SubTerra, Inc.

Civil & Mining Engineering
Engineering Geology
Tunnel Engineering & Construction Management
Rapid Excavation/Support Systems
Active/Abandoned Mine Subsidence
Quality Assurance / Quality Control
Safety Monitoring of Structures
Blast Optimization / Vibration Monitoring
Mine & Quarry Permitting
Material Science / Laboratory Testing

Tuesday, July 28, 2009

Mr. David Blanchard.
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Re: Final Draft City Heights, Cle Elum, WA Abandoned Mine Lands (AML) Report

Dear Mr. Blanchard:

Please find attached our Final Draft work product for the above noted project incorporating your comments and summary comments received from Aspect Consulting. If you have any questions please do not hesitate to call us at 425-888-5425.

Sincerely,

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1. INTRODUCTION

This Draft Report has been prepared for Sapphire Skies, LLC to document our initial evaluation of Abandoned Mine Land (AML) hazards for their proposed 358-acre development on Cle Elum Ridge above the town of Cle Elum located in Kittitas County, WA. The site location is shown in Figure 1 and a detailed site layout of the proposed development area, existing city streets, and historic, underlying coal mines is shown on Figures 2, 6, and 7. Figures 2, 6, and 7 are provided in two formats:

1. As a sequence of four 11 x 17 figures located at the end of the report. Sequential figures represent the site moving from the west towards the east.
2. As single "map scale" drawings either attached in plan pockets or provided on a CD ROM.

The property, collectively known as the "City Heights Property", is situated in Sections 25, 26, and 27 of Township 20N, Range 15E, Willamette Meridian, Kittitas County, Washington. A portion of two of the parcels (Tax Parcel 493935 and Tax Parcel 19165) are already within the City of Cle Elum. Other properties within the proposed development area identified in Table 1 below.

Table 1: City Heights Acreage, Parcel and Map Numbers

Tax Parcel Numbers	Map Numbers	Approximate Acreage
952904	20-15-25064-0001	20.66
952905	20-15-25064-0002	16.76
952906	20-15-25064-0003	21.45
952903	20-15-25064-0004	3.24
12528 that portion of Columbia St	20-15-25032-0002	0.25
19165	20-15-26057-0003	89.26
952818	20-15-26061-0001	20.00
952819	20-15-26061-0002	20.00
952820	20-15-26061-0003	20.00
952183	20-15-26060-0001	12.04
952184	20-15-26060-0002	12.00
493935 (Reeds Addition)	20-15-27051-0701	5.15
083835	20-15-27010-0001	70.18
593835	20-15-27020-0001	25.73
943835 (Must be sold with above)	20-15-27020-0007	21.52

1.1. Site Layout and Proposed Development Areas

The site has been subdivided into eleven Development Areas labeled 'A" through 'K'; individual Development Areas are further subdivided numerically (e.g., K1, K2). This subdivision may change as the project develops but has been used in this report to enable a more detailed designation of AML hazard areas than would otherwise be possible.

1.2. Scope of Work

SubTerra, Inc.'s scope of work for this initial planning phase included:

1. Kick-off meeting to discuss the project and obtain from the client group data they have available. These data include the topographic and geologic/geotechnical data, aerial photographs, and a plan of the proposed surface development including boundary adjustments, development areas, roads, utilities, drainage features, etc. As much as possible of this information would be provided in AUTOCAD file format.
2. Compiling and field verifying a plan and sections showing the mined out areas and surface features for the abandoned mines. The surface plan would show the location of the proposed development in relation to the undermined areas. Cross-sections would be prepared as appropriate to document mine conditions, depth to coal or voids, etc. Surface survey to be performed by Owner's surveyor under a separate contract. SubTerra, Inc. would liaise with Owner's surveyor to accurately locate important abandoned mine site features (e.g., portals, slag pile areas, subsided areas, etc.).
3. Determining the need for exploratory drilling to prove the location and extent of the abandoned mine workings. Conduct exploratory drilling as required.
4. Performing stability and risk analyses, determining the potential for surface subsidence, and the need for setbacks from potential subsidence areas. Prepare subsidence classification (severe, moderate, or de-classified) and recommendations of allowable land uses in severe and moderate areas.
5. Preparing a Draft Report that summarizes the above.
6. Incorporate client comments and produce a Final Report. Meeting with the City of Cle Elum as required answering questions and/or explaining the study and its conclusions. Updating, as appropriate, the Final Report to incorporate City comments.

Additional specific proof drilling of individual parcels, utility corridors, and access roads for areas that are not declassified during the Initial Project work would be carried out in subsequent phases according to the recommendations included in this report.

1.3. Approach

With minor exception, our approach followed the scope outline presented in our May 29, 2009 Proposal and summarized above. One exception was the use of sub-ft accuracy GPS to locate the abandoned mine features and proof drilling borehole collars; this location method may be supplemented at a later date by a detailed survey; however, the GPS method used was sufficiently accurate for the present purpose. Another exception was a more detailed subdivision of the Coal Mine Hazard Areas (see Sections 4 and 5).

Our initial work involved obtaining digital copies of the abandoned mine maps from the Washington State Division of Natural Resources along with pertinent references regarding coal mining in Cle Elum (e.g., Shideler, 1986; The Daily Record, 1999; Saunders, 1914; etc.). Base maps were prepared using the latest versions of the maps obtained.

We subsequently developed cross sections from the mapped data, evaluated the potential for impacts (e.g., sinkholes, trough type subsidence), developed the basis for and, in coordination with Aspect Consulting, implemented a proof drilling program, and prepared this Coal Mine Hazards Risk Assessment.

Neither the City of Cle Elum nor Kittitas County has developed regulations regarding development above coal mine areas. However, Kittitas County provides the following definitions in Title 17A, Critical Areas:

> ***17A.02.210 Mine hazard areas.*** *"Mine hazard areas" are geologically hazardous areas, directly underlain by, adjacent to, or affected by abandoned mine workings such as adits, tunnels, ducts or air shafts with the potential for creating large underground voids susceptible to collapse. Closed and abandoned mines shall be presumed not hazardous unless specifically identified by the U.S. Department of Mines or other relevant information. (Ord. 94-22 (part), 1994).*
>
> ***17A.06.030 Siting of structures on mine hazard areas****. Siting of structures on known mine hazard areas should be avoided. (Ord. 9422 (part), 1994).*

This lack of explicit regulatory guidance led us to use guidelines developed for King County, WA with regard to the preparation and content of Abandoned Mine reports and guidance regarding impact mitigation (see Attachment A). These guidelines may, or may not, be deemed applicable to work in Cle Elum and are simply included as a reference for standards that have been developed elsewhere in Washington State.

1.4. Report Contents

Section 2 summarizes the history of mining in the study area, provides a description of the six mines that were operated beneath the site, and presents the results of prior, available abandoned coal mine studies of the Cle Elum mines. Section 3 describes some of the engineering tools that were used to assess subsidence potential and Section 4 presents our Coal Mine Hazard assessment. Finally, Section 5 presents our findings and recommendations.

The report is intended to be read by a broad spectrum of stakeholders (project owner, EIS team members, public officials, and the general public) and to provide those readers with both a general and explicit understanding of the tasks that were accomplished.

1.5. Limitations

The enclosed and attached work products were prepared as input to the preliminary planning and EIS preparations for this project and for no other purpose. The work was performed under SubTerra, Inc.'s General terms and conditions and in a manner consistent with the level of care and skill ordinarily exercised by other professional contractors in similar circumstances at the time the Services were performed. No other warranty, express or implied is made.

2. History of Mining in the Study Area

Cle Elum traces its history to 1881 and two Pennsylvania prospectors who discovered coal and filed claim in 1891 (The Daily Record, 1999) to the site that is now the City of Cle Elum (historically referred to as CLEALUM). Other historians (Shideler, 1986; Saunders, 1914) place the start of mining near Cle Elum between 1890 and 1894.

Six mines in the project area extracted coal from a single seam, the Roslyn or No. 5 Bed, which averaged 4-ft 6-in in thickness. The Cle Elum Mines (No. 1, No.2, and No.3) opened in 1895, Roslyn No. 5 in 1905 followed by Roslyn No. 7 in 1907 and Independent Coal and Coke Company's no. 1 mine in 1918. Published annual coal production is summarized in Table 2.

2.1. Historic Coal Mines

The most comprehensive database of Washington's abandoned coal mines is maintained by the Division of Natural Resources in Olympia, WA. Schasse et al (1994) have prepared a list of available mine maps collated by Township, Range and Section; this database formed the starting point of our research for the subject property. Portions of the following mines that are known to underlie the site are illustrated on Figure 2 and described below. Mines are described starting at the west end of the proposed development area moving towards the east.

2.1.1. Roslyn No. 5 Mine (Figure 2, Sheet 1)

The western most part of the site is underlain by workings from the Roslyn No. 5 mine that was opened in 1905. Approximately 6.4 million tons were mined between 1907 and 1947.

The coal bed in the Roslyn No. 5 mine strikes N 45^{o} W and dips 20 to 30^{o} SW and was originally accessed by a slope driven from outcrop then from a rock tunnel. It is not expected that surface expressions of these features will be encountered on the City Heights site.

2.1.2. Roslyn No. 7 Mine (Figure 2, Sheets 1 and 2)

The central part of the site is underlain by workings from the Roslyn No. 7 mine that was opened in 1907. Approximately 7.6 million tons were mined between 1908 and 1936.

The coal bed in the Roslyn No. 7 mine strikes N 65^{o} W and dips 20 to 30^{o} SW and was initially accessed by driving a rock tunnel to the top of the coal then driving drifts down dip in the coal seam. Rock tunnel portals to this mine are present on the City Heights site as shown on Figures 2 and 7, Sheets 1 and 2, and Figure 3 and further described in Sections 4 and 5 of this report.

2.1.3. Cle Elum No. 1, 2, and 3 Mines (Figure 2, Sheets 3 and 4)

The eastern part of the site is underlain by workings from the Cle Elum No. 1, No. 2 and No. 3 mines which were opened in 1895. Approximately 4.1 million tons were mined between 1895 and 1943 with the majority of production prior to 1918.

These mines were accessed by drainage tunnels driven from outcrop. Drainage tunnel portals are located adjacent to Deer Creek that flows north to south across the site (see Figures 2 and 7, Sheet 3 and Figure 4). Sinkholes and shallow mine workings are located near the northern edge at the center of the site as shown on Figures 2 and 7, Sheet 2 and Figure 4. Shallow mine workings are also located at the eastern end of the site as shown on Figures 2 and 7, Sheet 4 and Figure 5. A shallow mine shaft is present at the eastern end of the site in Section 25 (see Figures 2 and 7, Sheet 4).

2.1.4. Independent Coal Company Mine No. 1 (Figure 2, Sheet 3)

Independent Coal and Coke Company Mine No. 1, otherwise known as the Queen Mine, was located in the E1/2, Section 26, Township 20 North, Range 15 East, WM and opened in 1916. Approximately 724,000 tons were mined between 1916 and 1927.

This mines workings are located at depth beneath the east central part of the site; abandoned coal mine entries to ICC No. 1 are therefore not expected to affect the City Heights project.

2.2. Coal Seams and Extraction Methods

Each of the mines in the proposed development area mined coal from a 4-ft 6-in thick seam called the Roslyn Bed or the No. 5 Bed (Saunders, 1914) that is described as uniform with few impurities. The seam was typically overlain by a thin, soft shale or mudstone layer grading to sandstone and underlain by sandy shale. The coal parted cleanly at these contacts so that little if any coal was left after mining.

Folds and rolls are present in the Roslyn Bed and the dip of the strata varies throughout the coal field between 10 and 30 degrees. Only one true fault was found in the field occurring in the Roslyn No. 5 mine to the west of the study area (Saunders, 1914).

Coal was extracted using room and pillar methods with subsequent pillar removal. Under this method, an entry and a counter were mined from the access decline along strike with a slight upward gradient (to promote drainage) to form each mine level. Crosscuts were mined between the lower entry and overlying counter as required to provide air circulation; intake air typically flowed along the entry to the active face then back to the access decline via the counter. Rooms were then mined upwards between levels using 24-ft wide single rooms and 20-ft wide pillars (for shallow coal) and 40-ft wide double rooms and 40-ft wide pillars (for deeper coal). Pillars were subsequently removed as indicated on the mine plans shown in Figure 2.

Turn of the century mining was by hand using pick and shovel with the later introduction of drilling-and-blasting using black powder in the early 1900s. Saunders, in 1914, estimated that 70% of the coal was being extracted while later estimates place the extraction ratio at 80% or higher. A scrutiny of the historic mine maps suggests an extraction ratio of at least 80%.

2.3. Previous AML Studies

2.3.1. Office of Surface Mines

Since the early 1980's, the Office of Surface Mines, based out of Denver, Colorado, has implemented a program of identifying and mitigating abandoned mine features typically including abandoned shafts, abandoned adits (horizontal tunnels), abandoned declines and sinkholes above abandoned coal mines in the State of Washington.

In 1984, Maddox and Associates (1984) were commissioned by the OSM to locate and document the condition of a subset of small Roslyn and Cle Elum mines on non railroad owned property.

This report did not examine land above mines in sections 25, 26, or 27 of Township 20 North, Range 15 East WM with the exception of ICC No. 1, the Queen Mine. An old air shaft, a portal, and an adit were located above ICC No. 1. However, these features are located to the south of the current property and have only been included in this report for completeness.

