The primary effects to be mitigated relate to settlement and typically this is likely to occur in Zone A and possibly Zone B. The primary means of addressing differential settlement exceeding the threshold of 25mm across a distance of 6m depends on the type of structure planned or type of utility to be installed.

There are documents that can assist in defining suitable arrangements to mitigate moderate differential settlements exceeding the threshold for settlements. These include:

- Ministry of Works (1985) provides a draft of code of practice for construction of buildings in mining areas. Although some of the building practices might appear to be inconsistent with modern building practice, the considerations and factors to be evaluated remain relevant.
- MBIE (2012) provides technical guidance on the arrangements for ground slab foundations and other house elements to resist the effects of unstable ground.

### 7.2.1 RESIDENTIAL

The following factors warrant consideration for residential developments:

- Limiting the lateral extent of a building foundation in any direction.
- Adopt suitable foundations that can either accommodate differential settlement or span across differential settlement.
- Consider the use of flexible building frames and materials that accommodate settlement and distortion.
- Provide flexible connections for all utilities at the interface between the ground and the structure.
- Drainage and sewerage systems should be piped to a distance at least 20 m from the structure and preferably connects to the urban drainage systems.
- Limiting or preventing the construction of permanent or in-ground swimming pools.

### 7.2.2 NON RESIDENTIAL

The following factors warrant consideration for non-residential developments, such as warehouses, shopping malls and offices:

- Limit the structural dimensions of buildings.
- Limit the number of storeys in commercial buildings.
- Provide a minimum separation between buildings.
- Ensure that concrete slabs are reinforced with, at least, steel mesh.
- The detailing of any utilities penetrating a ground slab should provide for movement and allow for repair of the utilities below the slab if this occurs.

### 7.2.3 ABOVE GROUND INFRASTRUCTURE

The following factors warrant consideration for above ground infrastructure associated with roads and other liner infrastructure:

- Road pavements should be flexible and allow for settlement in the gradients to maintain drainage after settlement.
- Road furniture such as lamp post and traffic lights should have bases that can allow for vertical realignment.
- Retaining walls should have movement joints at frequent intervals.
- Embankments should not be of an excessive height.

### 7.2.4 BELOW GROUND INFRASTRUCTURE

The following factors warrants consideration for below ground infrastructure such as buried utilities in ducts, pipes and cables:

- Fibre optic cables are brittle and not tolerant of extension or tight bends. Suitable allowances should be made to accommodate settlement.
- Below ground utilities can be brittle and sensitive to settlement. Suitable flexible materials, jointing systems and gradients should be considered for utilities.
- Where utilities, such as cables, interface with buildings there should be sufficient provision for movement.
- No wells should be permitted in the area.

## **8 CURRENT URBAN ENVIRONMENT**

The current urban development is primarily in Zones A and B. Much of the development in these zones is residential including the Kimihia Home & Hospital. The structures are typically:

- Single story homes some of these have garages below the main structure.
- Many of the houses have either brick or timber facades. Timber frames and facades for houses are typically more accommodating of settlement than other building materials.
- Most of the area in Zone A is open land. The Kimihia Home & Hospital is the most significant structure within this zone.
- Zone B is predominantly domestic housing.

Zone C, to the north of Russell Road, is primarily undeveloped farmland.

### **8.1 RISKS**

The primary mechanisms for damage in the area is settlement, which is the same as the risk for future developments. The inherent flexibility in houses of timber frames and facades results in a greater tolerance of settlement than other building materials. By contrast settlement and distortion is particularly evident in brick structures.

### **8.2 MITIGATION**

The existing urban environment is largely absent from Zone A and Zone C. The remaining area, Zone B, consists primarily of low-rise residential areas. The risk assessment suggests that mitigation against the possible effects of settlement on the existing houses in Zone B is not necessary in these circumstances.

## 9 MONITORING

Monitoring for both settlement and gas migration was considered in the workshops as a means of providing alerts to changing circumstances. Conceptually, the workshop participants considered adopting existing facilities and implementing new monitoring networks:

- There are no existing networks for the dedicated measurement of settlement or gas migration to the ground surface across any of the areas of interest.
- The design, development and implementation of a new monitoring network must be intermittent across the area (irrespective of the network density). In addition, critical thresholds for settlement and gas are not set as international standards.
- There is an extensive network of subsurface infrastructure across the urban area (Figure 8) and this will extend across future developments. These buried utilities are regularly monitored for deterioration (including settlement) and gas is monitored before entering the network. Workshop participants confirm that gas levels in excess of expected background levels have not been detected to date and there are no unusual settlement patterns across the area.

The monitoring of the condition of existing and future subsurface utility networks provides an extensive passive monitoring network. The regular monitoring will provide a means of identifying changes in both settlement and the presence of methane gas. If persistent high levels were to be identified (instead of the common spikes usually observed in sewerage systems) further investigations would be undertaken.

