ATTACHMENT B

CITY OF NANAIMO
THE HARBOUR CITY
PLANNING & DEVELOPMENT

GUIDELINES FOR GEOTECHNICAL ASSESSMENTS ABOVE ABANDONED MINE WORKINGS

DRAFT

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CITY OF NANAIMO
THE HARBOUR CITY

GUIDELINES FOR GEOTECHNICAL ASSESSMENTS ABOVE ABANDONED MINE WORKINGS

1 Introduction

This guideline outlines good practices for the geotechnical assessment of land intended for development that is underlain or influenced by abandoned underground mine workings in the City of Nanaimo (City). The guideline pertains to the geotechnical aspects of land development in the context of the City's land development and building approval process. The guideline falls under the broader umbrella of the City's *Guidelines for the Completion of Geotechnical Reports*[1]. The known extent of lands underlain by abandoned underground mine workings is described in the *City Plan Bylaw 2022 No. 6600* (City Plan) Development Permit Area 4: Abandoned Mine Workings Hazards (DPA 4) and shown on Schedule 9 to that bylaw, *DPA 4: Abandoned Mine Workings Hazards*.

Abandoned mine workings underlie approximately 13 of the 93 square kilometres of land within the City limits. A further 7 square kilometres of abandoned workings are located below adjacent coastal waters. The presence of abandoned mine workings introduces geological hazards that have the potential to negatively impact development in the form of health and safety, the stability of structures or lands, and/or the natural environment. These hazards must be assessed and, if determined to constitute unacceptable risk, mitigated through the development process to provide the City with assurance that the land can be used safely for the use intended.

In its role as the Approving Authority for land development and building permit applications, the City has developed these guidelines to provide proponents with background information and context on historical mining activities within the City, as well as good practices in the evaluation and mitigation of mining-induced geological hazards.

This Guideline is not intended to be prescriptive nor is it intended to serve as a substitute for engineering judgement and experience. This Guideline is a working document and will periodically be updated as historical information comes to light.

2 Historical Mining Background Information

The Nanaimo Coalfield in the period 1850 to 1950 produced almost half of the coal mined in British Columbia[2]. Over ninety per cent of the coal was commercially mined from three seams;

[1] City of Nanaimo Guidelines for the Completion of Geotechnical Reports, 2023.
[2] Canada Department of Mines and Resources Mines and Energy Branch, Geological Survey Paper 47-22. Prepared by A.F. Buckham.

the Wellington, Newcastle, and Douglas seams. The distribution of historical mining across the City, based on available historical records, is shown in Figure 1.

Stratigraphically, the lowest of the three main coal seams was the Wellington Seam. As indicated in Figure 1, this seam was worked in North Nanaimo in the vicinity of Wellington, Jingle Pot and Wakesiah. Beyond the City limits, it was also worked in the Extension area. The productive area of this seam was bound by its outcrop and by extensive faulting along the southwest and to the north. Although collectively described as the Wellington seam, there were up to four separate seams referred to as the No. 1 or Main Wellington; above which were the Little Wellington (No. 2) seam and the Wellington No. 3 and No. 4 seams, respectively. The upper two seams rarely exceeded 0.6m in thickness. The lower seams were commercially mined as upper and lower workings in several areas of Nanaimo, as indicated through hatching on Figure 1. The Main Wellington seam is described in the Annual Reports produced by the BC Minister of Mines[3] and generally ranged in thickness from 1.2 to 2.1m. The floor of the mine was typically sandstone with roof rock that included weaker shales as well as areas of sandstone and conglomerate.

Present some 300 m stratigraphically above the Wellington Seam was the Newcastle Seam[1]. Workings in the nominally 1 m thick coal seam were predominantly limited to the Central Nanaimo areas of Newcastle and Protection Islands and adjacent offshore areas.

The Douglas seam lies approximately 20m stratigraphically above the Newcastle seam and generally averages 1.5m in thickness. However, the seam thickness can vary widely and there are Annual Reports produced by the BC Minister of Mines[2] indicating seam thicknesses that exceed 5m. The seam was extensively worked in the Central and South Nanaimo areas, as shown in Figure 1.

The structural geology of Nanaimo is complex and the coalfield itself has been truncated, thrust and downthrown by a number of geological faults. Figure 1 indicates the inferred trace line of the main faults (projected surface expression) shown on the published bedrock geology mapping[4]. Further discussion related to the potential impacts of faulting on land development is provided later in the guideline.

Approximately fifty recorded mining operations have been identified within the City limits. Some, such as the No.1 Mine in Central Nanaimo, operated for over fifty years and withdrew millions of tons of coal. Others operated for less than a year and focussed on the removal of pillars of coal left for roof support from earlier mining operations, such as those in the Wellington area of North Nanaimo.

[3] British Columbia Annual Repot of Minister of Mines (1874 to 1965)
[4] Ministry of Energy and Mines Open File 1998-07. Geology of the Westward Lake Area, Nanaimo Coalfield, BC

A database of historical mining information is provided in Table 1. This information was assembled from a number of sources that included the Annual Reports of the BC Minister of Mines between 1874 and 1964 [2], records and mine plans held in the Nanaimo Community Archives and online information from the BC Ministry of Energy Mines and Petroleum Resources web site. Table 1 indicates the name of the mine and provides a location referenced in Figure 1. The age of the workings, mining method and physical attributes of the seam are included in the table along with a mine plan reference for the Nanaimo Community Archives, where available.

The two methods of mining used historically in Nanaimo were the room and pillar method and the longwall method. The room and pillar method, also known as "pillar and stall", "bord and pillar", post and stall", "post and bank" and "stoop and room", resulted in a rectilinear network of interconnecting roadways with un-mined "pillars" of coal left between them to support the roof. A review of historic working mine plans in the Nanaimo coalfield indicates that working areas were typically between 6 to 9 m wide with pillar widths of 10 to 20 m and an extraction ratio in the range of 50 to 60 per cent. However, pillars were often removed, or "robbed", to various extents during the retreat process prior to the closure and final abandonment of the mine. This naturally reduces the ability of the remaining pillars to support the roof of the mine, thereby resulting in the potential for future collapse and possible void migration to the ground surface. As indicated in Table 1, a number of the more modest mining operations were developed specifically to remove pillars of coal left behind from larger commercial workings that had previously been abandoned. The method of roof support used during those activities along with the current stability of the roof, is uncertain, as is the extent of pillar removal. Longwall mining in the Nanaimo coalfield in and around the turn of the century and extending into the mid-19th century was largely non-mechanised. This methodology involved the development of a face of coal that was typically in the order of several tens of metres long. The face was worked in a series of shifts to undermine, cut, and drop the coal into manageable-sized pieces for removal. The mine roof area exposed by the extracted coal was temporarily supported with timber props and the process was repeated to further advance the coal face. As the working face advanced, the props and temporarily supported ground collapsed to form an area of waste rock or "goal". The subsidence of the ground surface above and, to a limited extent in front, of the working face was a function of depth, seam thickness and the ratio of cut face length to overburden depth; along with local geological factors such as geology, the dip of the seam and the presence of faulting[5]. In contrast to the time-dependent process of room and pillar subsidence, the majority of ground subsidence associated with the longwall methodology of extraction occurred during and shortly after extraction.

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[5] National Coal Mining Department 1975. Subsidence Engineers' Handbook.

The reader is referred to CIRIA C758[6] (C758D for digital version) and Bell (1988)[7] for further discussion related to mining methodology and associated legacy issues.

3 Legislative Context

Proposed residential development in British Columbia is governed by several provincial statutes. The statutes that require assessments by Qualified Professionals in relation to hazardous conditions include the *Land Title Act* (typically in support of subdivision approvals); the *Local Government Act* (typically in support of Development Permits); and the *Community Charter* (Typically related to Building Permits).

The City has recognized the potential for hazardous conditions caused by historical undermining or mining-related activities within portions of the City's boundaries and has established Development Permit Area 4 in *City Plan*, along with these guidelines, to set out the framework for geotechnical assessments for approvals for new development.

4 Mining-Induced Geological Hazards

There is a broad range of mining-induced geological hazards associated with the historical mining in Nanaimo that have the potential to affect land development. There are various triggering mechanisms related to these hazards that include time-dependent natural geological processes of weathering erosion and stress relief, and more rapid changes induced by seismicity or land development activities such as earthworks, blast vibrations, changes in the water table, or additional loading. Table 2 identifies seven broad categories of abandoned mining elements, within which there are further sub-categories. For example, the category of abandoned entries to underground workings includes sub-categories for shafts, slopes and adits, and bell pits. The main categories shown in Table 2 are:

- Abandoned entries to underground workings;
- Room and pillar workings;
- Longwall coal mining;
- Fault reactivation and fissures;
- Mine gas;
- Mine Water; and
- Mine waste.

[6] Construction Industry Research and Information Association (CIRIA) C758 Abandoned Mine Workings Manual, 2019.
[7] Bell, F.G. 1988. The history and techniques of coal mining and the associated effects and influence on construction. *Bulletin Association Engineering Geologists,* 24, 471-504.