In 1999, Hart Crowser (1999) identified and located three openings in Section 26 (T20N, R15E) and identified three and located one opening in Section 27 (T20N, R15E). The features were described as follows:

> 26-01: A Priority 2, 25-ft by 15-ft subsidence from late 1955, with a 2-ft by 2-ft hole into bedrock. There was evidence of heavy water flow from the hole. This was a heavily visited area as suggested by trash and debris. The feature was probably an entry into the first level west of te Cle Elum Mine No. 3.
>
> 26-02 and 26-03: A pair of non-hazardous subsidence(s), approximately 25-ft long. 26-02 appeared to have been an entry into the slope of Cle Elum Mine No. 2. 26-03 appeared to have been the entry into the 1st Level East Gangway of the Cle Elum Mine No. 2.
>
> 27-01: A non hazardous, 30-ft long subsidence with a small, 1-ft by 1-ft opening. The feature appeared to be a caved portion of the Roslyn No. 7 Mine Rock tunnel.

The approximate location of the features identified by Hart Crowser is shown on Figures 3 and 4. Neither of these studies claimed to have found all the abandoned mine features that they had identified on the mine maps with Hart Crowser claiming to have located only 62 of 196 that were initially identified.

2.3.2. United States Geological Survey (USGS)

The USGS prepared an Open file report to document the availability and quantity of water in the Roslyn and Cle Elum coal mines in 1981 (USGS, 1981). This study confirmed the nominal extraction height of 5-ft in the studied coal mines but contains little additional useful information. We note that the study conclusions are marred by the assumption that little subsidence had occurred over mine areas where more than 80% of the coal had been extracted. We also note Saunders' (1914) observations that the Cle Elum mines were for the most part dry.

2.4. Summary

The historic mine data summarized above have been verified by surface reconnaissance to locate abandoned mine surface features (e.g., portals, sinkholes, etc.) and by drilling exploratory boreholes to confirm the thickness of mined coal and the current condition of the collapsed mine workings. Detailed descriptions of the work performed are contained in Sections 4 and 5 of this report.

3. Evaluating Subsidence Hazard Potential and Risks in the Study Area

There are two primary modes of subsidence occurrence as related to underground coal mining excavations. The first type is called Trough or "area-wide" subsidence and is typically characterized by a shallow, "trough" shaped depression related to deeper workings where the strata have deformed above the mine void space with minimal shear displacement. The potential for trough type subsidence is dependent upon the stability of the pillars, roof and floor. The second mode of subsidence is called Sinkhole or chimney type subsidence and is characterized by shearing, steep sided depressions, and large differential displacements.

3.1. Sinkhole or Chimney Type Subsidence

The Colorado Mined Land Reclamation Division (CMLRD) has studied the risk of sinkhole development above abandoned coal mines and has established a relationship for the probability of a mine void reaching the surface by using the following equation (CMLRD, 1986):

$$P = 1.0 \qquad \text{(for } h/m < 6.2\text{)}$$

$$P = 1516\,(h/m)^{-4} \qquad \text{(for } h/m > 6.2\text{)}$$

where,

P = Probability of void creating a sinkhole

h = Depth to mine floor (ft)

m = Void height (ft)

Regulations developed by King County (see Attachment A) indicate that acceptable stability is indicated by a probability less than 1%.

For the City Heights project area, the overburden thickness corresponding to a void height of 4.5-ft and a sinkhole incidence probability of 1% is 90-ft. Therefore, if no subsidence had occurred, the overburden thickness where sinkhole potential would be of concern is 90-ft or less. Our examination of the mining records coupled with the results of the proof drilling program indicate that significant subsidence has already occurred and any future potential for sinkhole occurrence should be limited to areas that are 50-ft deep or less.

We note the presence of sinkholes at the northern edge of the central part of the City Heights property located west of Deer Creek (Montgomery) road. These sinkholes, verified in the field, are significantly deeper (i.e., of greater vertical extent) and larger than sinkholes that would have typically been expected to form over the 4-ft 6-in thick coal seam. We assume that these features are associated with water borne migration of the surficial soft sandstone deposits into sinkholes that occurred over shallow (<20-ft deep) coal extraction areas. This assumption was confirmed, in part, by the proof drilling program and our observations of ongoing sinkhole development directly above the Roslyn No. 7 mine strip pit. Development in these areas should not be permitted.

3.2. Trough Type Subsidence

The potential for trough subsidence to occur beneath the City Heights property was evaluated using data obtained from the mine records (e.g., mine height, extraction ratio), comments on the mine plans and in retrieved publications (e.g., Saunders, 1914), anecdotal information from other coal fields (e.g., Boulder Weld Coalfield, CO; King County mines) and our experience analyzing and predicting subsidence from active coal mines. These records and analyses indicate that there is a very low probability that trough subsidence will be impactive to development on the City Heights site.

As noted in Section 2, the extraction ratio (ratio of area of coal extracted to the total area of coal in an area of the mine) for the Cle Elum mines was 80% or higher. That is, 80% of the coal between each mine level was systematically and sequentially removed. In a small number of areas, pillars were only partially removed as the failing roof made it too dangerous to complete that operation. Saunders (1914) notes that, in those situations, the pillars deformed vertically and crushed out.

Knuppe and Sisson (1923) provide a detailed description of the mining methods used in the Cle Elum mines, including the methodology of sequential pillar removal and control of the caving mine roof. Their notes regarding the nature of surface subsidence progressing from the mine roof caving are provided below:

> *In attempting to correlate surface subsidence with these underground caves it was found that where the cover over the coal was only 60 to 75-ft thick the settling invariably was transmitted to the surface, where it manifested itself in sharp caves, rounded sinkholes, and rock slides, with accompanying breaks and fractures. Where the cover increased in depth to over 120-ft the movement of the surface was not so evident. (Page 15).*
>
> *The last pillars were drawn from Mine No. 1 in the Roslyn seam, early in 1919 and subsidence immediately followed. The effects of this subsidence can now be traced on the surface, being most noticeable near the outcrops. The surface phenomenon is characterized by cracks, well defined fractures, surrounding areas of depression, and occasional small caves and sinkholes. The main line of fracture is parallel to the ends of the rooms that were driven close to the outcrop. Occasional blocks, the size of one or two rooms, have dropped abruptly for 3 to 4 feet. Gentle depression areas of 1 and 2 acres in extent exist over the workings with shallow cover. Marked depression of the surface followed the main line of fracture from the first west level (cover about 60-ft) to a point approximately over the seventh west level (cover about 400-ft) where depression and fracturing seemed to disappear. (Page 16,17).*
>
> *The caves and sinks occur only in places where the cover is shallow. They vary from 3 to 50-ft in diameter and 2 to 10-ft in depth and take on the shape of an inverted cone. (Page 17).*
>
> *According to William Shaw, superintendent, the subsidence described above took place closely after the drawing of pillars. Occasionally, the strata would hold up for some length of time after the drawing of pillars and then would cave suddenly without warning……Mr. Shaw cites subsidence as high as 50% of the thickness of seams in this vicinity and gives 400-ft as the limiting depth at which the surface is affected to any extent, and adds that most of the visible consequences of subsidence occur where the cover is relatively shallow, 200 feet or less. (Page 17).*
>
> *The visible effects of subsidence disappear at about 400-ft, while in the shallower portions caving and fracturing are prevalent and are accompanied by depression areas.*

These records confirm that roof failure followed by ground subsidence occurred shortly after deeper coal extraction where 80% or higher extraction occurred. Observations in other coal fields show that subsidence over deep coal mine areas is 95% complete within one year of mining and measurable movements cease within a decade. We note that these observations were made regarding trough type subsidence and not the sinkhole type subsidence noted above. Other studies (e.g., CMLRD, 1986) have concluded that trough type subsidence is considered complete over room and pillar workings after 40-years.

Shallow coal areas where pillars were not completely removed, either because of dangerous ground behavior or because of the need to preserve access entries or declines, may not have completely collapsed and there is evidence of this condition above the entries to the Roslyn No. 7 mine and at the eastern end of the City Heights property.

3.3. Subsidence Effects on Structures in Cle elum

Knuppe and Sisson (1923) describe the effects of subsidence on structures located in the city of Cle Elum that were undermined by workings that were 500 to 900-ft deep:

> *Most of the concrete and brick buildings are cracked to a greater or less extent. Sidewalks running north and south show a preponderance of east and west cracks. Buildings show small fractures beneath the windows and larger fractures are evident on the sides without windows. Taken as a whole the fractures are small although a few of considerable size were found. The Schober Building, built early in 1919, has split through its center……Other cracks of noticeable dimensions appear in the Post Office building, Stove's Drug Store, and the Travelers Hotel building.*

These are typical levels of trough subsidence related structural damage that would be expected to occur over mines practicing 80% extraction of a 4.5-ft thick coal seam at the noted depths.

3.4. Summary

Our examination of the historic mine records and observation and analysis of current subsurface conditions leads us to conclude that trough type subsidence is not expected to be impactive to development on this site. However, shallow mine workings located at the northern edge of the central part of the site and at its eastern end remain of concern with regard to sinkhole potential. An analysis of potential subsidence hazards is provided in the following section of this report.

4. Subsidence Hazard Evaluation and Mitigation

Subsidence hazards at the City Heights site have been evaluated using a combination of engineering analyses, related to depth of cover and extraction ratio, site reconnaissance, and proof drilling.

4.1. Field Reconnaissance for AML Features

Two separate site visits were made to locate and identify abandoned coal mine features (e.g., shafts and adit/decline entrances) that were indicated by historic mine maps and prior studies to be located on the site. Abandoned coal mine maps were geo-referenced then uploaded to a sub-meter Trimble, Global Positioning System (GPS) that was used to locate features shown on the maps. Photographs of the located features are included as Plates at the end of this report.

4.1.1. Section 27 AML Features (Figure 3)

Our second trip located the subsided rock tunnel located by Hart Crowser (Hart Crowser, 1999) in Section 27 and linear features consistent with collapse over the rock tunnels shown on the mine plans (see Figure 2, Sheets 1 or 2).

4.1.2. Section 26 AML Features (Figure 4)

Our first trip located two openings to the Roslyn No. 7 mine on the west side of Deer Creek (Montgomery) road just beyond Deer Creek. Two openings located on the east side of Deer Creek (Montgomery) road are believed to be features 26-02 and 26-03 identified by Hart Crowser and are drainage tunnels to the Cle Elum mines; water drained from the southernmost feature through a steel pipe.

A backfilled area was observed on the east side of Dear Creek (Montgomery) road to the north of features 26-02 and 26-03 and is believed to be the site of the northernmost entry to the Cle Elum mines located on the project site (see Figure 2, Sheet 3).

4.1.3. Section 25 AML Features (Figure 5)

A mine shaft to the Cle Elum No. 2 Mine was located on our second trip just west of the drainage that bisects Development Area K. This abandoned mine feature was not identified by the prior OSM sponsored AML studies (see Figure 2, Sheet 4).

4.2. Coal Mine Hazard Area Designations

Coal Mine Hazard Areas (CMHAs) have initially been defined as follows:

- CMHA 1: Areas where coal mine workings, rock tunnels, and drainage adits are shallower than 50-ft and areas within 25-ft of rock tunnel portals.
- CMHA 2: Areas where coal mine workings are between 50-ft and 100-ft deep.
- CMHA 3: Areas where coal mine workings are between 100-ft and 200-ft deep.
- CMHA 4: Areas where coal mine workings are between 200-ft and 300-ft deep.

- CMHA 5: Areas where coal mine workings are greater than 300-ft deep.
- CMHA 6: Areas underlain by coal mine tailings or waste rock stockpiles.

Coal mine maps were obtained from the Washington Division of Natural Resources, as previously described, scanned/digitized, geo-referenced, and entered into a 3-D Autocad model of the site. Existing topography and existing and planned surface developments were also added to this computer model that was used to produce the figures in this report.

Figure 6, Sheets 1 to 4 show the coal mine floor elevation data and coal seam elevation contours derived from the coal mine floor elevation data. Coal mine floor elevations were initially read from the abandoned mine plans, input into the 3-D Autocad model of the site, and used to create a surface representing the base of the No. 5 coal seam.

The base of coal seam surface was digitally subtracted from the topographic surface and contoured to develop the depth contours shown on Figure 7 and the cross-sections shown on Figure 8. Figure 7 also contains the color coded CMHA or Risk areas.

4.3. Historic Aerial Photograph Review

Aerial photographs of the site were obtained from the US army Corps of Engineers (1945) and the US Geological Survey (1956). These aerial photographs (see Figure 9) were taken after the majority of coal mining was complete and much of the intricate surface rail haulage system had been removed. More recent aerial photographs (see Figure 10) illustrate that few changes have occurred since the mines were closed.

4.4. Initial Proof Drilling Program

The initial proof drilling program was designed to evaluate subsurface conditions in several shallow coal mine areas. Proposed Development Areas E and K and the Deer Creek Road (i.e., extension of Montgomery Road) crossing of the coal seam outcrop were targeted.

4.4.1. Proof Drilling Methods

Two proof drilling methods were selected based on consideration of ease of access and cost. Air track borings were drilled by McCallum Rock Drilling, Inc., under contract to Sapphire Skies. A total of 13 borings were drilled using this method, to depths ranging from 60-ft to 130-ft bgs. Borings were drilled using a track-mounted drill rig equipped with a 3½-in outside diameter drill bit. Borings B-1 through B-7 were drilled on June 17, 2009, and borings B-8 through B-13 were drilled on June 18, 2009.

One borehole, D-1 (see Sheet 2 of Figures 2, 6, and 7), was advanced using a truck-mounted air rotary rig with a 6-inch outside drill diameter. Tumwater Drilling and Pump Company completed Boring D-1 to a total depth of approximately 230-ft bgs on June 18, 2008.

All boreholes were logged by Field geologists from Aspect Consulting, Seattle WA. Boreholes B-1 to B-4, D-1, and B-10 to B-12 were videoed by SubTerra, Inc. personnel.

4.4.2. Summary and Analysis of the Initial Proof Drilling Program

The generalized geologic summary of each borehole provided below has been extracted from the Mine Hazards Subsurface Exploration Data Report prepared by Aspect Consulting (Aspect Consulting, 2009); more detailed descriptions can be found in individual boring logs contained in that report. Comments have been added to the summary geologic descriptions for each borehole based on our examination of the video profile of each borehole; these data were not available to Aspect Consulting at the time their draft report was prepared.