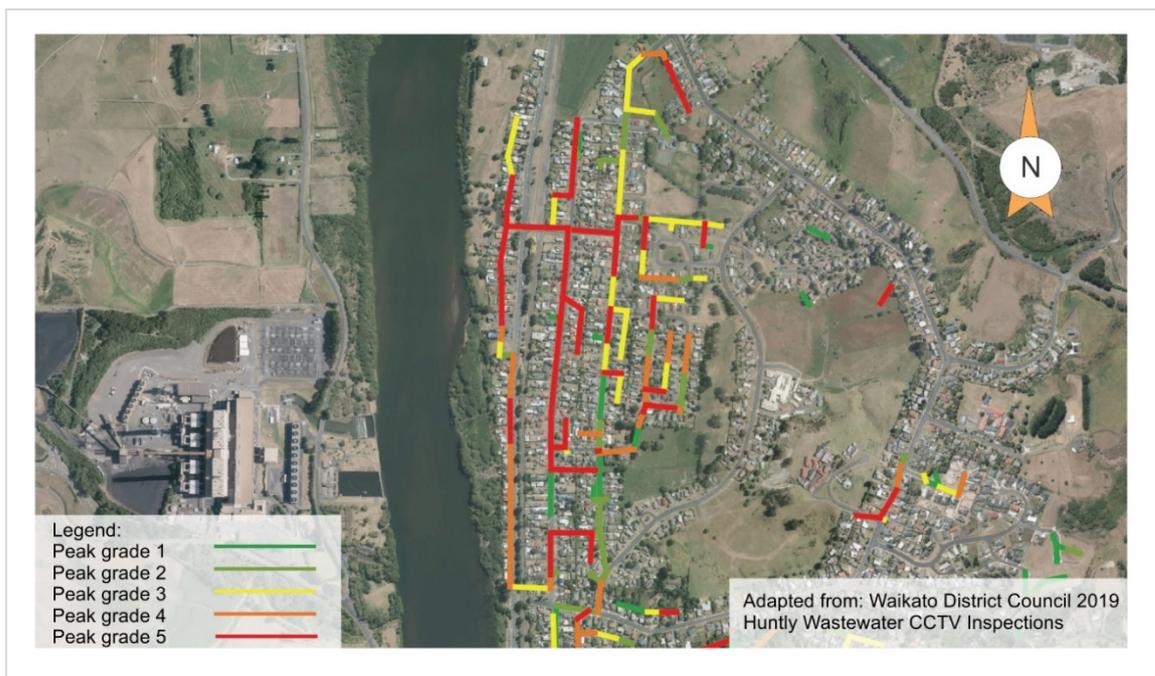


FIGURE 8 – WASTE WATER CCTV MONITORING

## 10 CONCLUSIONS

The risks to future development and to the existing environment are assessed within the AS/NZS ISO 31000 risk assessment framework. The assessment included:

- The context; based on historical reports and discussion in the workshops.
- Risk identification; the identification of causes and mechanics for settlement and coal gas migration to the surface environment. Possible consequences have been identified and the descriptive understanding of likelihood established.
- Risk analysis; the workshops elaborated on the consequences and the possible likelihood that these might occur.
- Risk evaluation; the risk register records the consequences and likelihood of occurrence in the future. In addition, these risk registers record possible mitigation measures where they are considered necessary.

The assessment has identified four separate areas that present different combinations of consequences and likelihood (Figure 6):

- Area A – Areas where the small pillar coal extraction methods were adopted.
- Area B – Areas where large pillar coal extraction methods were adopted.
- Area C – Area where long wall coal extraction methods were adopted.
- Mine road network - These areas have robust structure and are unlikely to manifest settlement or gas migration.

The outcomes of the risk assessment are presented in the risk registers. These registers record different risks depending on differences in mechanisms and possible near surface responses.

The main summary points are:

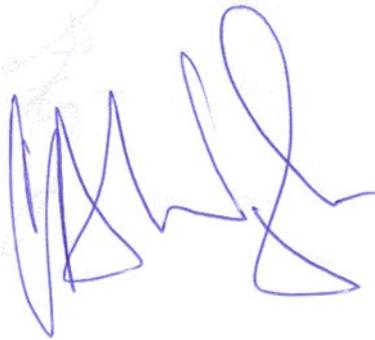
- The most prominent ongoing settlement effects are likely to be in Area A where small pillar mining techniques were adopted.
- The likelihood of coal seam gas migrating to the surface by credible mechanisms is considered to be theoretically possible but **is not** expected. This threshold is consistent with a society implementing no additional measures to mitigate a risk.

Monitoring for both adverse settlement and gas migration to the surface can be effectively achieved by maintaining and observing the behaviours of the extensive subsurface utility networks across urban areas above the mine. Given the current monitoring of the networks for both damage and gas in the voids, these networks are likely to be more comprehensive than the implementation of dedicated monitoring networks.

## 11 LIMITATIONS

- This report has been prepared for the particular purpose outlined in the project brief and no responsibility is accepted for the use of any part in other contexts or for any other purpose.
- No responsibility is accepted by Resource Development Consultants Ltd for inaccuracies in data supplied by others. Where data has been supplied by others, it has been assumed that this information is correct.
- This report is provided for sole use by the client and is confidential to the client and their professional advisors. No responsibility whatsoever for the contents of this report shall be accepted for any person other than the client.

Approved by:



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CPEng, CMEngNZ, MAusIMM, CP (Mine Geotech); CMIOD

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