Table 2 provides a synopsis of the principle mining-induced geological hazards that are related to each category. Along with the discussion on hazards, Table 2 summarizes the potential triggering issues related to the hazard and the potential primary consequences as they pertain to land development activities. Consequences fall broadly into considerations of health and safety, damage to land, buildings and infrastructure, and harm to the environment. In some cases, there may be consequences associated with a hazard that triggers the need for an environmental assessment under provincial law that is not considered in this geotechnically focussed guideline.

The hazards that are summarized in Table 2 will not be present at all sites that are underlain by abandoned underground mine workings. It is necessary to complete an engineering and/or environmental assessment to determine the presence of the hazard, possible triggers related to the proposed development activity and the associated potential consequences. In some cases, there may be compound or secondary issues that are not covered in Table 2 that require the judgement of an appropriately qualified and experienced professional.

Certain elements of historical mining such as abandoned entries, mine gas, mine water and mine waste may trigger requirements for an environmental assessment under the BC Environmental Management Act, Contaminated Sites Regulation. Where considered most likely, this potential consequence has been included in Table 2. Notwithstanding the legislated requirements for assessment for activities specifically identified in Schedule 2 Industrial and Commercial Purposes and Activities of the Regulation, there may be instances where mining-induced settlement has created fractures and openings in the rock mass that introduce secondary hazards such as potential migration pathways for mine gas or water that may fall outside of a Schedule 2 activity but may need to be considered in the City's approval process.

5 Abandoned Mine Workings Risk Assessment

Assessing potential risks related to mining-induced geological hazards is a critical part of the land development approval process. Where the assessed risk to health and safety, damage to land, buildings and infrastructure, or harm to the environment is judged to be unacceptable, some form of mitigation is required by the proponent to demonstrate that the land can be used safely for the use intended.

An abandoned mine working risk assessment must be completed by a professional engineer or geoscientist in good standing with Engineers & Geoscientists British Columbia experienced in geotechnical engineering ("Qualified Professional").

The City has completed a preliminary risk assessment of geotechnical issues of ground stability and mining legacy, which is included in Figure 2. The preliminary risk assessment was undertaken to assist the City at a planning level. The assessment is not to be used on a site-specific basis due to the coarseness of the information coupled with an inability to capture development-specific risk components. It is a requirement of Section 18.4.3 of the City of Nanaimo Zoning Bylaw that a geotechnical assessment specific to the site and nature of the project be submitted to support the Development Permit Area 4 development permit application.

For the purpose of the City's planning, Figure 2 separates the results of the preliminary assessment into areas of High (red), Moderate (yellow) and Low (green) risk. The risk screening criteria that were applied to each potential type of hazard are summarized in Table 3. The preliminary assessment was restricted to potential risks from ground stability-related hazards and did not consider potential risks associated with environmental hazards related to mine water, mine gas, or mine waste. Risks associated with all forms of potential hazard will need to be evaluated by the proponent on a specific application basis.

5.1 High Risk

The City's preliminary assignment of risk was based on the nature of the hazard and its potential consequences for land development. The High Risk designation was assigned to consequences that involve the potential for direct safety issues or sudden and severe distress to property. Areas of High Risk identified from the preliminary assessment are shown in red in Figure 2 and include:

- The potential for sudden ground collapse associated with all openings to mine workings and prospecting works including shafts, slopes, and adits. The preliminary assessment identified some 55 vertical shafts and some 35 inclined or level slopes and adits within the City limits. There may be significantly more unrecorded openings that were created for ventilation in shallow mines and related to the poorly recorded secondary mining extraction activities that followed the abandonment of the main workings. The attached Photo 1 shows an example of an open shaft on Protection Island while Photo 2 shows a partially collapsed unsupported slope leading to the shallow abandoned workings of the Fitzwilliam Mine; and
- The potential for roof rock failure leading to a crown or sink hole at the ground surface in areas above abandoned room and pillar mine workings with an inferred roof cover of rock of less than 10 times the seam thickness. Specific areas of high risk related to this hazard include portions of the west side of the Douglas Mine; the shallow workings of the Fitzwilliam Mine at the north end of Newcastle Island; and the north-westerly portion of the Wellington Mines, where there is a complex history of extraction from two shallow coal seams along with a poorly documented record of secondary pillar robbing that extended into the 1960's. Photo 3 shows shallow partially collapsed open workings under Victoria Road while Photo 4 shows a portion of crown hole that was encountered at the western edge of the Douglas Mine during a shallow utility replacement program. Photo 5 indicates the nature of open fracturing above the shallow abandoned Wellington Mines in the Gilfillan Road area.

5.2 Moderate Risk

Areas of Moderate Risk were defined through the City's preliminary assessment and are indicated as yellow in Figure 2. The Moderate Risk designation was assigned to the following circumstances:

- Areas of abandoned room and pillar mine workings where there is an elevated potential for future surface subsidence as a result of pillar crushing or collapse of temporary supports within the workings. This includes the western side of the South Wellington mine, the central zone of the Douglas Mine, and the northern area of the East Wellington (Jingle Pot) mine. The inferred primary consequences from the hazard of a deeper collapse are related to serviceability-type settlement distress in structures and/or infrastructure as opposed to a direct impact on health and safety;
- Areas where geological conditions are complicated by the presence of main faults. Such complications may impact the stability of sloped sites; influence possible pathways for the movement of water or gas; or create zones of inherent weakness in the rock mass. These potentially more complex ground conditions warrant the need for a specific assessment relative to the proposed land development (Hellewell 1988) 8 (Donnelly 2000) 9;
- An area in the Wellington Coalfield south of Divers Lake where faulting has impacted and upthrown the room and pillar worked Wellington Seam and where there are historical records of sinkhole features that have developed in thick soil deposits above the bedrock surface. A portion of this designated area also contains a localized area of upper workings as well as a prospect shaft that was abandoned due to "running sands". The historical records include notes on abandonment plans related to "lost houses" in this area as well as the documented case of sinkholes that were encountered during development in the Horth Road/Sloan Road area10 and at a private residential property on Goldfinch Crescent. Photo 6 indicates the extent of "lost" soil associated with migration into historical mining operations in the Horth Road area of Nanaimo.

The inferred consequences from the hazard of a secondary mechanism involving the migration of soil into open void space are difficult, if not impossible, to quantify and can be affected by the

[8] Hellewell, F.G. 1988. The influence of faulting on ground movement due to coal mining. The UK and European experience. *Mining Engineer*, 147, 334-337.

[9] Donnelly, L.J. 2000. The reactivation of geological faults during mining subsidence from 1859 to 2000 and beyond. *Transactions Institution Mining and Metallurgy*, Section A, Mining Technology, 109, A179-A190.

[10] Geotechnical Investigation Subsidence in North Nanaimo, BC. Prepared by EBA Engineering Consultants Ltd for the City of Nanaimo May 1994.

soil type, groundwater conditions and the depth to bedrock. These unusual ground conditions warrant the need for a specific assessment relative to the proposed land development.

The (surface) trace lines of the main faults that are shown in Figure 2 were transposed from published mapping produced by the BC Ministry of Energy and Mines[11]. The lateral extents of several of the abandoned mines within the City are defined by faults, such as the eastern side of the Douglas Mine and the west side of the Jingle Pot and Wakesiah Mines. The Wellington Mines are truncated by a number of main faults that have resulted in elongated shadow zones with no undermining. These zones are the result of either a physical displacement of the coal seam caused by vertical movement on an inclined fault plane or by structural disturbance of the seam including pinching or heavy shearing. Due to the inclination of geological faults, the surface trace lines may be offset from the location of the fault at the depth of mining shown on the mine plan.

5.3 Low Risk

The preliminary screening assigned a Low Risk of appreciable future subsidence impacting the ground surface to much of the lands underlain by abandoned workings within the City limits. This designation was applied to deeper (greater than 60 m) mines that utilized longwall mining methodology or deeper (greater than 60 m) room and pillar workings that were documented to have a very high percentage of extraction/pillar robbing.

Notwithstanding the City's Low Risk preliminary assessment designation, all undermined lands are potentially hazardous due to unrecorded workings; unrecorded openings; the impacts on the rock mass and drainage characteristics that historical subsidence and fractures may have caused; the potential for remnant movements (Ferrari 1997)[12] (Karfakis 1993)[13] as well as the environmental considerations of gas and water that were not considered in the preliminary risk assessment.

6 Site Investigation and Geotechnical Reporting

6.1 General

As part of the land development and building permit approval process, the City will require a geotechnical report that extends professional reliance to the City for any property that is directly underlain by abandoned mine workings or located sufficiently close that, in the opinion of the City, might be impacted. The Qualified Professional preparing the report must consider the latest

[11] BC Ministry of Energy and Mines. Open File 1998-07. Geology of the Westwood Lake Area, Nanaimo Coalfield, BC

[12] Ferrari, C.R. 1997. Residual coal mining subsidence - some facts. *Mining Technology*, 79, 177-183.