Boring B-1 located as shown on Figures 2, 6, and 7; Sheet 4 was drilled to a total depth of 105-ft. Glaciofluvial deposits consisting of sand, clayey sand, and slightly gravelly sand, were encountered to a depth of approximately 45-ft. Below this depth, weathered bedrock residuum consisting of gray silty, and slightly clayey sand overlying sandstone, was encountered at a depth of 50-ft and extended to completion depth of 105-ft. A siltstone layer was encountered from approximately 56 to 84-ft, and a small (approximately 6-in) void was noted at approximately 102-ft. Cuttings were not returned to the surface from below the void.

Examination of the video for Borehole B-1 located non-contiguous voids in the softer sand at approximately 50-ft bgs and coal fragments at the bottom of the hole. The non-contiguous voids in the soft sandstone were probably “mined” by the circulating compressed air used during drilling. Observations indicated that subsidence in this area was, for the most part, complete.

Boring B-2 located as shown on Figures 2, 6, and 7; Sheet 4 was drilled to a total depth of 60-ft. Residuum consisting of silty sand, was encountered to a depth of approximately 11-ft. Interbedded sandstone and siltstone were encountered to completion depth. A void was noted from approximately 53 to 57-ft. Cuttings were not returned to the surface from below the void. No groundwater was encountered.

Mud that formed on the borehole wall just below 20-ft bgs covered the camera lens and prevented examination of the bottom of Borehole B-2.

Boring B-3 located as shown on Figures 2, 6, and 7; Sheet 4 was drilled to a total depth of 60-ft. Residuum, consisting of silty sand and gravelly, silty sand, was encountered to a depth of approximately 11-ft. Layers of siltstone and sandstone were logged from this depth to approximately 40-ft. A layer of coal-rich siltstone was encountered between 40-ft and 42-ft and was underlain by a 2-foot void. Mudstone was encountered below the void to the bottom of the boring at 60-ft. No groundwater was encountered.

Examination of the video for Borehole B-3 indicates that voids observed by the driller were enlarged sections of the hole and not contiguous voids.

Boring B-4 located as shown on Figures 2, 6, and 7; Sheet 4 was drilled to a total depth of 72-ft. Residuum, consisting of silty sand, was encountered to a depth of 25-ft. Below this depth, sandstone was encountered to approximately 36-ft. Siltstone was present from 36-ft to 50-ft. Coal was encountered from 50-ft to 56-ft, underlain by coal-rich mudstone to a depth of 60-ft. Mudstone was encountered to the bottom of the boring at 72-ft. No groundwater was encountered.

Examination of the video for Borehole B-4 indicates intact strata throughout the hole. It is interpreted that B-4 encountered the intact coal seam at the north end of the workings (see Figure 2, Sheet 4).

Boring B-5 located as shown on Figures 2, 6, and 7; Sheet 4 was drilled to a total depth of 130-ft. Residuum, consisting of silty sand, was encountered to a depth of 40-ft. Trace coal was present from approximately 39 to 40-ft. Underlying the residuum, mudstone was encountered to a depth of 64-ft. Mudstone and siltstone are interbedded with sandstone between 64-ft and 94-ft. Coal was noted from 94 to 98-ft, and was underlain by siltstone to the bottom of the boring at 130-ft. No groundwater was encountered.

This boring was not videoed. Borehole B-5 was interpreted to have located the intact coal seam at the expected depth (e.g., 100-ft bgs) indicating that the pillars in this area were not removed.

Boring B-6 located as shown on Figures 2, 6, and 7; Sheet 4 was drilled to a total depth of 130-ft. Residuum, consisting of slightly silty sand, was present to a depth of approximately 35-ft, and was coal-rich from approximately 10 to 12-ft. Below the residuum, coal was present from approximately 35 to 36-ft. Mudstone, present from approximately 36 to 55-ft, was underlain by sandstone to a depth of 86-ft. Another coal seam was present from approximately 86 to 90-ft, underlain by siltstone to a depth of approximately 120-ft. The siltstone unit contained coal from approximately 90 to 108-ft. Sandstone was encountered from 120-ft to the bottom of the boring at 130-ft. No groundwater was encountered.

This boring was not videoed. Borehole B-6 was interpreted to have located the intact coal seam at the expected depth (e.g., 90-ft bgs) again indicating that the pillars in this area were not removed.

Boring B-7 located as shown on Figures 2, 6, and 7; Sheet 3 was drilled to a total depth of 72-ft. Glaciofluvial deposits consisting of silty fine sand with fine, rounded gravel were present to 12-ft. Sandstone was present below 12-ft. Two voids were encountered, from approximately 19 to 22-ft and from approximately 23 to 30-ft. A coal seam was encountered from 43 to 49-ft. Cuttings were not returned to the surface from below the void at 49-ft. No groundwater was encountered.

The video for Borehole B-7 indicated a dry hole with no visible voids to a depth of 48-ft where the hole had evidently collapsed.

Boring B-8 located as shown on Figures 2, 6, and 7; Sheet 3 was drilled to a total depth of 72-ft. Glaciofluvial deposits were encountered from the surface to 5-ft. Residuum, dominated by slightly silty fine to medium sand, was encountered from 5-ft to 20-ft. Sandstone was encountered between 20 and 24-ft, underlain by siltstone between 24-ft and 27-ft. Coal was noted from 27 to 30-ft, underlain by mudstone to the bottom of the boring at 48-ft. Perched groundwater was encountered at approximately 42-ft and 48-ft.

We interpret that this borehole encountered the mine workings between 42-ft and 48-ft then filled with water to a depth of 32-ft as evidenced by the video camera log. This elevation is consistent with the elevations of the drainage tunnels located either side of Deer Creek (Montgomery) road.

Boring B-9 located as shown on Figures 2, 6, and 7; Sheet 3 was drilled to a total depth of 108-ft. Residuum, consisting of sand and slightly clayey sand, was encountered to a depth of approximately 36-ft. Mudstone, encountered from 36-ft to 45-ft, was underlain by soft sandstone interbedded with void spaces to a depth of approximately 59-ft. Cuttings were not returned to the surface from below the void to the bottom of the boring at 108-ft. No groundwater was encountered.

This boring was not videoed. The void encountered at a depth of 45-ft is believed to be the soft sand encountered and videoed in B-1 and B-3.

Boring B-10a located as shown on Figures 2, 6, and 7; Sheet 2 was drilled to a total depth of 18-ft. Numerous voids were encountered near the surface. This boring location was relocated approximately 15-ft to the west and resumed as boring B-10b. No groundwater was encountered.

Boring B-10b located as shown on Figures 2, 6, and 7; Sheet 2 was drilled to a total depth of 84-ft. Residuum, consisting of silty, slightly clayey sand, was encountered to a depth of 22-ft. A void was encountered from 18 to 22-ft. Sandstone was encountered at 22-ft. Cuttings were not returned to the surface from below 22-ft to the bottom of the boring at 84-ft. Groundwater was encountered at an unknown depth.

The video of this borehole confirmed several nominally 2-ft high voids that were characteristic of partially collapsed mine workings at shallow depth.

Boring B-11 located as shown on Figures 2, 6, and 7; Sheet 2 was drilled to a total depth of 72-ft. Residuum, consisting of slightly silty sand, was encountered to a depth of 20-ft, underlain by sandstone to a depth of approximately 32-ft. A void was encountered from approximately 32 to 34-ft, and was sealed by the driller using water. Siltstone was encountered between 36-ft and 40-ft. Coal was present from 40 to 46-ft. Mudstone underlies the coal to a depth of 62-ft, where sandstone was present to the bottom of the boring at 72-ft. Groundwater was encountered at 68-ft ATD.

Boring B-11 is interpreted to have encountered partially collapsed mine workings at a depth of 30 to 35-ft.

Boring B-12 located as shown on Figures 2, 6, and 7; Sheet 2 was drilled to a total depth of 60-ft. Residuum, consisting of slightly silty sand, was encountered to a depth of 12-ft. Sandstone was encountered to a depth of 33-ft containing a void from approximately 21 to 33-ft. Cuttings were not returned to the surface from below the void. Drill action suggested rock of unknown composition from approximately 33-ft to the bottom of the boring at 60-ft. No groundwater was encountered.

Borehole B-12 is interpreted to have encountered un-collapsed mine workings at a depth of 20 to 30-ft.

Boring B-13 located as shown on Figures 2, 6, and 7; Sheet 2 was drilled to a total depth of 96-ft. Residuum, consisting of silty sand and silty sand with trace gravel, was encountered to a depth of approximately 12-ft. Mudstone was encountered from 12-ft to 24-ft. Sandstone was present below 24-ft. Voids were encountered from approximately 52 to 56-ft, 78 to 80-ft, and 83 to 86-ft. Cuttings were not returned to the surface from below the void at 52-ft. No groundwater was encountered.

Borehole B-13 is interpreted to have encountered the soft sand (at 52-ft) and the partially collapsed coal seam at 78-ft.

Boring D-1 located as shown on Figures 2, 6, and 7; Sheet 2 was drilled to a total depth of 230-ft. Residuum consisting of silty sand was encountered in this boring to a depth of 22-ft. Below this depth, sandstone was encountered to approximately 35-ft, underlain by siltstone to 90-ft. The siltstone contained coal from 50 to 52-ft. Void spaces were encountered from approximately 90 to 92-ft, 122 to 123-ft, 128 to 129-ft, and 143 to 146-ft. Cuttings were not returned to the surface from below the void at 90-ft. Water was noted at the bottom of this hole during observation with the downhole televiewer, but appeared to be originating from perched water layers draining out of fractured rock from a depth of approximately 122-ft.

Borehole video confirmed that the zones identified by drilling action as voids were actually zones of fractured rock; sideways viewing revealed no lateral extent. One zone at 150-ft bgs was interpreted to be the fully collapsed coal mine.

4.5. AML Hazards and Mitigation Methods

As detailed in the preceding paragraphs, abandoned mine hazards on the Century Heights site include abandoned shafts, portal entrances to inclines and adits, sinkholes that have formed above the mine workings, mine tailings or waste piles, and the potential for future subsidence over partially collapsed mine workings.

Mitigation of the abandoned mine openings and remnant sinkholes could include:

1. Over-excavation and backfilling of surface depressions over the shallow rock tunnel portals shown on Figure 3.
2. Backfilling and installation of a surface seal in the abandoned air shaft shown on Figure 5.
3. Backfilling and grading of sinkholes shown on Sheet 2 of Figure 2.
4. Grouting and compaction of shallow mine workings in CMHA 1.

Mitigation in CMHA 6 may involve removal or stabilization of the mine tailings at the western end of the site. We understand that this aspect of the work is being studied separately by Aspect Consulting.

5. Findings and Recommendations

Proposed development criteria and potential mitigation have been developed for each of the coal mine hazard areas previously described and provided below. Development criteria have been proposed based on the initial analysis of risks underpinned by the Subsidence Hazard Evaluation described in Section 4.

5.1. CMHA Description, Proposed Development Criteria and Potential Mitigation

5.1.1. Coal Mine Hazard Area 1:

Description: Coal Mine Hazard Area 1 includes areas where workings are less than 50-ft deep and areas where abandoned mine features are present.

Proposed Development Criteria: These areas are not deemed suitable for development at the current time.

Potential Mitigation: Mitigation may include drilling and grouting of the remnant voids beneath the site and sealing of air shafts and adit/decline/incline portals.

5.1.2. Coal Mine Hazard Area 2:

Description: Coal Mine Hazard Area 2 includes those areas where the abandoned coal mines are between 50-ft and 100-ft deep beneath the site and abandoned mine features are not present. This CMHA does not include areas where there are significant accumulations of mine waste (see CMHA 6).

Proposed Development Criteria: These areas may be developable after detailed site investigation to prove the absence of remnant voids and/or after mitigation. Otherwise, this area should be considered a buffer zone between CMHAs 1 and 3.

Very detailed abandoned mine site investigations including at least 2 boreholes per acre with proof drilling below proposed building foundation areas and access roads, may be used to demonstrate the suitability of CMHA Area 2 sites for development. The requirements for building design and future AML reports in Section 5.1.5 apply.

Potential Mitigation: Mitigation may include drilling and grouting of the remnant voids beneath the site and sealing of air shafts and adit/decline/incline portals.

5.1.3. Coal Mine Hazard Area 3:

Description: Coal Mine Hazard Area 3 includes those areas where the abandoned coal mines are between 100-ft and 200-ft deep beneath the site and abandoned mine features are not present. This CMHA does not include areas where there are significant accumulations of mine waste (see CMHA 6).

Proposed Development Criteria: Development may occur in these areas subject to standard site investigation, civil engineering design, and local, state and federal code compliance. In addition, proof drilling shall be conducted at each proposed building site (minimum of one hole per 5-acres) to demonstrate that subsidence is substantially complete.

Potential Mitigation: Clean up of abandoned mine structures.

5.1.4. Coal Mine Hazard Area 4:

Description: Coal Mine Hazard Area 4 includes those areas where the abandoned coal mines are between 200-ft and 300-ft deep beneath the site and abandoned mine features are not present. This CMHA does not include areas where there are significant accumulations of mine waste (see CMHA 6).

Proposed Development Criteria: Development may occur in these areas subject to standard site investigation, civil engineering design, and local, state and federal code compliance. In addition, building foundation design shall accommodate the requirements of 5.1.5 below.

Potential Mitigation: Clean up of any abandoned mine structures.

5.1.5. Additional Development Criteria and Mitigation for Construction in CMHAs 1 to 4

Building designs shall accommodate standard requirements for construction in abandoned mine areas including, at a minimum, the use of rigid foundations (conventional reinforced concrete spread footings) supporting a flexible superstructure (metal or wood-frame); concrete slab-on-grade construction should use “rebar” rather than wire mesh for added strength; no brick or rock construction other than for fireplaces, nonstructural facades or landscape features.