[13] Karfakis, M.G. 1993. Residual subsidence over abandoned coal mines. In: *Comprehensive Rock Engineering, Volume 5, Surface and Underground Case Histories*, Hoek, E. (Ed.), Pergamon Press, Oxford, 451-476.

version of the City's Guidelines for the Completion of Geotechnical Reports. The geotechnical report should conclude with a summary of the abandoned mining legacy risks, any further investigations, remedial works and/or mitigation measures required to ensure the safety and stability of the proposed development. In the case of a building permit application, there may be requirements for the Geotechnical Engineer of Record to sign a BC Building Code Schedule B for the geotechnical aspects of the project and, upon successful completion of the project, a Schedule C-B along with a geotechnical validation or completion report.

Geotechnical reporting in relation to mining risk assessments typically proceeds in a phased manner commencing with preliminary investigations that involve desktop studies and site reconnaissance and progressing to ground investigations of varying intensity. The feasibility and requirements for development are weighed during this process. In some cases, the process may require the implementation of ground treatment and the remediation of workings and/or the use of specialized foundations. The geotechnical reporting documents that may need to be submitted in the overall development process include:

- Geotechnical Report that includes the findings of an abandoned underground mining risk assessment (which may be part of a broader scope of geotechnical reporting for the development);
- Detailed Geotechnical Report in which the measures required to mitigate or remediate unacceptable mining legacy risks are discussed and recommendations presented; and
- Geotechnical completion or validation report that documents the mitigation or remediation measures that were implemented, such as grouting up of the mine workings. In the case of a building project, the geotechnical completion report may accompany the Engineer of Record's Schedule C-B.

6.2 Content of an Abandoned Underground Mining Risk Assessment

The geotechnical report must include a mining risk assessment of sufficient detail to satisfy the land development and building permit approval process. The initial stage of the assessment will be a desktop-based mining risk assessment. Based on the review of the relevant information, the report may potentially discount the risks posed to the site or development by past mining activity. Where the associated risks cannot be discounted, the report should include details of the further investigations and/or land management strategies that are required.

The City's recommendations for the scope of the mining risk assessment portion of the geotechnical report are outlined below. These recommendations conform in general to the guidelines presented in CIRIA C758 Abandoned Mine Workings Manual (2019). Recommended content for the assessment includes:

INTRODUCTION

The introduction should include the site location and a description, including a site location plan. It should also include a description and layout of the proposed development, including the planning application description and the inclusion of layout plans where possible.

SOURCES OF INFORMATION USED TO PREPARE THE REPORT

This could include, but is not limited to:

- Mine abandonment and other historical plans
- Historical annual reports of the BC Minister of Mines
- Surficial and bedrock geological information
- A site history based on documentation of the area
- Past desk-based assessments of ground conditions for the application site or adjacent/nearby sites
- Results of past intrusive site investigation works undertaken to assess ground conditions for the application site or adjacent/nearby sites

IDENTIFICATION AND ASSESSMENT OF SITE-SPECIFIC COAL MINING RISKS

This part of the report should identify the potential risks associated with mine working legacy for the proposed development site, as identified from sources of information. This should include consideration of such specific risks as:

- Mine entries;
- Shallow coal workings, recorded and probable;
- Workable coal seam outcrops;
- Mine gas;
- Recorded mine working-related hazards;
- Geological features, including fissures, faults, and topographic features; and
- Former surface mining sites or waste materials.

The potential for interaction between different factors which may have a bearing on relative ground stability should also be appropriately considered, such as the depth of competent rock cover above shallow coal workings, type and thickness of soil cover, specific geological characteristics, seismicity, and hydrological factors.

While the initial stage of a mining risk assessment is primarily desk-based with site reconnaissance, the exact location of such features as mine entries should be established, if present. This is particularly important when the feasibility and layout of a given development is being considered. It should be demonstrated that the layout of the development has duly considered the location of mine entries, their potential zones of influence and associated 'no-build' zones.

For mining features identified as being present or potentially present, a more detailed discussion and assessment should be made of the risks to the application site and the proposed development. Consideration should be given to both individual risks and also their possible cumulative effects.

MITIGATION STRATEGY PROPOSED

This section is a key part of the report. It should explain how the mine working issues have influenced the proposed layout and design of the development, where necessary.

The mitigation strategy should set out and illustrate with plans in the case of mine entries, how any on-site issues identified in the assessment will be dealt with to ensure the safety and stability of the development. This should include the assessment of mine gas and the mitigation measures required, as necessary. Consideration should also be given to the possible influence of other land development activities or elements on the safety and stability of the land such as blasting, grading, in-ground stormwater disposal or geothermal installations.

The reader is referred to the Construction Industry Research and Information Association (CIRIA) C758 Abandoned Mine Workings for further technical reference.

In circumstances where the preliminary risk assessment cannot provide adequate evidence to discount the risks posed to the development by past mining activity, details of the proposed intrusive site investigation work necessary to establish the legacy present should be set out within the report.

CONCLUSION

The geotechnical report should conclude with a summary of the mining legacy risks, any further investigations, remedial works and/or mitigation measures required to ensure the safety and stability of the proposed development. If no further investigations, remedial works, or mitigation measures are required, the report should include an opinion by the Qualified Professional on whether the land may be used safely for the use intended and within the BC Building Code performance objectives for structural safety and sufficiency, and health.

The report should demonstrate a clear strategy for addressing the mining legacy.

RELEVANT APPENDICES

The City will expect copies of the relevant information to be referenced or included within the appendices of the mining risk assessment; this is particularly important when information has been used to discount any risks posed by past mining activity such as borehole data.

6.3 Detailed Geotechnical Reporting

A detailed geotechnical report may be required in the event the preliminary desktop study concludes the mining legacy risks to be unacceptable to the development or the uncertainty in information too great. The nature of the geotechnical works for the detailed report should be governed by the complexity of the development and the nature of the ground conditions with the intent of refining the risk assessment and, if necessary, establishing and maintaining ground stability. The Canadian Foundation Engineering Manual 4th Ed[14] states that "investigations must be extremely thorough wherever such differential settlement conditions are suspected". The reader is referred to CIRIA C758 as a technical resource for the planning and execution of a site investigation over abandoned mine workings.

As noted previously, a separate environmental assessment may be required.

The geotechnical report should provide a clear strategy for addressing the mining legacy issues in the context of the BC Building Code performance requirements for structural safety and sufficiency, and health. Depending on the findings of the further investigations, possible outcomes that might be discussed in the geotechnical report include:

- Optimization of building footprint locations or the alignment of linear or development features;
- Geotechnical design aspects of foundations and civil works;
- Design of remedial ground treatment; and
- Identification of the need for performance monitoring of treated and untreated areas for residual risk purposes.

If no further investigations, remedial works, or mitigation measures are determined from the detailed work to be necessary, the report should include a statement that the land may be used safely for the use intended.

6.4 Geotechnical Completion Or Validation Reporting

It is important that the City be provided with good quality construction records, as-built drawings, and completion reports for ground improvement works. These are essential for the immediate project as well as future project planning, maintenance, and repair. The geotechnical completion or validation report will provide the City with a statement from the design engineer that the works have met the intent of the design in a manner akin to that of the BC Building Code Schedule C. Information provided in the completion report will:

- Identify the extent of ground treatment;

[14] Canadian Foundation Engineering Manual 4th Edition, 2006

- Identify the nature of ground conditions encountered during the works;
- Describe the methodology and nature of the improvement works;
- Present the results of interpretations/testing that establish the status of the site on completion of the works. This should include clear detailed record drawings and progress photographs;
- Confirm that the work has been completed to the standard required for the particular development and that the site may be used safely for the use intended; and
- Clearly define any residual risks present and future requirements for their mitigation. This will include any monitoring and surveillance requirements as well as pre-approved agreements to manage future settlements within the context the BC Building Code structural design requirements for sufficiency and any City infrastructure.

The completion report will be filed on the land title.

6.5 Third-Party Geotechnical Peer Review

In its role as the Approving Officer, the City has the right to request a third-party peer review to assess the adequacy of any geotechnical report submitted as part of the land development or building permit application process.

In the case of an application for land development in an area identified as High Risk of future subsidence from the preliminary risk assessment described in Section 5, the proponent should expect that the City will conduct a third-party peer review of the geotechnical report; this review will be at the cost of the proponent.