Any additional AML work and/or studies shall meet, at a minimum, the requirements and guidance outlined in Attachment A.

5.1.6. Coal Mine Hazard Area 5:

Description: Coal Mine Hazard Area 5 includes areas where coal mines are deeper than 300-ft and where abandoned mine features (e.g., spoil piles, adits, portals, shafts, etc.) are not present. This CMHA does not include areas where there are significant accumulations of mine waste (see CMHA 6).

Proposed Development Criteria: Development may occur in these areas subject to standard site investigation, civil engineering design, and local, state and federal code compliance.

Potential Mitigation: Clean up of any abandoned mine structures.

5.1.7. Coal Mine Hazard Area 6:

Description: Coal Mine Hazard Area 6 includes areas covered by abandoned coal mine spoils.

Proposed Development Criteria: No development is permitted in these areas until a qualified Geotechnical / Civil Engineer has conducted investigation, stability analyses, and foundation valuations and certified that the site is suitable for building construction.

Potential Mitigation: Potential mitigation would involve complete or partial removal of the spoil material from the development area to the satisfaction of the qualified Geotechnical / Civil Engineer.

5.2. Findings

As noted in the introduction, we have elected to describe potential impacts and mitigation for each of the proposed Development Areas. Figure 7 and the criteria presented above in Section 5.1 have been used as a reference for each of the impact evaluations which are presented below.

5.2.1. Development Area A:

Development Areas A1 and A2 are underlain by coal mine waste piles (CMHA 6) composed of waste rock excavated from mines west of the project site. These areas may be developed from a mine subsidence perspective but require investigation, stability analysis, evaluation and design by a qualified Geotechnical/Civil Engineer before their development potential can be confirmed. Guidance on Coal mine Spoil Pile hazard mitigation is provided in Attachment A.

5.2.2. Development Area B:

Coal mine workings are between 550-ft and 650-ft deep below Development Area B placing Development Area B in CMHA 5. No mitigation or development restrictions are proposed. However, surface inspection is required to confirm the absence of coal mine spoils.

5.2.3. Development Area C:

Coal mine workings are between 600-ft and 700-ft deep below Development Area C placing Development Area C in CMHA 5. No mitigation or development restrictions are proposed. However, surface inspection is required to confirm the absence of coal mine spoils.

5.2.4. Development Area D:

Similar to Development Area C, coal mine workings are between 500-ft and 700-ft deep below Development Area D placing Development Area D in CMHA 5. Section 27 Rock Tunnels have been identified above Development Area D2 (see Figure 7, Sheet 2) and will need to be remediated during site development. No additional mitigation or development restrictions are proposed.

5.2.5. Development Area E:

Development Area E is underlain by mine workings ranging from outcrop (0-ft deep) to 150-ft deep placing Development Area E into CMHAs 1, 2, and 3. As noted in Section 5.1.1, CMHA 1 is not deemed suitable for development at this time and CMHA 2 is deemed marginally suitable for development subject to the proposed development criteria in 5.1.2. Boreholes drilled in CMHA 1 located extensive voids within 20-ft of the surface and Borehole 13 in CMHA 2 located voids at 52-ft, 78-ft (approximate depth of coal seam), and 83-ft. These data indicate that voids are migrating towards the surface and that collapse is not yet complete.

Development in CMHA 3 is considered more feasible, subject to the proposed development criteria in 5.1.3.

5.2.6. Development Area F:

Development Area F contains four Development Areas located immediately north of the current City limits (Figure 7, Sheets 2 and 3). Development Areas F1 and F4 are underlain by coal mine workings that are between 300-ft and 500-ft deep placing these Development Areas in CMHA 5. No mitigation or development restrictions are proposed.

Development Area F3 is underlain by coal mine workings that are between 200-ft and 300-ft deep placing this Development Area in CMHA 4. Proposed development criteria are provided in section 5.1.4.

Development Area F-2 is underlain by coal mine workings that are between 150-ft and 300-ft deep placing this Development Area into CMHAs 3 and 4. Proposed development criteria are provided in sections 5.1.3 and 5.1.4.

5.2.7. Development Area G:

Development Area G is underlain by coal mine workings that are between 200-ft and 280-ft deep placing Development Area G in CMHA 4. Proposed development criteria are provided in section 5.1.4.

5.2.8. Development Area H:

Development Area H is underlain by coal mine workings that are between 200-ft and 240-ft deep placing Development Area H in CMHA 4. Proposed development criteria are provided in section 5.1.4.

5.2.9. Development Area I:

Development Area I contains two Development Areas bisected by a north south running access road (Figure 7, Sheet 4). Development Area I-2 is underlain by coal mine workings that are between 150-ft and 250-ft deep placing this Development Area into CMHAs 3 and 4. An air shaft is also located east of I-2 as shown on Figure 2, Sheet 4. Proposed development criteria are contained in Sections 5.1.3 and 5.1.4.

Development Area I-1 is underlain by coal mine workings that are between 270-ft and 320-ft deep placing Development Area I-1 in CMHAs 4 and 5. We propose that development criteria for CMHA 5 should be applied to this Development Area as the shallowest coal mine workings are located on the order of 270-ft below the developable surface and no abandoned mine features are indicated to be present.

5.2.10. Development Area J:

Development Area J is underlain by coal mine workings that are between 260-ft and 340-ft deep placing Development Area J in CMHAs 4 and 5. We propose that development criteria for CMHA 5 should be applied to this Development Area as the shallowest coal mine workings are located on the order of 280-ft below the developable surface and no abandoned mine features are indicated to be present.

5.2.11. Development Area K:

Development Area K contains two Development Areas bisected by a north south running access road (Figure 7, Sheet 4). Development Area K-2 located at the east end of the property is underlain by coal mine workings that are between 10-ft and 90-ft deep placing Development Area K-2 in CMHAs 1 and 2.

However, it is our opinion, based on the results of the proof drilling program, that mitigation (i.e., grouting) may be applied, in conjunction with additional proof drilling and stability analyses to allow this area to be developed. It is therefore proposed that development criteria for CMHA-2 be applied to the entire K-2 area.

Development Area K-1 located west of the access road is underlain by coal mine workings that are between 100-ft and 150-ft deep placing this Development Area in CMHA 3. Proposed development criteria are provided in Section 5.1.3.

5.3. Conclusions and Recommendations

This report has provided an initial evaluation of abandoned coal mine hazards for proposed development of the 358-acre City Heights site located on Cle Elum Ridge above the City of Cle Elum, Kittitas County, Washington. Coal Mine Hazard Areas have been defined along with proposed development criteria and potential mitigation for Development Areas defined by the project owner, Sapphire Skies, LLC.

It is our opinion that this study should be sufficient to accompany the project through the planned EIS process.

Our recommendations for future work that may be undertaken during or after the EIS process includes:

1. Finalize this report based on comments from the Owner, Team Members, and the City of Cle Elum.
2. Attend meetings with the Owner and City Staff.
3. Provide assistance as required to develop and implement additional characterization and plans for mitigation suggested for Development Areas E and K.
4. Provide assistance as required to develop and implement closure designs for abandoned mine features in Sections 25, 26, and 27. This task would involve liaison with OSM.
5. Provide assistance as required to develop and implement coal mine waste stockpile disposal alternatives.

6. References

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FIGURES and DRAWINGS

TABLES

Table 2: Coal Production from Mines Underlying the City Heights Site				
Year	Roslyn No. 5	Roslyn No. 7	Cle Elum Coal Company	ICC Queen Mine
			25,471	
1900				
1901				
1902			212,584	
1903			331,400	
1904			377,114	
1905			313,987	
1906			434,629	
1907	204,334		443,259	
1908	173,613	65,298	284,536	
1909	160,149	130,228	314,092	
1910	203,195	215,995	307,683	
1911	155,110	174,896	157,744	
1912	170,224	198,954	150,207	
1913	123,105	183,546	181,196	
1914	113,146	148,885	148,091	
1915	86,763	114,693	89,012	
1916	158,681	195,141	136,968	7,271
1917	262,415	284,389	118,304	93,769
1918	228,078	313,764	39,605	143,259
1919	149,140	274,613	1,613	80,317
1920	162,268	469,046	3,332	94,432
1921	126,808	419,312	2,806	33,609
1922	74,524	289,582	2,137	56,516
1923	99,518	379,414	533	54,442
1924	68,092	334,101	115	60,304
1925	95,314	270,915	647	44,791
1926	175,105	348,821	540	37,818
1927	233,810	477,461	177	17,890
1928	219,945	399,202		
1929	274,744	390,888	273	
1930	189,602	397,854	1,896	
1931	173,388	293,062	2,817	
1932	176,264	244,541	2,247	

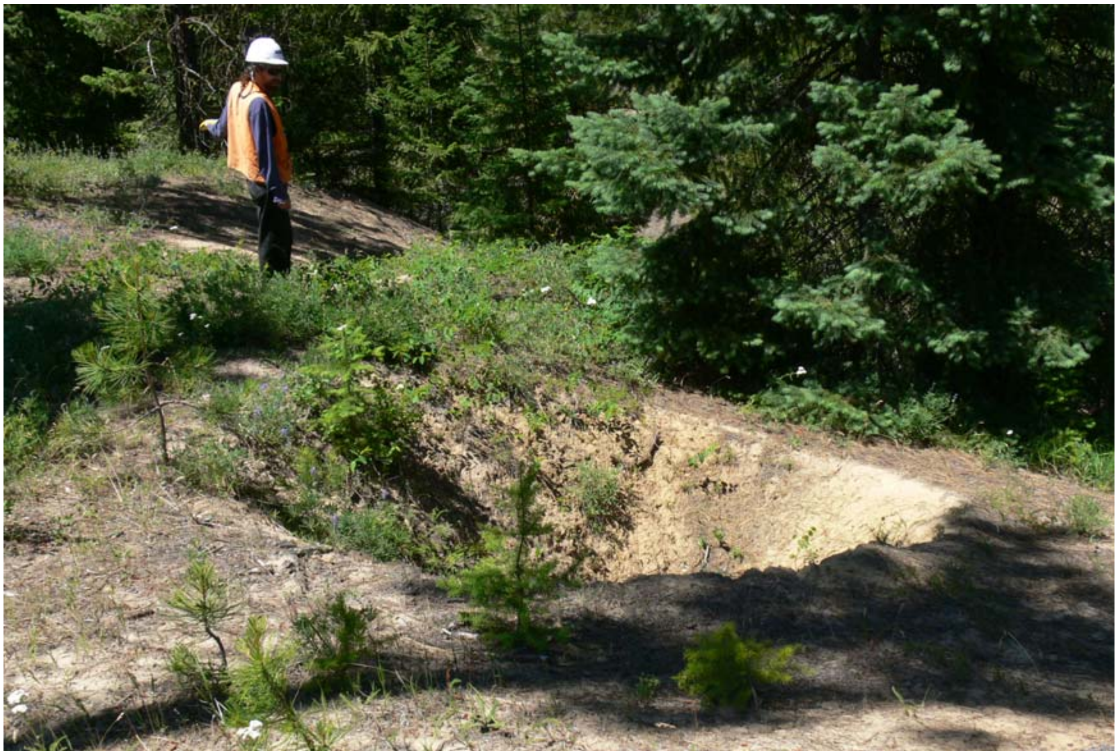
Table 2: Coal Production from Mines Underlying the City Heights Site

Year	Roslyn No. 5	Roslyn No. 7	Cle Elum Coal Company	ICC Queen Mine
1933	108,593	163,308	2,551	
1934	57,744	177,499	2,267	
1935	38,270	160,538	2,751	
1936	129,056	77,134	3,581	
1937	252,509		2,852	
1938	189,683		1,811	
1939	199,316		1,265	
1940	171,358		970	
1941	182,386		813	
1942	176,386		1,045	
1943	132,483		60	
1944	139,135			
1945	160,084			
1946	118,675			
1947	83,800			
1948				
1949				
1950				
Totals	6,396,813	7,593,080	4,104,981	724,418