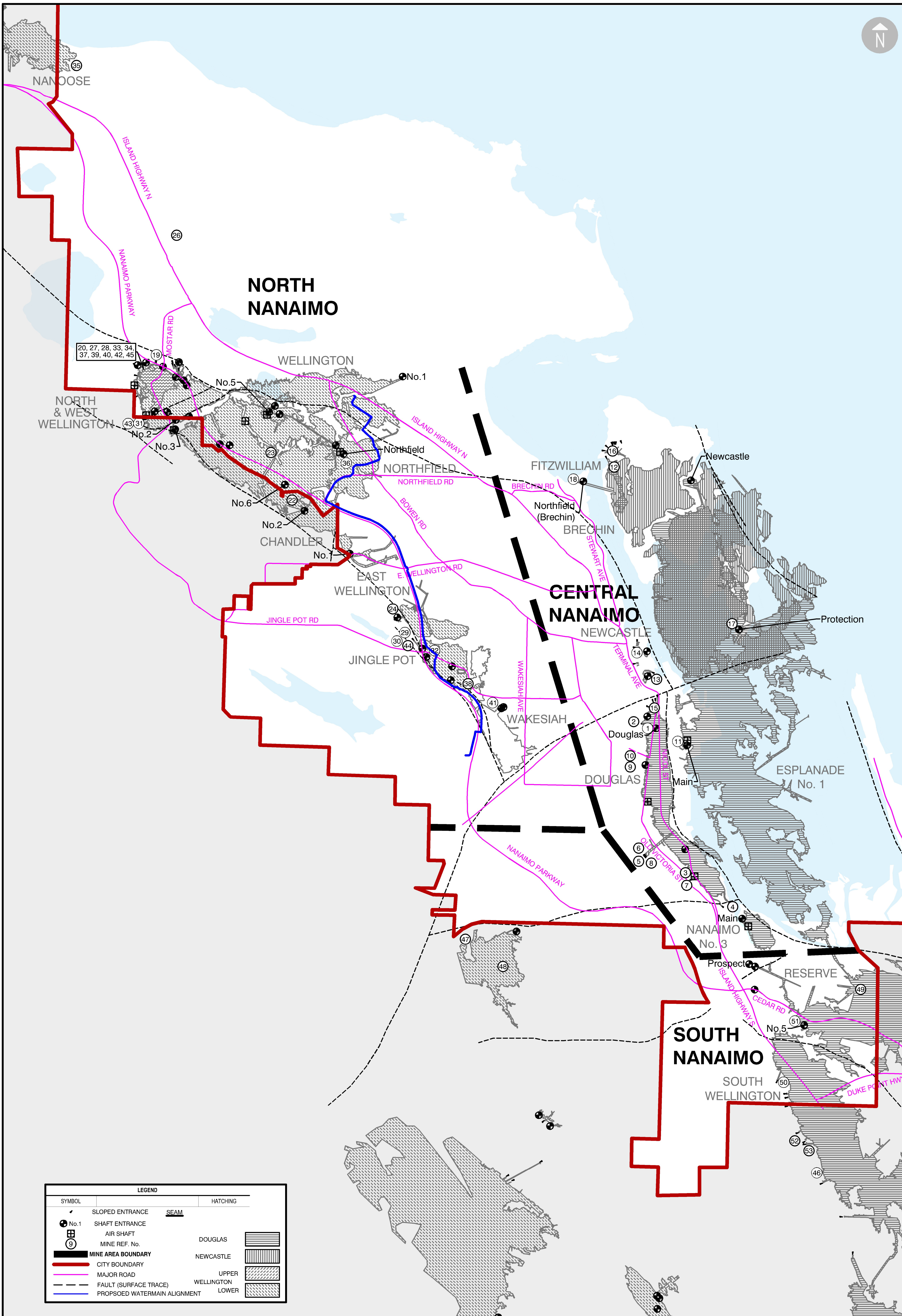
7 Use of Guidelines and Limitations

These Guidelines are not intended to be prescriptive nor are they intended to serve as a substitute for engineering judgement and experience. It is anticipated that variations in the application of the Guidelines may be required for certain specific projects.

The information contained in these guidelines has been prepared for use by applicants, consultants, and staff in preparing, submitting, and reviewing applications for development within the City that may be impacted by abandoned mine workings.

The content of these guidelines is based on a compilation of historical information available at the time of preparation. The accuracy and completeness of the historical information has not been independently verified. Additional information may become available over time that will result in periodic updates to the guidelines.

Changes to these guidelines may occur periodically as new information becomes available and/or conditions are verified.



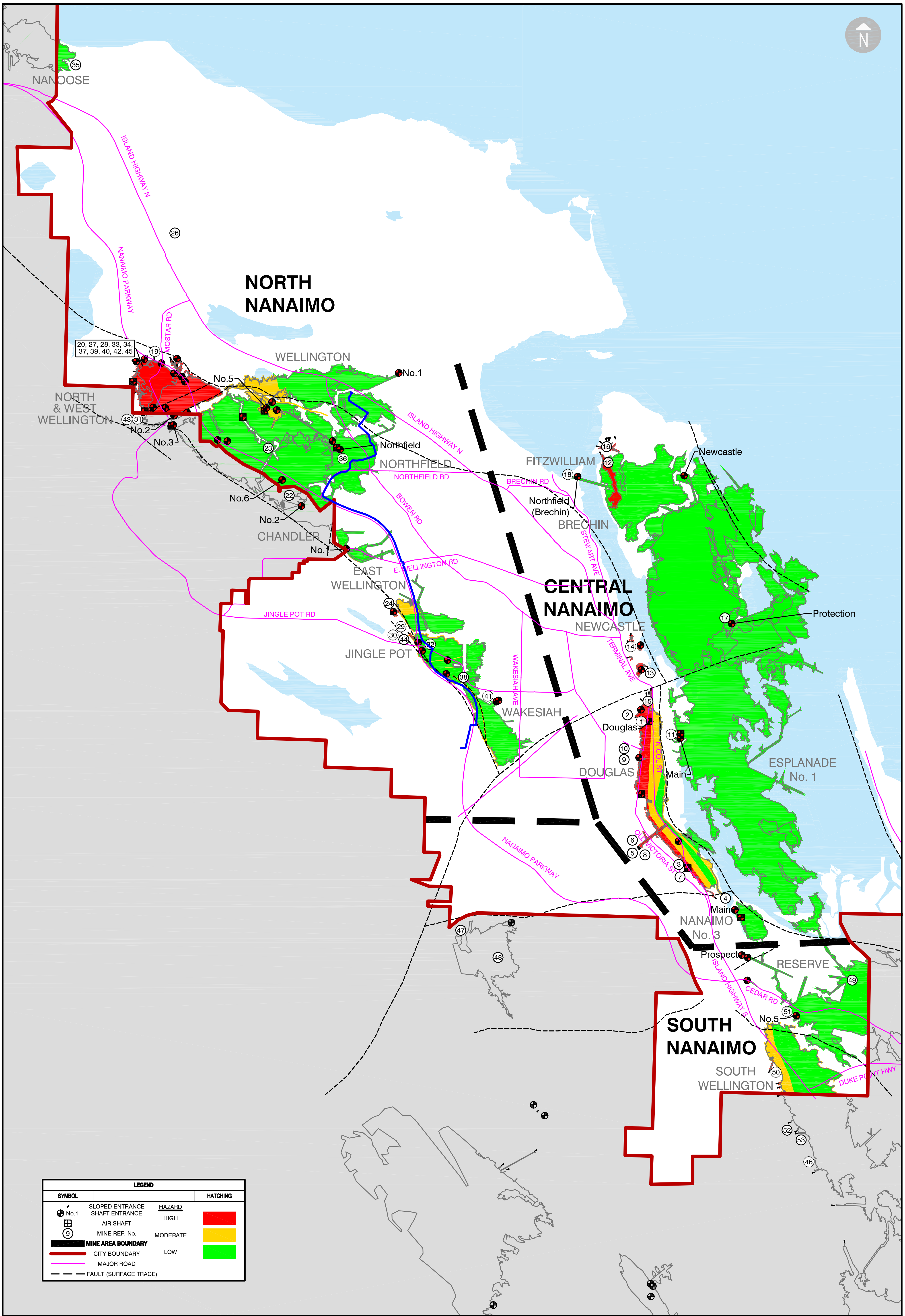
CITY OF NANAIMO
THE HARBOUR CITY

GUIDELINES FOR GEOTECHNICAL ASSESSMENTS ABOVE ABONDONED COAL MINE WORKINGS

FIGURE 1:

PLAN OF RECORDED UNDERMINED AREAS

NOTES:
1. THIS FIGURE IS FOR ILLUSTRATIVE PURPOSES AND MAY ONLY BE USED IN CONJUNCTION WITH THE FULL REPORT.
2. THIS DRAWING SHOULD BE PLOTTED TO TABLOID SIZE (11x17 in.).
3. SCALE: 1:50,000



CITY OF NANAIMO
THE HARBOUR CITY

GUIDELINES FOR GEOTECHNICAL ASSESSMENTS ABOVE ABONDONED COAL MINE WORKINGS

FIGURE 2:
PRELIMINARY RISK ASSESSMENT OF MINING-INDUCED GEOLOGICAL HAZARD AREAS

NOTES:
1. THIS FIGURE IS FOR ILLUSTRATIVE PURPOSES AND MAY ONLY BE USED IN CONJUNCTION WITH THE FULL REPORT. THE FIGURE IS INTENDED FOR THE EXCLUSIVE USE OF THE CITY OF NANAIMO.
2. THIS DRAWING SHOULD BE PLOTTED TO TABLOID SIZE (11x17 in.).
3. FAULT LINES ADAPTED FROM BCGS OF 1998-07.
4. SCALE: 1:50,000

Table 1. Inventory of Recorded Mine Workings
Abandoned Underground Mine Workings, City of Nanaimo

Name	Ref #	Mining Company	Seam	Started	Completed	Years since abandonment	Method of Mining	Nominal Depth of workings (m)	Seam thickness (m)	Percentage extraction	Mine Access Type	Archive Map Ref	Comments
CENTRAL NANAIMO													
Douglas Mine												OS22/Map	
Douglas shaft	1	Vancouver Coal Mining & Land	Douglas	1862	1886	132	Room and pillar (drawn pillars)	shallow to +100 m	1.5 to 1.8	High	Shaft		
Douglas slope	2												
New Douglas Slope	3	Vancouver Coal Mining & Land	Douglas	1874	1886	132	Room and pillar (drawn pillars)		2.1	High	Slope	Map 6	Near Island Hwy between McKenzie/Melideo Road
New Douglas Mine (adit level)	4												
Also see Level Free Workings/Parkhead Level													
New Douglas Slope	5	Western Fuel Company	Newcastle	1911	1914	104	limited workings	shallow		Low	Two slopes approx 500 m long		workings consist of two slopes 11 by 6 feet about 1700 ft long well timbered, limited workings
Chase River prospect	6		Newcastle				Prospect	shallow outcrop		Limited workings	Adit	Map 6	900 Douglas Ave approx
McKenzie Prospect	7		Newcastle				Prospect	shallow outcrop		Limited workings	Adit	Map 6	1019 Old Victoria Road
River Prospect	8		Newcastle				Prospect	shallow outcrop		Limited workings	Adit	Map 6	End of Ryan Road/Pine Street
Connaught Prospect	9		Newcastle				Prospect	shallow outcrop		Limited workings	Adit	Map 6	717 Connaught Ave approx
Duke Prospect	10		Newcastle				Prospect	shallow outcrop		Limited workings	Adit	Map 6	58 Duke Street approx
No. 1 Mine (Esplanade No 1 and 2)	11	Western Fuel/Vancouver Coal Mining & Land	Douglas	1881	1938	80	room and pillar - drawn pillars	200 to 300	0.9 to 2.1	High	Shaft 200 m deep		Extensive submarine workings including Protection Island
No. 1 Mine (Esplanade No 1 and 2)	11	Western Fuel/Vancouver Coal Mining & Land	Newcastle	1887	1938	80	longwall and room and pillar	200 - 300 m	0.9	High			
Fitzwilliam (Newcastle Island)	12	HBC/Vancouver Coal Mining & Land	Douglas	1872	1882	136	room and pillar (drawn)	shallow to 75 m	0.8 to 1.5	High	Slope 730 m long		
Hudson Bay Co. No.1 Pit	13	Hudson Bay Company	Douglas	1852	1856	162	Limited room and pillar	shallow	1.1	Uncertain	Shaft approx 10 m deep	M1 38/A	
Hudson Bay Co. No.2 Pit		Hudson Bay Company	Douglas		1860	158	Dead workings	Unknown	N/A	Uncertain		M1 38/A	
Hudson Bay Co. No.3 Pit	14	Hudson Bay Company	Newcastle	1857	1861	157	Limited room and pillar	25 m	1.8	Uncertain	Shaft and adit	M1 38/A	Shaft located under former Malaspina Hotel minor workings accessed by adit off of Front Street
Level Free Workings / Park Head Level	15	Hudson Bay Company	Douglas		1860	158	Limited room and pillar	shallow	1.2	Uncertain	Slope	M1 38/A	Begining of the Douglas Mine at the south end of Victoria Road
Newcastle (Sage) - on Newcastle Island	16	HBC/Nanaimo Coal Company	Newcastle	1853	1876	142	Limited room and pillar	shallow outcrop	0.9 to 1.8	Uncertain	slope 220 m long	M1 38/A	
Protection Island Shaft	17	New Vancouver Coal Mining & Land Co	Douglas	1890	1938	80	Room and pillar (pilars drawn)	Deep 200 to 400 m	1.2 to 2.1	High			Became a part of No.1 mine. Significant faulting reported. Shaft is 3.6 m by 5.5 m
Protection Island	17	Western Fuel/New Vancouver Coal Mining & Land Co	Newcastle	1890	1938	80	Longwall	Deep 200 to 400 m	0.9	high	shaft approx 250 m deep		Protection Island
Brechin Mine (Brechin Connection) also refered to in 1911 as Northfield Mine	18	Western Fuel Company	Douglas	1903	1914	104	longwall	70 -150	0.8 to 1.5	High	shaft 18 m deep leading to slope to workings. Served as ventilation shaft	OS 21/OS22	Connection to No 1 mine workings under Newcastle Island
		Western Fuel Company	Newcastle	1903	1914	104	Longwall	70 - 150	0.9	High	As above		Connections to Fitzwilliam Mine on Newcastle Island
NORTH NANAIMO													
Biggs Mine near Well. No 9	19	J.Biggs	Wellington	1937	1939	79	Robbing pillars from retreat operations	Shallow	0.9 typ	High	slope 35 m long	M1/20	on the site of the old original Wellington Colliery (Dunsmuir). Some opencast mining
Carruthers Mine No. 3 (& Wakeham)	20	R. Carruthers	Upper Wellington	1944	1961	57	Room and pillar - uncertain details	Shallow	0.9 m typ	Uncertain	Slope ?	E-06-02 Box 10	Near to abandoned Wellington No 9 workings and seperated from Loudon Mine by 35 feet wide barrier pillar in the upper wellington seam
Wellington Collieries (East)													
Wellington Extension No 9 (formerly Island Colleries Ltd)	19	Robert Dunsmuir & Sons Ltd.	Upper Wellington	1895	1931	87	Longwall	10 m	0.4	High		OS 14	Seam badly fissured from earlier operations in deeper workings
Slope 2	21	Dunsmuir, Diggle and Company	Wellington	1882	1896	122	Longwall		0.9	High	Slope		Location not shown on Figures
East Wellington Colliery	22	East Wellington Coal Company (W.S.Chandler)	Wellington	1882	1893	125	Longwall		0.9	High	Shaft		Highly faulted, coal locally to 1.8 m
Wellington Colliery: No 1, 2, 3, 4, 5 and 6 shaft	23	Robert Dunsmuir & Sons Ltd.	Wellington	1895	1899	119	Longwall and room and pillar (drawn)		0.9 typ	High	Shafts		Dunsmuir purchased and pumped out the failed mine.
East Wellington Mine	24	Sabiston, Horne, Dick and Blessing	Wellington	1879	1881	137	Room and pillar (pillars drawn)	150 m	0.9		Slope		
		Heisterman & Fagan E.W.C. Co.	Wellington	1924	1928	90	Longwall	150 m	0.9	High	Slope		Faulting on west and north side of mine
South Wellington Colliery	25	Francis and Nicholas (Cornish Shaft)	Wellington	1876	1878	140	Room and pillar	45 to 50 m	2.4	uncertain	Shaft 45 m deep		Location not shown on Figures
		R.D. Chandler	Wellington	1878	1879	139	Room and pillar	45 to 50 m	2.4	uncertain			
		Dunsmuir, Diggle and Company	Wellington	1879	1900	118	Room and pillar	45 to 50 m	2.4	uncertain			
Hydesville Mine	26	D.Caldwell	Wellington ?		1939	79	Prospect	35 m	Uncertain		Slope 50 m long		Lot 14 Wellington District on Uplands Road
Island Collieries (Wellington No 9)													
No 2 Mine	27	Island Collieries Ltd	Upper Wellington	1920	1929	89	Longwall	Shallow	0.9 typ	High	Two slopes		Seam disturbed by mining in lower seam
No 5 Mine	28	Island Collieries Ltd	Lower Wellington	1920	1929	89	Room and pillar (drawn pillars)		0.9 typ	High			Faulted ground. Weak roof rock
Jingle Pot (New East Wellington)	29	Vancouver-Nanaimo Coal Mining Co	Wellington	1907	1917	101	Room and pillar and longwall		0.6 to 2.4	High	Two slopes 430 m long and shafts		
		British Columbia Coal Mining Co	Wellington	1917	1918	100	Room and pillar - all pulled		1.5 (locally greater)	High			Barrier pillars on east and north side 15 m wide. Faulted. Shale roof, sandstone floor.
		E. Wellington Coal Co. (Maynard & Grant)	Wellington	1920	1923	95							
		Sinclair	Wellington	1930	1934	84	Retreat drawing pillars			High			
Lewis Mine	30	T & G Lewis	Wellington	1937	1940	78	Removal of remnant pillars	shallow	0.9 typ	Uncertain	Using old Jingle Pot Slope		
Little Ash Mine (West Wellington/Jordan Mine)	31	R. Cambers & Co.	Wellington	1928	1931	87	Uncertain	Shallow	1.8	Uncertain	Slope west side of workings		Half a mile from old No 9
Little Jingle Pot Mine	32	J.Stewart	Wellington		1930	88	Retreat drawing pillars from Jingle Pot mine	Shallow	0.6 to 2.4	High	Old slope		situated on the site of the Jingle Pot Mine
Loudon Mine No 3 Well.	33	W. Loudon	Wellington	1936	1939	79	Outcrop coal	Shallow	1.2	High			
Loudon Mine No 5 and 6 Well.	34	W. Loudon & Associates	Upper Wellington	1944	1964	54	Outcrop coal	Shallow	1.2	High	Slope 60 m long		Looking to intercept the No 9 workkings to rob pillars
Nanoose Collieries	35	Nanoose Wellington Collieries Ltd	Wellington	1920	1926	92	Room and pillar	120 m	1 to 2.7	Moderate	Shaft		Only a small portion of the colliery is in the City of Nanaimo
	35	Canadaian Collieries (Dunsmuir) Ltd	Wellington	1926	1926	92	Room and pillar	120 m	1 to 2.7	Moderate	Shaft		Only a small portion of the colliery is in the City of Nanaimo
Northfield (North Field)	36	New Vancouver Coal Mining & Land Co	Wellington	1889	1895	123	Longwall	Deep	0.6 to 1.2	High	Shaft	OS 18, OS 34	Adjacent to Wellington Mines - 1911 MR indicates that coal was working under Newcastle Island
	36	Canadian Collieries (Dunsmuir) Ltd	Wellington	1936	1941	77	Longwall		0.6 several seams	High	Shaft		Reopened after 42 year shut down