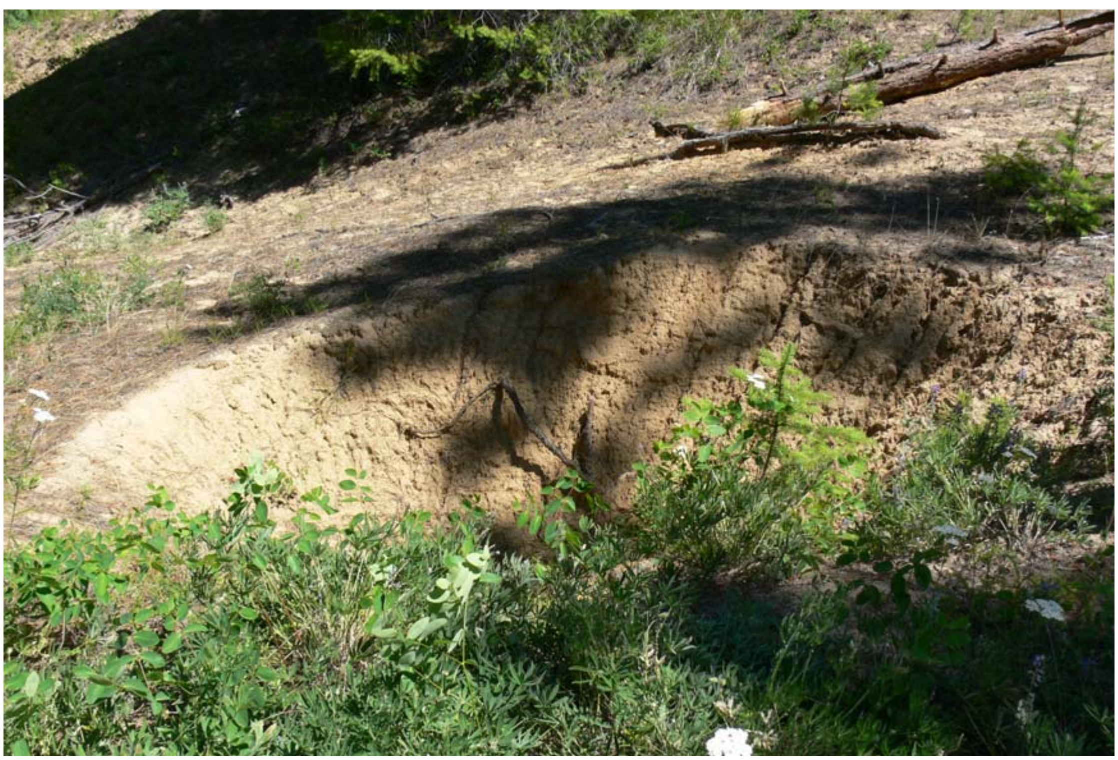
PLATES

3-1 Collapsed Rail Tunnel North alignment

3-1 Collapsed Rail Tunnel Northeast alignment



Sinkhole near B11 top of Section 26



Sinkhole near B11 top of Section 26

4-6 Outcrop Mine #3 between 1st and 2nd levels

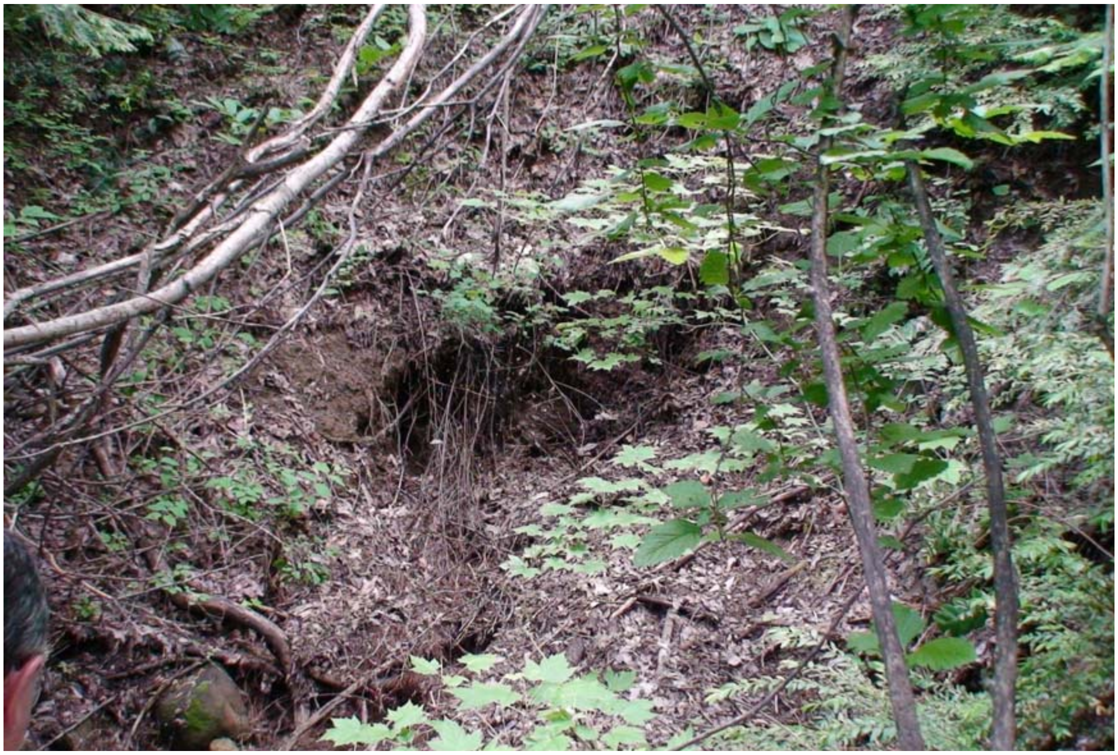
Open Pits top of Section 26

Sinkhole at the top of Section 26

4-3 Collasped Adit to Mine #3 1st level West

4-1 Collapsed Adit on West Side of Deer Creek

4-2 Adit to Mine #3 1st level West



4-2 Adit to Mine #3 1st level West

4-4 Adit to Mine #6 1st level East

5-1 Air Shaft near creek in Section 25

5-1 Air Shaft near creek in Section 25

ATTACHMENT A
KING COUNTY, WASHINGTON
COAL MINE HAZARD AREA GUIDELINES
TECHNICAL ANALYSIS to EVALUATE HAZARDS

Part Two – Critical Areas

Coal Mine Hazard Areas

Coal mine hazards in King County are related to past mining activities in some areas, for example areas like Ravensdale, along Black Nugget Road, near Black Diamond and in the Coal Creek area (place names often reflect geologic setting). Coal miners were active in King County in the late 19th and early 20th centuries, and they exploited both surface exposures in open pit mines and deeper coal beds with underground mines. For the most part, the coal seams are thin and discontinuous compared to others exploited elsewhere, which means that they are uneconomical today.

The hazards that are present from past mining activities are several (including dangers of open underground workings and discharges of acid-rich mine waters) but the King County Zoning Code only addresses one category, which is the nature of the foundation materials beneath proposed structures and the likelihood of the collapse of underground workings. If there are no underground workings, the only "hazard" is the potential presence of uncontrolled fill (mine waste) that might not provide suitable foundation support. If underground workings are present, then geologic and engineering studies are sometimes required to both quantify the nature of the hazard (basically, the potential for surface subsidence) and to recommend measures to deal with the hazard. The potential for catastrophic mine collapse can make a lot unbuildable. Because accurate mine maps are not always available, some mining sites are isolated with a recommended "buffer" that separates the area of potential collapse from any future development.

The first step when reviewing for potential coal mine hazards is to examine the nature of mining at the site and classify the hazard level. This is typically done through a critical area report prepared by a consulting geologist or geotechnical engineer. The type of developments that are allowed depends upon the classification of the hazard.

Classifications

For the purposes of regulation, coal mine hazards are classified into three types of hazard:

1. "Declassified" coal mine hazard areas are those areas where the risk of catastrophic collapse is not significant and that the hazard assessment report has determined do not require any special engineering or hazard mitigation. These areas typically include sites not underlain by underground workings

and sites underlain by underground workings that are in excess of 300 feet below the surface.

2. “Moderate” coal mine hazard areas are those areas that pose significant risk of property damage because of coal mine subsidence, but that can be mitigated through special engineering or architectural recommendations. These areas often include areas underlain or directly affected by abandoned underground workings that are less than 300 feet deep or with overburden cover-to-seam thickness ratios of less than 10 to one, depending on the inclination of the seam.
3. “Significant” coal mine hazard areas include those sites that pose a significant risk of catastrophic surface collapse, such as unmitigated openings (portals, adits, mine shafts, sinkholes, improperly filled mine openings) and other areas of past or probable surface collapse, including shallow subsurface workings extending to a depth of 100 feet.

Development standards

Within declassified coal mine hazard areas, all alterations are allowed without mitigation because it has been determined that there is no effective hazard. Within moderate and severe hazard areas, the code requires that:

1. Within moderate coal mine hazard areas, the risk of structural damage be minimized (through effective mitigation); and
2. Within severe coal mine hazard areas, the risk of personal injury be minimized or eliminated (again through mitigation).

Allowed alterations

All alterations are allowed in declassified hazard areas. Within moderate coal mine hazard areas and coal mine byproduct stockpiles (areas of uncontrolled fill), all alterations are allowed provided the risk of structural damage is minimized. Within severe hazard areas, the following alterations are allowed:

1. All grading, filling, stockpile removal and reclamation activities in accordance with a hazard assessment report for the purposes of mitigating threats to human health, public safety, environmental restoration, and property protection, if accompanied by plans and as-built drawings prepared by a professional engineer and submitted to the department for review;
2. Private road construction when significant risk of personal injury is eliminated or minimized;
3. Building of less than 4,000 square feet of floor space that contains no living quarters or places of employment or public assembly when significant risk of personal injury is eliminated or minimized; and
4. Additional land activities if consistent with recommendations within any mitigation plan required by a hazard assessment report.

21A.24.180 Sensitive area tracts and designations on site plans.

A. Sensitive area tracts shall be used to delineate and protect those sensitive areas and buffers listed below in development proposals for subdivisions, short subdivisions or binding site plans and shall be recorded on all documents of title of record for all affected lots:

1. All landslide hazard areas and buffers that are one acre or greater in size;
2. All steep slope hazard areas and buffers that are one acre or greater in size;
3. All wetlands and buffers; and
4. All streams and buffers.

B. Any required sensitive area tract shall be held in an undivided interest by each owner of a building lot within the development with this ownership interest passing with the ownership of the lot or shall be held by an incorporated homeowner's association or other legal entity which assures the ownership, maintenance and protection of the tract.

C. Site plans submitted as part of development proposals for building permits, master plan developments and clearing and grading permits shall include and delineate:

1. All flood hazard areas, if they have been mapped by FEMA or King County or if a special study is required;
2. Landslide, volcanic, coal mine and steep slope hazard areas;
3. Streams and wetlands;
4. Buffers; and
5. Building setbacks.

D. If only a part of the development site has been mapped pursuant to K.C.C. 21A.24.120C, the part of the site that has not been mapped shall be clearly identified and labeled on the site plans. (Ord. 14449 § 11, 2002: Ord. 14449 § 11, 2002: Ord. 10870 § 465, 1993).

21A.24.190 Alteration. Any human activity which results or is likely to result in an impact upon the existing condition of a sensitive area is an alteration which is subject to specific limitations as specified for each sensitive area. Alterations include, but are not limited to, grading, filling, dredging, draining, channelizing, applying herbicides or pesticides or any hazardous substance, discharging pollutants except stormwater, grazing domestic animals, paving, constructing, applying gravel, modifying for surface water management purposes, cutting, pruning, topping, trimming, relocating or removing vegetation or any other human activity which results or is likely to result in an impact to existent vegetation, hydrology, wildlife or wildlife habitat. Alterations do not include walking, fishing or any other passive recreation or other similar activities. (Ord. 10870 § 466, 1993).

21A.24.200 Building setbacks. Unless otherwise provided, buildings and other structures shall be set back a distance of 15 feet from the edges of all sensitive area buffers or from the edges of all sensitive areas, if no buffers are required. The following may be allowed in the building setback area:

A. Landscaping;

B. Uncovered decks;

C. Building overhangs if such overhangs do not extend more than 18 inches into the setback area; and

D. Impervious ground surfaces, such as driveways and patios, provided that such improvements may be subject to special drainage provisions specified in administrative rules adopted for the various sensitive areas. (Ord. 10870 § 467, 1993).

21A.24.210 Coal mine hazard areas: Development standards and permitted alterations.

A. Alterations within coal mine hazard areas shall not be permitted without prior acceptance of a coal mine hazard assessment report and provided that:

1. Based upon recommendations contained within the report, a studied site shall be classified as one or a combination of the following:

a. declassified coal mine areas;
b. moderate coal mine hazard areas; or
c. severe coal mine hazard areas.

2. The coal mine hazard assessment report shall be prepared by a professional engineer using methodology and assumptions consistent with standards or professional engineering guidelines adopted by the department. The report may contain the following as determined by the department to be necessary for the review of the proposed use:

a. a statement of the professional engineer's qualifications and licensing information, together with a signature and stamped seal;

b. a list of references utilized in preparation of the report;

c. a description of the analytical tools and processes that have been used in the report;

d. surface exploration data such as borings, drill holes, test pits, wells, geologic reports, and other relevant reports or site investigations that may be useful in making conclusions or recommendations about the site under investigation;

e. a description of historical data and information used in the evaluation, together with sources. Such data and information shall include:

(1) topographic maps at a scale and contour interval of sufficient detail to assess the site. The site boundaries and proposed site development shall be overlain with the mine plan view map, as appropriate;

(2) copies of illustrative coal mine maps showing remnant mine conditions, if available;

(3) aerial photography, as appropriate;

(4) geological data including geologic crosssections and other illustrative data as appropriate; and

(5) available historic mine records indicating the dates of operation, the date of cessation of active mining, the number of years since abandonment, mining methods, shoring and timbering information, the strength of the overlying rock strata, the extracted seam thickness, the dip or inclination of the strata, workings and surface, the projected surface location of the seam outcrop or subcrop, the estimated depth of the seam outcrop or subcrop, if covered by glacial outwash, glacial till or other materials at depth, total coal tonnage produced, estimated coal mine by-product material produced and the estimated extraction ratio.

f. a mine plan view map, reproduced at the same scale as the topographic map, showing the location of the mine, the extent of mining, the proposed site development, if applicable, and any remnant abandoned mine surface features. The following shall be included:

(1) the layout of the underground mine;

(2) the location of any mine entries, portals, adits, mine shafts, air shafts, timber shafts, and other significant mine features;

(3) the location of any known sinkholes, significant surface depressions, trough subsidence features, coal mine spoil piles and other mine-related surface features;

(4) the location of any prior site improvements that have been carried out to mitigate abandoned coal mine features; and

(5) zones showing varying overburden-cover-to-seam-thickness ratios, when appropriate.

g. a statement as to the relative degree of accuracy and completeness of the maps and information reviewed, especially regarding historic mine map accuracy, and reasons why such sources are considered reliable for the purpose of the hazard assessment report;

h. a mitigation plan containing recommendations for mitigation, as appropriate, for the specific proposed alteration;

i. recommendations for additional study, reports, development standards or architectural recommendations for subsequent and more specific proposed alterations, as appropriate;

j. analysis and recommendations, if any, of the potential for future trough subsidence and special mitigation; and

k. a delineation of coal mine hazard areas for the site under investigation using a map identifying the specific category (i.e., severe, moderate, or declassified) of mine hazard area. For the purposes of obtaining accurate legal descriptions, the mine hazard areas shall be surveyed and the survey map shall be drawn at a scale of not less than 1"=200'.