Table 1. Inventory of Recorded Mine Workings
Abandoned Underground Mine Workings, City of Nanaimo

Name	Ref #	Mining Company	Seam	Started	Completed	Years since abandonment	Method of Mining	Nominal Depth of workings (m)	Seam thickness (m)	Percentage extraction	Mine Access Type	Archive Map Ref	Comments
Pacific Mines No 1 and 2	37	F.John & G.Gerlock	Wellington	1942	1945	73	Removal of remnant pillars	shallow	0.9 typ	High	short slope		
Renney Prospect	38	Renney & Assoc.	Uncertain		1935	83	Prospect	Shallow	Uncertain	Limited	Short slope		Midway Jingle Pot and Wakesiah
Stronach Mine (Old Adit Colliery)	39	C. Stronach	Upper Wellington	1933	1963	55	Removal of remnant pillars	Shallow	0.9 typ	High	Adit mine		Biggs area - closed in 1934 and reopened
Victory Mine	40	S.Dines & J.Colby	Wellington		1942	76	Outcrop coal	shallow	0.9 typ	Limited	Drifts		Biggs area - worked for 2 months
Wakesiah (New Wakesiah Mine)	41	Canadian Western Fuel Company	Wellington	1918	1930	88	Room and pillar and long wall	80 to 200 m	0.9 to 4.3	High	Shaft 1 and 2 approx 100m		Mine produced 770,000 tonnes
Wende Mine Well.	42	J. McArthur	Upper Wellington	1952	1954	64	Outcrop coal	Shallow	0.5	Limited	Drifts		
West Wellington	43	Brannan Claim	Wellington	1882	1895	123	Limited working		1.2 to 1.8				
		West Wellington Coal Co. Ltd (D.Jordan)	Wellington	1896	1897	121	Limited working		1.2 to 1.8				Near Jingle Pot
Westwood Prospect	44	Ira Westwood	Uncertain		1935	83	Limited workings	Shallow	Uncertain		Short slope with shaft for ventilation		Near Jingle Pot Mine
White Mine	45	J. White	Lower Wellington	1957	1959	59	Removal of pillars (from old Wellington slope and Pacific No 2 mine)	Shallow	1.8 to 2.4	limited workings			60 m south of stronach
SOUTH NANAIMO													
Alexandria (south wellington)	46	James Beck	Douglas	1879	1882	136	Room and pillar		0.9 - 5.4		Slope at the south end 200 m long	M1/5	Chase river area - mine was started then stopped for 18 years
		Dunsmuir, Diggle and Company	Douglas	1882	1902	116	Room and pillar		0.9 to 5.4		Slope at the south end 200 m long	M1/1 Also OS 2, OS24	Wellington Colliery refused to publisg returns
Furnace Portal Mine (Harwood Ridge)	47	J.Biggs	Douglas ?	1945	1951	67	Removal of pillars and outcrop coal	Shallow		High	slope	M1-20	Located on Harewood Ridge
Harewood	48	Harewood Coal Company	Wellington (Harewoo	1864	1865	153	Room and pillar	120 to 150	0.9 to 2.7		slope and shafts	M1-20	Poor roof conditions
		Thomas Bulyley (lease)	Wellington	1874	1878	140	Room and pillar		2.1 to 2.4				Mine closed from 1902 to 1917
		Vancouver Coal Mining & Land	Wellington	1878	1923	95	Removal of pillars			High			
Reserve	49	Western Fuel Company	Douglas	1910	1939	79	Room and pillar (drawn)	Deep 300 m	up to 6	High	two shafts 290 m deep		Roof conditions poor
Southfield No 1 and 2	50	Vancouver Coal Mining & Land	Douglas	1882	1894	124	Room and pillar (drawn)	40 to 70	0.9 to 1.2	High	Slope approx 240 m long	OS 18, OS 22	Conglomerate roof/faulted
Southfield No 4 and 5	51	Vancouver Coal Mining & Land	Douglas	1888	1901	117	Room and pillar (drawn)	150 m	1.8 to 9	High	Shaft to No 5 155 m deep	OS 2,OS 18,OS 21	Coal from No 5 was brought to surfac e using the No 4 mine slope
South Wellington												OS 2,OS 15,OS 18	
Fiddick slope (Slope 1 to Fiddick Colliery)	52	Pacific Coast Coal Mines Ltd	Douglas	1907	1928	90	Room and pillar, some longwall	Shallow	1.8 to 6 (2.4 typ)	Uncertain	Slope 450 m long and shaft		Roof poor many cave ins to surface
		R.Fiddick	Douglas	1928	1936	82	Removal of pillars	Shallow		High			
		P.Phillips & Assocaites	Douglas		1938	80							
Richardson slope (Slope 2 to Fiddick Colliery)	53	Pacific Coast Collieries	Douglas	1913	1921	97	Room and pillar, some longwall	Shallow	1.5 to 4.3	Uncertain	Slope (near Fiddick)		
Richardson slope		Richardson Bros.	Douglas	1928	1931	87	Removal of pillars	Shallow		High			
Richardson slope (Ida Clara Mine)		Richardson	Douglas	1933	1937	81	Removal of pillars	Shallow		High			
South Wellington Mine (see Fiddick)		South Wellington Coal Mines Ltd	Douglas										
South Wellington No 5		Canadian Collieries (Dunsmuir) Ltd	Douglas	1918	1930	88	Room and pillar (drawn)		up to 6		Slopes		Ground faulted
END OF CITY OF NANAIMO TABLE													

CITY OF NANAIMO
THE HARBOUR CITY

Table 2. Summary of Mining Induced Geological Hazards
Abandoned Underground Mine Workings, City of Nanaimo

Category	Sub-category	Hazard	Triggers	Potential Consequence
Abandoned Entries to Underground Workings	Shafts	Due to their age and method of construction, abandoned mine shafts that remain untreated are susceptible to sudden collapse and/or subsidence. The prediction of a collapse event is not possible although the risk of an old mine shaft failing in some manner is high. Within the mines of Nanaimo, shaft opening dimensions ranged from small area ventilation shafts to production shafts with an area in excess of 20 m^2. Recorded shaft depths ranged from less than 10 m to in-excess of 250 m.	• Triggering issues include the nature of historic mining, ground related and environmental related factors. • Critical degradation of an internal support or cap. • Change in equilibrium related to groundwater level variation • Disturbance from construction activity • Disturbance related to mine subsidence • Additional loading from construction/seismic /development	Range from localized settlement of backfill within a shaft to catastrophic collapse. Sudden and unexpected collapse can result in consequences of safety and severe damage. See below for related issues of mine gas and mine water which may be trapped in the shaft or use the shaft as a preferred pathway. Elevated potential for environmental assessment under the Contaminated Sites Regulations.
	Slopes and Adits	Horizontal or inclined openings to access and remove coal and facilitate ventilation were widely used in the Nanaimo mines. Slopes were typically lined with dimensions of 10 to 20 m^2 and could be in-excess of 500m in length. Adits typically evolved as simple unsupported entries into a hillside, becoming lined or supported in the event of successful exploration or workings. There are a number of adit type prospects recorded at coal outcroppings in Nanaimo.	• Triggering issues include the nature of historic mining, ground related and environmental related factors. • Critical degradation of an internal support. • Change in equilibrium related to groundwater level variation • Disturbance from construction activity • Disturbance related to mine subsidence • Additional loading from construction/seismic /development	Subsidence tends to manifest as crown holes or a linear trough towards the opening in areas of lesser roof cover similar to that of roof collapse above room and pillar workings. Open slopes or adits provide ready egress to hostile/gassy mine environments with potential safety consequences. Elevated potential for environmental assessment under the Contaminated Sites Regulations.
	Bell Pits	The use of bell pit to extract coal from shallow depths is unproven in the Nanaimo area but considered quite plausible. The bell pit shaft section was typically unlined and should be considered unstable and prone to sudden collapse and/or subsidence. The dome section from which coal was mined presents unsupported ground prone to subsidence. Subsidence typically take the form of a circular crater wider than the shaft and less than the bell diameter. Bell pits typically limited to depths of 10 m or less.	• Triggering issues include the nature of historic mining, ground related and environmental related factors. • Critical degradation of an internal support or cap. • Change in equilibrium related to groundwater level variation • Disturbance from construction/seismic activity • Additional loading from construction/development	Consequences range from localized settlement of backfill within the shaft to catastrophic collapse. Sudden and unexpected collapse can result in life safety consequences. Elevated potential for environmental assessment under the Contaminated Sites Regulations.
Room and Pillar Workings	Roof failure	Collapse of roof rock to the floor of the mine thereby propagating the void towards the ground surface. Void will either become choked off through bulking, arrested by competent strata or result in a crown hole at surface. The roof height in certain portions of the mine such as main headings may exceed the typical worked seam height. Temporary timbers/supports may be in place from pillar removal that deteriorate with time.	• Nature of roof rock, depth of workings, bulking factor influence critical migration height of void • Triggering issues include the nature of historic mining, ground related and environmental related factors. • Change in equilibrium related to groundwater level variation • Disturbance from construction/seismic activity • Additional loading from construction/development	Crown hole at surface constitutes the greatest consequence to development and safety. Collapse can be sudden and potentially result in loss of support to foundation elements, roads or buried infrastructure.
	Floor heave	Floor heave is the result of a bearing failure of pillars into weak pavement deposits lying at the floor beneath the pillars.	• Nature of floor materials, most notably presence of seat earth beneath pillars • Disturbance from construction/seismic activity • Additional loading from construction/development.	General lowering of the ground surface above the impacted pillars along with induced straining, differential settlement and tilt. Extensive pillar removal can lead to sag subsidence comparable with longwall but may occur over a longer time frame and with less predictability (see below)
	Pillar failure	Pillar failure occurs when they can no longer sustain the overburden pressures they were intended to support. Factors that influence the potential for pillar collapse include depth, pillar dimensions, coal strength along with time relate of weathering and erosion. Temporary timbers/supports may be in place from pillar removal that deteriorate with time.	• Collapse of remnant failures after cessation of workings is most prevalent in workings at depths between 30 and 60 m • Nature of roof/floor rock, changes in imposed loading • Triggering issues include deterioration of pillar through weathering and erosion and environmental related factors. • Disturbance from construction/seismic activity • Additional loading from construction/development	Lowering of the ground surface above the impacted pillars along with induced straining, differential settlement and tilt. Potential for local pillar failures to lead to a "domino" effect and an increased impact at surface. Extensive pillar removal can lead to sag subsidence comparable with longwall but over a longer time frame and with less predictability.
Longwall Coal Mining	Longwall	Complete removal of coal seam results in trough shaped sag subsidence at surface. Amount of subsidence depends on dimensions of the worked area, its depth and extracted seam thickness.	• Appreciable subsidence reported finishes shortly after longwall mining • Residual subsidence of 2.5 to 5 % can occur in the subsequent 2 to 4 years following mining • Haulage roads and other protected openings within the collapsed longwall workings may experience collapse well after sag subsidence	General lowering of the ground surface above and beyond the mined area along with induced straining, differential settlement and tilt. Impacts to buildings, roads and underground infrastructure. Can be a complicating factor in relation to mine gas and surface drainage well after subsidence is complete
Fault reactivation and Fissures	Mining activity	Pervasive discontinuities in the ground influence the deformational behaviour of the rock mass. There are multiple case records where underground mining activities have reactivated movements along fault zones. In the case records, the movement occurred at the time of mining subsidence.	• Structural geology and the presence and orientation of faults • Removal of ground support (most typically associated with long wall workings)	Ground displacements, ruptures constitute zones of weakness and potential differential movement and should be avoided when siting foundations, roadways and utilities unless mitigative measures are undertaken. Reactivated faults constitute preferential pathways or potential barriers to the movement of groundwater and gas.
Mine Gas	In mine workings or fractured rock near workings	Mine gas may accumulate in the unsaturated portions of mine openings and fractured rock. Mine gas contain oxygen, nitrogen, methane, carbon dioxide, carbon monoxide and hydrogen sulphide. For mine gas to reach the surface it must travel through a permeable pathway, either man-made or natural. An obvious man-made pathway is mine openings although activities such as trenching and excavation can remove low permeable soils that might normally provide a barrier to migration. Exploratory investigations should be planned with respect to mine gas hazards.	• A rapid fall in barometric pressure is the most important emission trigger. Flows in and out of abandoned workings are controlled by pressure differences between the interior of the mine and the surface • Changes of pressure within the mine can be triggered by changes in the watertable, subsidence or development. • Can be mobilized during drilling works through drilling "flush" activities. This should be reviewed as part of the exploratory works safety plan.	Noxious, flammable and potentially explosive gas accumulations. Confined space entry leading to asphyxiation and death. Elevated potential for environmental assessment under the Contaminated Sites Regulations.
Mine Water	Discharge	Environmental risks associated with mine water discharge are long term and can result from discharge from underground workings or spoil heaps (mine waste).	• The presence of gravitational mine drainage increases the potential for partially saturated mine workings, the promotion of pyrite oxidation and the opportunity for direct discharge to the environment. • The introduction of water into unsaturated workings may initiate pyrite oxidation and create acidic mine water	Consequences are most notably associated with aquatic pollution related to low pH and elevated metals concentrations. Elevated potential for environmental assessment under the Contaminated Sites Regulations.
Mine Waste	Surface spoil piles or areas of made ground (fill).	Waste from coal extraction mainly comprises siltstones and mudstones with seat earth and other sedimentary rocks separated from the coal in its preparation process. Potential hazards are wide ranging and include geotechnical (settlement and stability), combustion and chemical properties of the spoil waste.	• Infiltration and movement of water through the waste material can result in geotechnical and environmental hazards. • Disturbance of material allowing the introduction of oxygen can initiate combustion. • Imposed loading and increase in effective stress through development or lowering of the watertable can initiate settlement.	Spontaneous combustion can occur in well compacted waste materials during ground disturbance. Pollutants in the form of acidic and elevated metals discharge Settlement or stability issues related to loose waste subject to imposed loads or saturation. Elevated potential for environmental assessment under the Contaminated Sites Regulations.

CITY OF NANAIMO
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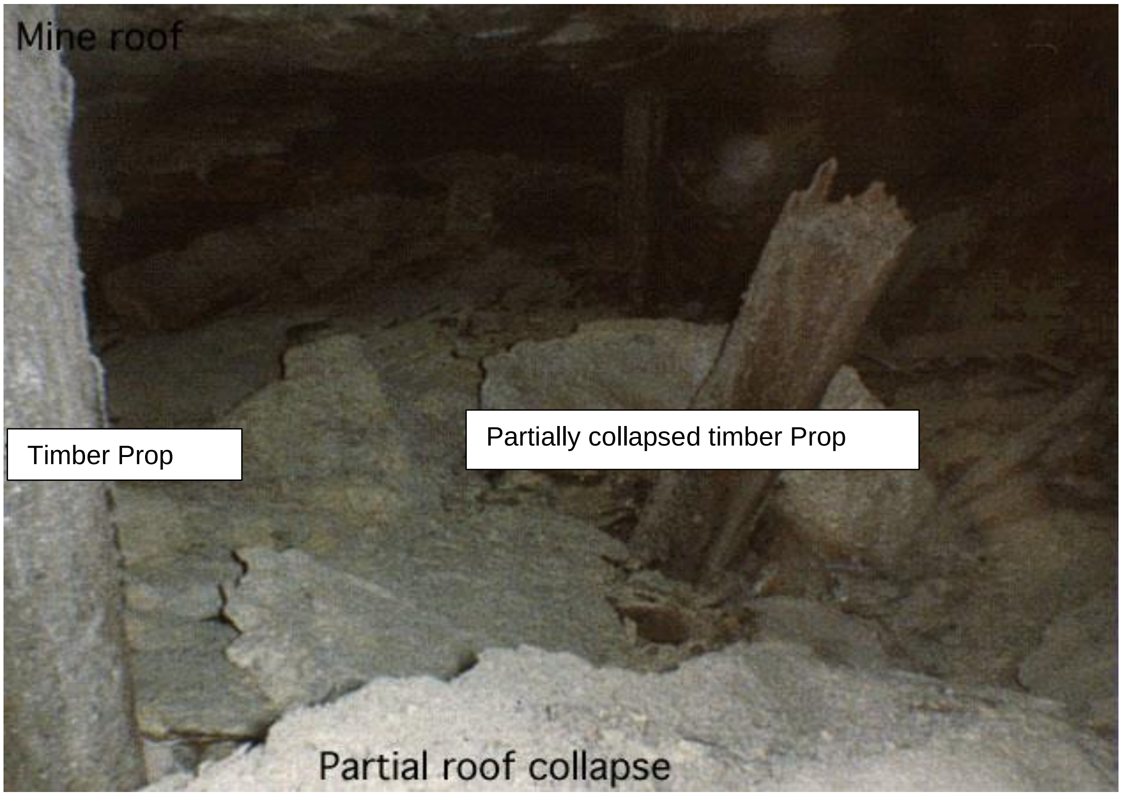
Table 3. Preliminary Geotechnical Risk Assessment Screening Criteria
Abandoned Underground Mine Workings, City of Nanaimo