3. Giving great weight to the licensing requirements of professional engineers and standards of professional accountability and liability, the department shall review the coal mine hazard assessment report and within the time period specified in K.C.C. 20.20.050 either accept the report, recommend revisions or additions to the report or return the report to the applicant as unaccepted and detail the specific deficiencies. In the event of a disagreement, the applicant may submit the report to a mutually agreed-upon third party professional engineer who will conduct the review and issue a decision binding upon the department and applicant.

4. When a hazard assessment report has been accepted, the applicant shall record a notice on the title of the property as follows:

"NOTICE"

"This property is located in an area of historic coal mine activity. A coal mine hazard assessment report has been prepared to characterize the potential hazards contained on this property. The report is dated *[insert date of the final report]*, was prepared by *[insert name of professional engineer with license number]* at the direction of *[insert name of property owner]*, and reviewed by the King County department of development and environmental services *[and, if necessary, include name of peer reviewing professional engineer with license number]*. A review of the report is advised prior to undertaking unregulated or exempt land use activities and is required prior to undertaking regulated land use activities."

B. Permitted alterations within a coal mine hazard area are allowed as follows, subject to other King County Code permit requirements:

1. Within declassified coal mine areas all alterations are permitted.

2. Within moderate coal mine hazard areas and coal mine by-product stockpiles, all alterations are permitted subject to a mitigation plan to minimize risk of structural damage using appropriate criteria to evaluate the proposed use.

If required or recommended by the hazard assessment report, the mitigation plan to address potential trough subsidence must be prepared by a professional engineer and may be included in the coal mine hazard assessment report or may be an additional study or report, as appropriate.

3. Within severe coal mine hazard areas the following alterations are permitted:

a. all grading, filling, stockpile removal, and reclamation activities undertaken pursuant to a coal mine hazard assessment report with the intent of eliminating or mitigating threats to human health, public safety, environmental restoration or protection of property, provided that:

(1) signed and stamped plans have been prepared by a professional engineer;

(2) as-built drawings are prepared following reclamation activities; and

(3) the plans and as-built drawings shall be submitted to the department for inclusion with the coal mine hazard assessment report prepared for the property.

b. private road construction and maintenance activities, provided that mitigation to eliminate or minimize significant risk of personal injury are incorporated into road construction or maintenance plans.

c. buildings with less than four thousand square feet of floor area that contain no living quarters and that are not used as places of employment or public assembly, provided that mitigation to eliminate or minimize significant risk of personal injury are incorporated into site, building, and/or landscaping plans.

d. additional land use activities provided that they are consistent with recommendations contained within any mitigation plan required by the hazard assessment report. (Ord. 13319 § 7, 1998: Ord. 11896 § 1, 1995: Ord. 10870 § 468, 1993).

Guidance on Analyses to Characterize Hazards and Develop Mitigation

Proposed developments in Coal Mine Hazard Areas are required to mitigate specific hazards. King County will usually require specific studies as part of a sensitive area report that will evaluate and define these hazards and develop appropriate mitigation. Guidance is provided in this document on the appropriate geotechnical analyses necessary to characterize hazards and develop mitigation measures that will meet the standards in K.C.C. 21A.24.210. These guidelines include details of reporting requirements for abandoned mine related studies, procedures for evaluating potential hazards including ground failure mechanisms and analysis methods, determination of hazard areas, methods to eliminate hazards and reference materials.

A. GENERAL GUIDELINES FOR COAL MINE HAZARD EVALUATIONS

All permitted alterations within hazard areas must demonstrate to the satisfaction of the Department of Development and Environmental Services (DDES) that the hazard will not impact the alterations and that the alterations will not impact the hazard areas. In order to acceptably evaluate the potential impacts of and to the proposed alteration in Coal Mine Hazard Areas, the following aspects must be addressed:

- The potential impacts of catastrophic effects and/or predicted trough subsidence and associated ground deformations from the underlying coal mine workings.
- The response of proposed development activities to predicted ground deformations.
- The interaction of the proposed activity with the coal mine workings, including; potential impacts from introducing or removing water from the mine; changes to the subsurface environment that might lead to, or accelerate degradation processes; and plans for adequately sealing any new penetrations.
- Methods of mitigating impacts that are contained in the development proposal. Acceptable methods are contained in Section E.
- Conditions of occupancy in the proposed development.

This guidance provides details on conducting acceptable hazard evaluations and the format for providing that information to DDES.

B. GUIDANCE ON ABANDONED MINE RELATED STUDY AND REPORT SUBMITTALS

The abandoned mine studies and reports, referred to in this Section, shall be prepared by a qualified engineer or engineering geologist as defined in K.C.C. 21A.06. Reports will be required for:

- Determining whether coal mine areas will be regulated as hazard areas.
- Proposed developments in a coal mine hazard area.
- Proposals to change land use or zoning designations in a coal mine hazard area.

Studies and reports shall be submitted to the Department for review and approval, if acceptable. At its discretion, the Department may also require the qualified engineer or engineering geologist to present the results of their studies to Department staff.

Preliminary Site Evaluation Report (PSER). A preliminary site evaluation shall be required for proposed developments in any coal mine hazard area. This material should be submitted for and discussed in the preliminary application meeting. As a minimum, the PSER shall contain:

1. A work plan outlining the proposed approach to evaluating hazards, including reference to any analytical tools and processes that will be used, in subsequent stages, for hazard evaluation.
   - Reference to methods recommended in Section F shall demonstrate compliance with this requirement.
   - If hazards as described in K.C.C. 21A.24.240A are identified; a proposed program of site investigation to support engineering design for mitigation of those hazards shall be included in the Work Plan.

1. Historical data and sources for historical information used, or to be used, in the hazard evaluation. Such data and information shall include, as a minimum:
   - Coal Mine Hazards Maps.
   - Copies of the original coal mine maps, illustrating the remnant mine condition(s). Reproductions from original maps are acceptable as long as they clearly illustrate conditions that are important to the hazards analysis.
   - Aerial photographs. Where possible, aerial photographs showing the current, as well as the mine abandonment, surface conditions shall be provided.
   - Readily available records indicating the extracted seam thickness, dip/inclination of the workings, location of seam outcrop or subcrop, and dates of working.

1. Plan(s) showing the location of the mine(s) and the extent of mining; the proposed site development; and any remnant abandoned mine surface features. The plan(s) should include, as a minimum;
   - The layout of the underground mine(s)
   - The location of any mine entries, sinkholes, or surface depressions, recorded on title documents, in published records, or discovered during the preliminary site reconnaissance.
   - The location of any abandoned mine surface features.
   - The location of any prior site improvements that have been carried out to mitigate or eliminate catastrophic effects, including any remedial work performed by the Office of Surface Mining (OSM). Evidence of adequate sealing of sinkholes or mine entries shall include as-built drawings, completion records recorded with King County, and/or a letter from the Regional OSM Representative stating that the closure was performed to OSM's standards.
   - Statement as to the accuracy of locating the abandoned mine workings with respect to the surface, and the basis for the stated accuracy.
   - Any additional assumptions that limit the accuracy or completeness of the information provided.

1. The results of a preliminary surface-based reconnaissance of the proposed development site. A Preliminary Site Reconnaissance shall be required to identify any subsidence features or mine hazards that are present on or within 100 feet of the property including, but not limited to:

- surface depressions,
- sinkholes,
- mine shafts,
- mine entries,
- coal mine spoil piles, and
- any indication of combustion in underground workings or coal mine waste dumps.

The surface reconnaissance shall include, but not be limited to, inspection, review, and documentation of any known hazards that have previously been documented by the Office of Surface Mining, Abandoned Mined Land program (see references Lucas and Assoc., 1987; Skelly and Loy, 1988; and USHUD, 1977a for examples), or that have been identified from review and interpretation of air photographs or other sources.

1. Existing surface exploration data (borings, test pits, wells) that exist for the site and copies of any reports of other investigations in the vicinity of the project.

Site Investigation Program. Subsurface conditions for coal seams located within 200 feet of the ground surface are required to be investigated by drilling and logging of subsurface conditions consistent with the following:

- Drill holes shall be located adjacent to, but not within, coal pillars that are shown on the mine plans, unless the objective is to retrieve samples for testing purposes.
- Holes shall be drilled along the alignment of any linear structure, such as a road or utility line, where coal mines are indicated to be within 200 feet of the surface.
- Rotary drilling is an acceptable method of drilling provided it is used in combination with downhole geophysical logging, including caliper logs. Core drilling is preferred, but is not compulsory, immediately above and through the predicted coal seam location(s). Drill holes shall be logged continuously throughout their length, including lithology at 5-foot intervals for rotary drill holes, drill fluid circulation, penetration rate, and free fall of the drill string. Greater confidence will be placed in core drilling logs than in rotary drilling logs; this may result in less drill holes being required if core drilling is used in the vicinity of coal seams instead of rotary drilling.
- Hazards very near the surface such as slope entry portals, shaft collars, prospects and mine waste dumps may be investigated by test pits or trenching, providing the method enables investigation to an adequate depth for the hazard being investigated.
- Indirect means of subsurface evaluation, including geophysics, geologic projection, and evaluation of mining records, may be used to supplement drilling results, but shall not be used as the sole source for evaluating subsurface conditions.

Final Site Evaluation Report. A Final Site Evaluation Report shall be provided for all proposed permitted alterations in Coal Mine Hazard Areas. Repetition of information provided in the PSER is not required unless changes have occurred since the original submittal. As a minimum, the report shall contain:

1. The results of the hazards assessment performed according to the Work Plan submitted in the PSER.
2. If hazards were identified in the PSER. the report shall provide:
    - The results of the Site Investigation Program carried out to gather engineering data required for remedial designs.

- The results of subsidence predictions, including documentation of the trough subsidence evaluation.
- Plans, engineering studies, and specifications for proposed elimination of catastrophic effects and or mitigation of predicted trough subsidence effects.
- Proposed construction contractor(s) and estimated construction schedule for mitigation.

As-Built Hazards Mitigation Report. An As-Built Hazards Mitigation Report shall be required to document any remedial or mitigation activities carried out in Coal Mine Hazards Areas. The report shall contain, as a minimum:

1. As-built surveys showing the location of mine closures. Any closures carried out by the OSM, or its supporting contractor(s), are subject to these location reporting requirements.
2. Documentation certifying the mine closures have been constructed as designed.
3. Documentation, if appropriate, that mitigation for trough subsidence areas is not required as this will be controlled through building permit inspections. Such documentation will clearly identify the tilt and strain levels that any building permit will need to comply with.

C. PROCEDURES TO EVALUATE COAL MINE HAZARDS

This section presents the methods used for the evaluation of coal mine hazards. The section is composed of two parts. The first evaluates the potential for sinkhole development. This evaluation is used to determine if there is any site that will need to be mitigated because of an unacceptably high probability that a sinkhole could develop from shallow mine workings. The second section presents the recommended procedures for estimating the subsidence potential of underground mine workings and to the resulting forces any development would be subjected.

Potential for Sinkhole Development

Matheson (1991) has developed an equation to fit the sinkhole development probability curve (Figure 1).

$$P = 1.0 \qquad \text{(for } h/m < 6.2\text{)}$$
$$P = 1516\,(h/m)^{-4} \qquad \text{(for } h/m > 6.2\text{)}$$

where,

P	=	Probability of void creating a sinkhole
h	=	Depth to mine floor
m	=	Extracted seam height

The extracted seam height (m) used in the formulae should be adjusted for seam inclination as follows:

$$m = \frac{seamthickness}{\cos(\theta)}$$

This equation can be used to predict the probability of sinkhole development over areas where secondary or "retreat mining" has not been fully carried out and remnant pillars preserve the subsurface void space into which the mine roof can collapse.

Figure 1. Probability of Sinkhole Development

Source: Boulder County Subsidence Investigation report, Figure 8-3, page 8-36 (CMLRD, 1986).

No additional mitigation will be required if the maximum probability of sinkhole development is less than one percent (< 1%). The recommended procedure for determining the probability of sinkhole development simplifies what is otherwise a complex analysis. The threshold of P = 1% has been set bearing this in mind. If the probability is over 1%, then the potential for sinkhole development will have to be mitigated by the voids being filled, grouted or otherwise acceptably mitigated to the satisfaction of the department.

Alternative methods for evaluating sinkhole potential may be utilized provided they meet the intended standard of long-term surface stability. For example, methods commonly utilized in civil tunnel stability analyses may be utilized.

Estimation of Tilt and Strain from Potential Subsidence

The recommended procedure for calculating tilt and strain is based on the empirical methods in the Subsidence Engineers Handbook, 1975 (see References). Alternative methods of calculating potential subsidence magnitudes, strains, and tilts may be used provided they incorporate similar assumptions to those specified in the recommended procedure. If alternative calculation methods, design parameters or assumptions are proposed, detailed justification must be provided to the Department, in the PSER, for review and approval.

The recommended procedure includes the following steps:

1. Estimate the remaining equivalent mining height by either 1) direct subsurface exploration or 2) using mine records and published information on coal seam characteristics.

    - Subsurface conditions may be evaluated by drilling. Although drilling is not compulsory, it is the most acceptable method for providing information that is acceptable for reducing the remaining mining height value used in subsidence calculations.

- If the applicant wishes to conduct a subsurface investigation, the proposed approach must be submitted with the PSER for review and approval.
- If a drill hole encounters voids at or above the location of the coal seam, the cumulative length of the voids shall be added to the void observed at the coal seam horizon to determine the remaining mining height.
- Direct evidence of the condition of panels in the same seam with similar dimensions, similar extraction ratios, and at a similar or shallower depth, shall be accepted as evidence of the condition of mine workings at any point.
- Surface geophysics, or other indirect means, may be used to assist in projecting information between and beyond drill holes, but shall not be accepted as the sole method for evaluating the condition of underground mine workings and calculating remaining mining height. Assumptions concerning the extent of collapse of mine workings based on recorded extraction ratios shall be conservative because of possible inaccuracies of mine records, the likely presence of remnant pillars and the lack of data to accurately locate them, and because uncollapsed mine workings have been documented under similar conditions in King County.

2. In the absence of site specific data derived from drilling, the remaining equivalent mining height shall be estimated as follows:

- For workings between 0 and 200 feet, the REMH is assumed to be equal to the seam thickness or recorded mining height.
- For workings between 200 and 1000 feet deep, the REMH is estimated from Table 1 and the extracted thickness (from mine records or published data (see References A and B)). The extraction ratio shall be based on an examination of the detailed mining records. Where detailed maps or data are unavailable, or drawings are unclear, a "worst case" extraction ratio shall be used.

Table 1 - REMH for Workings Between 200 and 1000 ft

Extraction Ratio (%)	Remaining Equivalent Mining Height in terms of Extracted Thickness (%)
0	0
10	10
20	15
30	25
40	30
50	25
60	20
70	10
80 - 100	5

- For workings deeper than 1000 feet, the REMH is assumed to be 0.

3. Estimate the maximum vertical subsidence for each mining panel using the remaining equivalent mining height and the panel width to depth ratio applying corrections for limited face advance, where appropriate (see Fig. 3 and Fig. 4 of the Subsidence Engineers Handbook (SEH, 1975, pp. 8-11).

4. Estimate the maximum vertical subsidence for an inclined seam as the maximum subsidence that would be predicted for a horizontal seam, multiplied by the cosine of the seam dip.

5. Adjust the downdip, centerline, and updip limit angles for seam inclination using Table 2, and estimate the subsidence profile (see Section 3, SEH). Topography is considered in determining the point at which the limit angle intersects the ground surface, and hence the limits of predicted subsidence.

Table 2 - Down-Dip, Centerline, and Up-Dip Limit Angles

Seam Dip	Rise or Up-Dip Limit Angle	Centerline Projection Angle	Down-Dip Limit Angle
0	20	0	20
10	15	5	25
20	10	10	30
30	10	15	35
40	5	20	40
50	5	20	40
60	10	15	35

These values are based on a survey standard for the subsidence limit of 0.1 ft.

6. Estimate slope (tilt) from the predicted subsidence curve at intervals of 1/20th of the average seam depth.

7. Estimate maximum horizontal strain and the strain profile from either:

   - Ground curvature using the method outlined on pages 33 - 37 of the Subsidence Engineers Handbook, or,
   - Predicted subsidence and average seam depth using the method outlined in Section 3 of the Subsidence Engineers Handbook

8. For conditions involving multiple seams, separate predictions shall be made for each seam and superimposed.

No additional mitigation will be required if the maximum predicted ground slope change (tilt) is equal or less than 1:350 (V:H) and the predicted surface strains are equal or less than 0.003 (in/in). The recommended procedure for determining the predicted tilt and strain simplifies what is otherwise a complex analysis. For conditions where the predicted ground slope change is greater than 1:350 (V:H) and/or the predicted surface strains are greater than 0.003 (in/in), then the potential for damage form subsidence is significant and will need to be mitigated by designing the alterations to withstand the forces. Depending on the alteration proposed, K.C.C. 21A.24.210B identifies the safety factors required. Note that special designs may be needed to mitigate potential impacts.

D. DETERMINATION OF COAL MINE HAZARD AREA

The definition of Coal Mine Hazard Areas states that any area is defined as a hazard if, among other criteria, it is "subject to the risk of trough subsidence, catastrophic collapse or combustion...". Only those areas meeting the definition of Coal Mine Hazard Areas are subject to the requirements of the Sensitive Areas Code and K.C.C. 21A.24.210. This section provides guidance on how to determine if a site with identified coal mine workings is subject to these risks and therefore a regulated hazard area or not.

Demonstration of Risk

Combustion. *(Need a clear test for combustion*

Catastrophic Collapse. Risk of catastrophic collapse can be demonstrated by conducting the evaluation for potential sinkhole development presented in Section C. If the maximum probability of sinkhole development is less than one percent (< 1%), then the site is not at risk of sinkhole development.

Trough Subsidence. Risk of through subsidence can be demonstrated by conducting the evaluation for the estimation of tilt and strain from potential subsidence presented in Section C. If the maximum predicted tilt (ground slope change) is less than 1:350 (V:H) and the predicted surface strains are less than 0.003 (in/in), then the site is not at risk of trough subsidence. Alternative methods for demonstrating that abandoned workings will remain stable under existing and planned future loads are acceptable if the procedures presented below are used to evaluate remnant roof, floor and pillar stability.

Alternative Evaluation of Trough Subsidence Using Roof, Floor and Pillar Stability

The recommended procedures for evaluating roof, floor, and pillar stability are provided below. Alternative methods may be acceptable provided they incorporate similar assumptions.

Pillar Stability and Failure. Coal pillar stability is calculated assuming each pillar supports an area equivalent to its own area plus an area of roof spanning half the distance to the next pillar. The pillar load (or stress) is calculated using the following formula:

$$PL = (OL \times AT) / AP$$

where,

PL = Pillar load (lb/in^2, or lb/ft^2)
OL = Overburden Pressure, (lb/in^2, or lb/ft^2) calculated by multiplying the overburden thickness (ft) by the overburden unit weight (lb/ft^3)
AT = Total area supported by pillar (ft^2)
AP = Area of pillar (ft^2)

This equation can be re-written using the extraction ratio instead of the area supported by pillars:

PL = OL / (1 - ER)

where,

ER = Extraction ratio ((AT - AP) / AT)

Traditional pillar strength formulae account for the intact coal strength (determined in the laboratory) and the pillar's aspect ratio. Two methods are suggested in this guidance document.

1. Method suggested by Baushinger (described by Hustrulid (1976), p129; Peng (1978), p188):

PS = CRMS x (0.778 + 0.222(Wp/Hp))

where,

PS = Pillar Strength (lb/in^2, or lb/ft^2)
CRMS = Coal Rock Mass Strength (lb/in^2, or lb/ft^2)
Wp = Coal Pillar Width (ft)
Hp = Extracted Seam Height (ft)

2. Method suggested by Hustrulid, 1976:

PS = CRMS x SQRT(Wp/Hp)

The factor of safety (FS) is calculated from the ratio of pillar strength/pillar stress. Ranges in the value of FS, required for stability, have been suggested by Brady and Brown (1985)(FS = 1.3 to 1.9), and by Peng (1978) (FS = 1.5 to 2.0).

Floor Stability and Failure Floor stability or failure is a function of the ability of the floor rock to resist the shear forces associated with the pillar punching into the floor. Pillar punching is analogous to bearing capacity failure of a foundation and is analyzed using traditional foundation design methods; two solution methods are described below:

1. Method suggested by Brady and Brown (1985):

Qb = 1/2 (GMA x Wp x NG x SG) + (c x cot(PHI) x Nq x Sq) + (c x cot(PHI))

where,

Qb = Bearing Capacity (lb/in^2, or lb/ft^2)
Wp = Coal Pillar Width (ft)
NG = 1.5 x (Nq - 1) x tan(PHI)
Nq = $e^{PI \times \tan(PHI)}$ x tan^2(PI/4 + PHI/2)
SG = 1.0 - 0.4(Wp / Lp)
Sq = 1.0 + sin(PHI)(Wp / Lp)
c = material cohesion (lb/in^2, or lb/ft^2)
PHI = material friction angle

2. Method suggested by Vesic, 1969 (Reported in CMLRD, 1986):

$$Qb = SS \times Nc$$

where,

SS = Shear Strength (lb/in^2, or lb/ft^2)

Nc = $5.61 + 0.146(Wp / t)$ for $Wp/t > 3.8$

t = thickness of floor strata (ft)

The disturbing force is the vertical pillar load (PL) previously defined in **Pillar Stability and Failure**. The factor of safety is the ratio of the two forces (Qb / PL).

Roof Stability and Failure. The process of collapse over a mine opening involves loosening and relaxation of the horizontally bedded roof strata which induces tensile and shear stresses at the abutments. If these stresses exceed the material strengths, then failure will occur. This failure will progress up into the roof until a stable arch is formed or partial support is provided by the broken rock pile. An analysis of the bulking potential of roof strata, typical of the Laramie formation, indicates that movement would be arrested a distance approximately equal to 5-to-6 times the extracted seam height. This hypothesis has been field verified as part of work conducted by the CMLRD.

Roof stability or failure can be determined by analyzing the resisting and disturbing forces present in the roof strata immediately prior to failure. Assuming that the roof strata behave as a simple beam, the maximum tensile stress occurs at the outer fiber at the center of the beam.

$$TS = (3 \times GMA \times L^2) / (4 \times t)$$

where,

TS = Maximum Tensile Stress in Roof Beam (lb/ft^2)\

GMA = Unit Weight of Roof Strata (lb/ft^3)

L = Roof Span (ft)

t = Thickness of Roof Beam (ft)

The maximum shear stress occurs at both ends of the beam above the rib:

$$SS = (3 \times GMA \times L) / 4$$

where,

SS = Shear strength (lb/in^2, or lb/ft^2)

In the case where lateral deformation is restrained, and the roof can be considered to act as a beam clamped at both ends, the maximum tensile stress occurs at the upper side on both ends of the beam.

$$TS - (GMA \times L2) / (2 \times t)$$

The resisting forces are the tensile (ZIGt) and shear strengths (TOR) of the roof strata. The factor of safety is again expressed as the ratio between the two resisting and disturbing forces (ZIGt / TS), and (TOR / SS).

E. GUIDANCE ON THE ELIMINATION OF HAZARDS

This section provides additional guidance on acceptable methods for mitigating identified hazards in Coal Mine Hazard Areas.

Mine Entries, Shafts, and Existing Sinkholes. Mine entries, shafts, and existing sinkholes shall be permanently sealed using controlled backfill and/or grouting, or an approved, engineered seal.
Acceptable seal construction consists of a tapered, reinforced concrete plug constructed within a steel form; a below grade reinforced concrete cap constructed over shaft collars; and a reinforced concrete plug for sealing horizontal mine entries. Other proposed methods of sealing will be considered on a case by case basis.

Site preparation prior to installation of the plug shall include permanently diverting surface drainage away from the shaft or mine entry, and excavating loose rock and soil away from the collar of the shaft or the mine entry portal.

Shaft and slope entry seals shall be designed and installed so that they are bearing on competent bedrock or dense, competent glacial sediments. The top of the tapered plug or the base of the cap shall extend a minimum of two feet in all directions beyond the shaft or slope entry. The length of any plug used to seal a horizontal mine entry shall not be less than the maximum dimension of the entry. The need for installing additional backfill behind the seal of a horizontal mine entry to prevent potential subsidence over the entry shall be determined on a case by case basis.

Compaction grouting, in conjunction with placement of uncompacted fill, is an acceptable method of backfilling and grouting. Compaction grouting shall be carried out from the bottom of the filled zone to the top in increments/stages sufficient to ensure adequate filling, and compaction of voids.

Prospect Pits. Shallow Prospect Pits shall be backfilled to surface using controlled placement of suitable backfill. Surface drainage shall be permanently diverted away from existing sinkholes and prospect excavations.

Potential Sinkholes. Demonstrate by direct subsurface investigation that coal mine workings either do not exist, or that the workings have fully collapsed so that there is no remaining potential for sinkhole development; or show that the hazards associated with any voids that are identified are fully mitigated by backfilling, grouting, or other approved means such that the potential for sinkhole development is eliminated.

A fence shall be constructed along the sinkhole boundary to prevent access to the area if the potential for sinkhole development has not been eliminated. Signs shall be posted on the fence at intervals of no more than 100 feet warning of danger due to possible sinkholes.

Any sinkholes that develop shall be promptly backfilled and surface drainage shall be diverted away from the sinkhole.

Coal Mine Spoil Piles. Any coal mine spoil piles from which springs or seeps are discharging, or which shows evidence of seasonal discharge of springs or seeps, shall be removed or regraded to expose the source of the spring or seep.

The stability of the coal mine spoil pile(s) shall be verified by a slope stability analysis meeting the King County standards for such work.

All coal mine waste materials, incorporated within a development, shall be covered with a minimum of two feet of clean soil and shall be revegetated in accordance with applicable King County requirements.

No construction shall be permitted over coal mine waste material unless a geotechnical investigation is completed by a soils engineer, and specific design and construction criteria are developed to mitigate the potential impacts of the coal mine waste on foundation stability and performance. Construction shall not be permitted within 100 feet of any coal mine waste dump that shows evidence of current or past combustion.

Mine Gases. Potential hazards associated with mine gases shall be mitigated by backfilling all mine entries, shafts, and sinkholes in accordance with these Regulations.

Mine Fires. Construction shall not be permitted over workings where surface or subsurface investigations indicate the possible presence of combustion in the underlying seam or seams.

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Whittaker, Barry N., and David J. Reddish, 1989. ***Subsidence, Occurrence, Prediction, and Control.*** Developments in Geotechnical Engineering, 56, published by Elsevier.

ATTACHMENT B

PREPARERS QUALIFICATIONS

SubTerra, Inc.

Dr. Chris D. Breeds, Ph. D., P.E.

EDUCATION:	B.Sc., Mining Engineering (Honors), University of Nottingham, U.K., 1973. Ph.D., Rock Mechanics, University of Nottingham, U.K., 1976.
AFFILIATIONS:	Member American Institute of Mining Engineers (SME) Member American Society of Civil Engineers (ASCE) Charter Member, Institute of Shaft Drilling Technology (ISDT) Fellow Institute of Mining and Metallurgy (FIMM) Director American Rock Mechanics Association (ARMA) Member, Construction Specifications Institute (CSI) Member American Concrete Institute (ACI), Committee 506 Shotcrete. Member, International Society of Explosives Engineers (ISEE) Member, National Society of Professional Engineers (NSPE)
REGISTRATION:	Registered Professional Engineer (PE), Washington, Colorado, Oregon, Arkansas, Montana, Texas and Nevada: Chartered Engineer, UK.
PATENTS:	Patent No. 5746,540 Method of Isolating a Nuclear Reactor or Other Large Structures.