Hazard Category	Sub-Category	Potential Consequence	Preliminary Risk Screening Criteria
Abandoned Entries to Underground Workings	Shafts	Range from localized settlement of backfill within a shaft to catastrophic collapse. Sudden and unexpected collapse can result in consequences of safety and severe damage. See below for related issues of mine gas and mine water which may be trapped in the shaft or use the shaft as a preferred pathway. Elevated potential for environmental assessment under the Contaminated Sites Regulations.	All shafts are considered **High Risk** features. It is important to assess the potential lateral extent of collapse beyond the actual shaft when considering the specifics of the land development project.
	Slopes and Adits	Subsidence tends to manifest as crown holes or a linear trough towards the opening in areas of lesser roof cover similar to that of roof collapse above room and pillar workings. Open slopes or adits provide ready egress to hostile/gassy mine environments with potential safety consequences. Elevated potential for environmental assessment under the Contaminated Sites Regulations.	All slopes and adit entrances are considered **High Risk** features. In assessing risks, it is important to consider the durability of any remaining opening supports, the reliability of the roof materials and the potential for shallow interconnectivity with other openings or abandoned workings.
	Bell Pits	Consequences range from localized settlement of backfill within the shaft to catastrophic collapse. Sudden and unexpected collapse can result in life safety consequences. Elevated potential for environmental assessment under the Contaminated Sites Regulations.	All bell pits are considered **High Risk** features. Although no documented cases were found in the inventory search, bell pits were an early form of mining that was likely not documented.
Room and Pillar Workings	Roof failure	Crown hole at surface constitutes the greatest consequence to development and safety. Collapse can be sudden and potentially result in loss of support to foundation elements, roads or buried infrastructure.	Room and pillar workings with a roof rock cover of less than 10 times the seam thickness are considered to carry a **High Risk** designation due to the consequences of roof failure impacting the surface. Workings with greater than a 10 times cover are considered to have a low risk of roof failure impacting the surface. The actual project assessment should consider the dip of the strata, bulking characteristics of the collapsed rock/soil, groundwater flow, pillar robbing and temporary support, strong rock layers which may attenuate upward migration and the influence of seismic loading.
	Floor heave	General lowering of the ground surface above the impacted pillars along with induced straining, differential settlement and tilt. Extensive pillar removal can lead to sag subsidence comparable with longwall but may occur over a longer time frame and with less predictability (see below)	Future surface subsidence associated with room pillar workings that is attributed to a mode of failure other than roof collapse, is considered of **Moderate Risk** to land development for workings that occur at depths of less than 60 m. At depths greater than 60 m, the substantial overburden pressures have likely led to the crushing of the small pillars used in early mining operations and reduced the risk of surface subsidence to that of remnant movements in the order of 2.5 to 5 % of the total subsidence. The actual assessment should consider the impact of pillar failure, stress transfer to adjacent pillars and the potential for a "domino effect". In cases where original pillars have been robbed/removed, consideration must be given to the possible presence of temporary roof support and the potential risks from their collapse.
	Pillar failure	Lowering of the ground surface above the impacted pillars along with induced straining, differential settlement and tilt. Potential for local pillar failures to lead to a "domino" effect and an increased impact at surface. Extensive pillar removal can lead to sag subsidence comparable with longwall but over a longer time frame and with less predictability. Potential for secondary migration of soils into open fractures in the rock mass.	
Longwall Coal Mining	Longwall	General lowering of the ground surface above and beyond the mined area along with induced straining, differential settlement and tilt. Potential for secondary migration of soils into open fractures in the rock mass. Impacts to buildings, roads and underground infrastructure. Can be a complicating factor in relation to mine gas and surface drainage well after subsidence is complete	Appreciable future surface subsidence associated with historical mines that were worked using the longwall technique is generally considered to be of **Low Risk**. The actual assessment should consider the potential for residual subsidence of 2.5 to 5 % of the total subsidence related to changes in effective stress or seismic shaking. Strategies should be developed for possible fractures in the rock mass related to foundation/infrastructure support and preferential pathways.
Fault reactivation and Fissures	Mining activity	Ground displacements, ruptures constitute zones of weakness and potential differential movement and should be avoided when siting foundations, roadways and utilities unless mitigative measures are undertaken. Reactivated faults constitute preferential pathways or potential barriers to the movement of groundwater and gas, along with the potential for secondary migration of soils into open fractures in the rock mass.	Mining induced fault reactivation takes place virtually contemporaneously with mining subsidence. The magnitude of any residual movement is relatively small. Notwithstanding that, because of the potential influence of main faults to gas and groundwater migration, as well as to larger scale slope/rock stability, the inferred trace of main fault lines has been assigned of **Moderate Risk** to land development, subject to specific project review.
Mine Gas	In mine workings or fractured rock near workings	Noxious, flammable and potentially explosive gas accumulations. Confined space entry leading to asphyxiation and death. Elevated potential for environmental assessment under the Contaminated Sites Regulations.	Not considered in this review
Mine Water	Discharge	Consequences are most notably associated with aquatic pollution related to low pH and elevated metals concentrations. Elevated potential for environmental assessment under the Contaminated Sites Regulations.	Not considered in this review
Mine Waste	Surface spoil piles or areas of made ground (fill).	Spontaneous combustion can occur in well compacted waste materials during ground disturbance. Pollutants in the form of acidic and elevated metals discharge Settlement or stability issues related to loose waste subject to imposed loads or saturation. Elevated potential for environmental assessment under the Contaminated Sites Regulations.	Not considered in this review

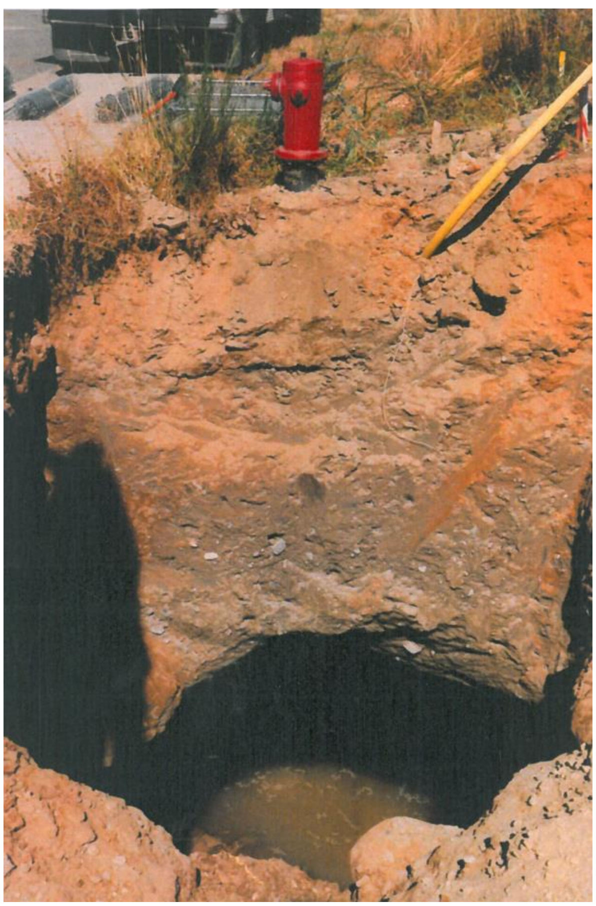
PHOTOGRAPHS

Photo	Description
	**Photo 1:** Partially open mine shaft on Newcastle Island approximately 200 m deep
	**Photo 2:** Partially collapsed and backfilled slope entrance to the shallow abandoned workings of the Fitzwilliam Mine

PHOTOGRAPHS

Photo	Description
	**Photo 3:** Partially collapsed shallow room and pillar workings of the abandoned Douglas Mine at a depth of 15 m beneath Victoria Road
	**Photo 4:** Mine roof collapse and migration of soils above the Douglas Mine on Fifth Street, Nanaimo encountered during shallow utility replacement works.

PHOTOGRAPHS

Photo	Description
	**Photo 5:** Open fractures above shallow workings of the Wellington Mine in the Gilfillan Road area.
	**Photo 6:** Secondary migration of soil resulting in open void and sinkhole in the Horth Road area near Divers Lake. Note presence of watermain and gas in vicinity of sinkhole.