EXPERIENCE:

1991 to date	President, SubTerra Inc., North Bend, Washington. Director, SubTerra Engineering Ltd., UK.
1984 to 1991	Senior Mining Engineer then Associate, Golder Associates Inc., Redmond, Washington.
1979 to 1984	Mining Engineer, International Ground Support Systems Inc., Denver, Colorado
1976 to 1979	Assistant Professor, Mining Department, Virginia Polytechnic Institute and State University, Blacksburg, Virginia (VPI & SU).
1973 to 1976	Research Engineer, Mining Department, Nottingham University, U.K.

PROFESSIONAL SUMMARY

Dr. Breeds professional career has exposed him to a unique combination of education, applied research, engineering, and field experience on underground mining, civil and environmental engineering projects. His broad experience includes: subsurface rock mechanics and geotechnical engineering; subsidence engineering; shotcrete and concrete technology; feasibility studies and conceptual design for mined facilities; mine systems analysis; preparation of construction cost estimates, bid documents, and specifications; and project management for both private and government projects. This broad technical expertise is complimented by management experience, which includes incorporating and managing companies in the US and Europe as well as managing large multidisciplinary groups involved in project work.

SubTerra Inc. was set up in 1991 to operate as the focal point for a small network of independent consultants working in the mining, civil, and environmental industries. SubTerra Engineering, Ltd. was formed in 1992 to provide similar services in the UK and Europe.

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EXPERIENCE in SUBSIDENCE ENGINEERING

Dr Breeds has extensive experience in predicting and analyzing the effects of subsidence on surface features and structures, and in the design of remedial measures, and site investigation programs. This experience has involved work with mining companies, federal agencies (DOE, USBM), developers, communities, and municipal, county, and state authorities. He is well versed in the application of predictive methods and has been directly involved with the development of computerized subsidence prediction models.

Related Resume Sections

Subsurface Design

Instrumentation and Data Acquisition

Geotechnical Engineering and Rock Mechanics

Abandoned Mine Impact Evaluation

Responsible for developing regulations for development over abandoned coal mines in King County, WA, the 13th largest county in the US. Responsible for analyzing impacts from abandoned mines in Virginia, Colorado, North Dakota, Indiana, Illinois, Oklahoma, New York, and Washington on surface facilities ranging from landfills to residential and commercial buildings.

- Preparation of an Administrative Rule for use by the 13th largest county (2,200 sq.mi) in the US (King County, WA) for permitting development over abandoned mines. This rule contains; criteria and methodology for quantifying subsidence from abandoned mines; quantification of significant risk with regard to property damage from subsidence; and criteria for declassifying undermined areas that are not expected to pose a significant risk of property damage. For DDES, King County, Washington.
- Consultant to the City of Bellevue for Abandoned Mine Site evaluations. Responsible for maintaining City of Bellevue's AML maps and for reviewing developer submittals for properties underlain by abandoned mines.
  - Reviewed Quadrant plan for proof drilling shallow tunnels in the Primrose seam. Observed field work and reviewed field work report.
- Expert Support to the US Army Corps of Engineers as part of a multidisciplinary team evaluating potential impacts from abandoned lead mines on surface stability in Ottawa County, OK. Involved obtaining and digitizing several hundred mine maps representing over 50 separate underground mines with digitized data input to a GIS and a 3-D model of the underground. The 3-D model provided additional data for input ti the GIS, which was subsequently used for subsidence prediction. For MWH and US Army Corps of Engineers.
- Participation in expert panel convened by the City of Bellevue to review City's planned zoning regulations for the Newcastle-Coal Creek proposed annexation. Work included reviewing City's consultant work product and mining records, and suggesting appropriate methods of analysis to be used in redefining the City's proposed zones, for Forest Ridge Home Owners Association.
- Evaluation of subsidence potential and impacts following closure of US Gypsum's Plasterco mine. This 100-yr old mine contains extensive stopes mined from 14 levels. Subsidence ranging from 5 –to- 50 ft, will create a large surface water body and require re-routing of several roads. A detailed evaluation of subsidence was made for key mine areas and a proposed re-route alignment over solution mined cavities adjacent to the mine.

- Evaluation of subsidence potential from 2000 to 3000-ft deep solution mined brine wells with well-developed cavity systems. This project involved a detailed analysis of brine production records, back analysis of existing cave zones, and prediction of the area potentially subject to subsidence along with a risk analysis.
- Evaluation of impacts for closure of US Gypsum's Oakfield mine near Oakfield, New York. This 100-yr old mine has a strike length of over 10 miles and was worked using room and pillar methods. Workings are very shallow and rock cover over the mined out rooms varies from 20 –to- 100 ft. Subsidence effects are expected to be minimal due to the strong overlying rocks and the limited surface development.
- Evaluation of impacts for partial closure of US Gypsum's Hagersville mine. Involved a review of consultant work products related to subsidence and hydrogeologic impacts and proposed bulkhead siting and design for separating active and closed workings.
- Evaluation of Renton Avenue Property: Responsible for characterizing and evaluating the potential effects of near surface (100-200 ft deep) mine workings on a proposed surface residential development in Renton, WA.
- Evaluation of potential for backfilling shallow (<50-ft deep) mine workings to permit surface development. For Suncadia Development, Roslyn, WA.
- Habitat Newcastle Property. This project involved plotting and verifying the location of shallow mine workings relative to twelve condominiums to be constructed by Habitat for Humanity and developing recommendations for set-backs from the workings.
- Evaluation of Petrovitsky Road Property for DevCo, Inc. Responsible for evaluating a 25 acre property underlain by workings from two mines. Phase 1 involved the record review, preliminary site reconnaissance, scanning mine maps from 35 mm fiche, digitizing mine map and surface features for incorporation in an AUTOCAD drawing of the site, and preparation of a preliminary report. Phase 2 involved
- Landsburg Mine Site Investigation. This project involved compilation of mine maps and production records, mining sequence and extraction ratio, nature and degree of faulting, water inflow and pumping, and preliminary stability analyses for a unique, near vertical, four level coal mine.
- Subsidence Evaluation, Coal Creek Technological Center, Lafayette, Colorado for Affiliated National Bank. This study involved the evaluation of subsidence potential for a 33 lot commercial park underlain by workings from the Vulcan mine located from 75 to 160 feet beneath the site. Activities included data collection, analysis of previous deep boring and soils investigations, stability analyses, inspection of existing structures on and in the vicinity of the site, subsidence prediction, and presentation of methods which could be utilized to promote the stability of future structures.
- Investigation, analysis, and prediction of settlements for a proposed municipal landfill expansion over abandoned coal mine workings. This work has included: collection and review of historical mining and geotechnical/rock mechanics data; preliminary stability analyses (pillar, roof, and floor) based on collected, regional data; coring and laboratory testing to define site specific parameter values for input to the final stability analyses; final stability analyses including the use of probabilistic techniques; subsidence prediction (subsidence, strain, and tilt); closure designs for two shafts and a decline; presentations to Colorado Department of Health and Colorado Geological Survey groups.

- Evaluation of proposed 105 acre development underlain by abandoned workings from the Newcastle mine, for the City of Bellevue, WA. Work included review of AML report submitted by the applicant, development of permit requirements and developer submittals, and review of developer work products. The engineered approach developed by Dr. Breeds for this project was eventually incorporated in the City of Bellevue's regulations for developments in abandoned coal mine areas.
- Review of subsidence evaluation report for municipal landfill site underlain by coal mine workings in six seams.
- A proposed 240 acre apartment development was found to be underlain by workings from the Spring Brook coal mine which was active from 1940 to 1952. Existing mine maps and mine production data suggested the presence of unmapped workings. Preliminary estimates of site investigation and remediation costs were made.
- Investigation of the potential impacts of the Richmond Stanley tunnel on proposed development.
- Investigation of site underlain by old (Circa 1900) coal mines to evaluate the potential for subsidence and potential impacts to a proposed housing project, for King County Housing Authority. The project involved researching historic data (mine plans, production records), interviewing state agency personnel and local residents, projection of mine data on surface plans and trenching to determine whether surface depressions were caused by underground workings.
- Abandoned/Active Salt Mine Evaluation Project Manager for the evaluation and analysis of abandoned and active salt mines for use as LLW disposal facilities in New York. This involved developing remedial designs for abandoned facilities, and partitioned disposal space in active mines, shaft design, long term stability analyses, and life-cycle cost estimates.
- Mechanical/Hydrological Characterization of Mechanically Disturbed Zone: This project involved an in depth analysis of the disturbed zone surrounding underground openings in salt with regard to sealing and backfilling. An extensive salt mine rock mechanics database was also established.

Active Mine Projects

- Preparation of input to Permit Revisions for the Twentymile Mine's Northern Mining District regarding subsidence effects on the railroad, county roads, Twentymile cliff (Rockfall hazards), Fish and Middle Creeks, and associated Alluvial Valley floors.
- Preparation of a report on Subsidence Related Horizontal Displacements and Strain Monitoring in the Western Coalfields, for the United States Bureau of Mines. This report examines the current approach to measuring and predicting strain (and related structural damage) based on Western US, longwall case study data.
- Preparation of subsidence predictions for the Belrock mining area, Cyprus Empire corporation. Project involved analysis of existing survey data from 300 to 900 ft deep workings and prediction of subsidence, tilt, and strain for the new panels.
- Preparation of subsidence predictions, damage potential, and remedial methods for the existing western area of the Foidel Creek mine, Cyprus Coal Company, Oak creek, Colorado. Presentation of findings to the Routt County planning commission as part of Cyprus' permit process.

- Development of mitigation for potential rockfall hazards associated with undermining a 200 ft high sandstone cliff in Colorado. This work involved mapping the site, retrieving geotechnical and topographic data for calibrating the CRSP model, evaluating rockfall hazards using the CRSP model, designing mitigation measures, and as-builting the completed project. Barrier designs that were evaluated included steel fences, a vertical, reinforced-soil wall and a 20-ft deep trench/berm combination.
- Preparation of subsidence predictions for Eastern expansion to Cyprus Coal Company's Foidel Creek mine involving 29 longwall panels, 840 ft wide and over 20,000 ft long. Subsidence, and related strain and slope, predicted for 3 alluvial valley floors, county road, railway line, and 3 sets of overhead electricity transmission lines. Report prepared as input to Cyprus' permit documentation.
- Preparation of subsidence displacements (subsidence, tilt, strain, and curvature) for 9 longwall panels planned for extraction beneath 3 overhead (345 KV) transmission lines. Detailed analysis of foundation displacements for 4-legged steel towers and wooden pylons and presentation of displacement predictions to the three major power companies involved in power transmission.
- Energy Spur, Southern Pacific Railroad. Prediction of track settlement and re-ballasting requirements for multi-panel undermining of SP's Energy spur. This project also involved preparation of a monitoring plan, scheduling track remediation, and interactions on a daily basis during live track re-leveling while the rail subsided up to 5 ft.
- Fish Creek Alluvial Valley Floor (AVF) Study. This project has involved back-analysis of subsidence and horizontal displacement survey data for single and multi-panel, longwall, coal extraction; development of start and transverse subsidence profiles for sub-critical (W/h=0.6) workings; prediction of subsidence impacts to an AVF affected by panels with W/h of 0.6 and 0.85; preparation of permit revisions; and development of monitoring plans.
- Preliminary evaluation of surface subsidence for a 24 panel longwall development for Wolf Creek Collieries, Kentucky. Project involved ground subsidence prediction, evaluation of potential impacts to wells, roads, railroads, and dwellings, and requirements for mining adjacent to the Big Sandy river.
- Liaison with USBM Denver Research Center on Mine Subsidence Engineering and development of Subsidence Information Center.
- Development of a strata simulator to model surface movements resulting from longwall coal extraction. Research sponsored by DOE.
- Subsidence Engineering with the NCB (National Coal Board, U.K.), North Nottinghamshire Area, involving:
  - Analysis of over 200 documented subsidence case studies involving longwall and partial (room and pillar) extraction coal mining in single and multiple (up to 7) seams. Analysis performed to provide a statistical evaluation of the effects of geology on the magnitude of mine subsidence deformations.
  - Investigation of CLASP (Consortium of Local Authorities Special Programs) structures subjected to mining subsidence: Phase I involved the analysis of over 50 case studies of undermined CLASP structures. Phase II involved the instrumentation of a site containing both CLASP and conventional structures. Monitoring of the ground surface movements and structures was carried out during longwall undermining.

- Investigation of more than 15 undermined industrial sites to evaluate and quantify the effects of remedial measures used to control subsidence induced structural damage. Key projects included:
  - Subsidence investigation of a brick manufacturing plant; involved the monitoring of surface and structures at a site where trenching was used to reduce the damage due to longwall undermining.
  - Instrumentation of the Rolls Royce Hucknall site during longwall undermining; involved the instrumentation of large structures, hangars, precision machinery, runway and gas pipeline during undermining. Site and mining precautions were taken to minimize surface damage.
  - Instrumentation of a large textile factory; involved the monitoring of a large factory subjected to maximum compression from longwall mining. Several structural precautions, including trenching, were incorporated in and monitored at the site.
  - Bench scale modeling, field verification, and analysis of effectiveness of trenching used to protect structures from compressive ground strains resulting from longwall undermining.
  - Investigation of the impacts of longwall undermining of a large brickbuilt structure underlain by spacious, deep cellars. Project included structural precautions, surface subsidence and strain measurement (monument layout designed to facilitate principal strain magnitude and direction calculation).

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- Breeds, C.D., et al., 1996. "Predicting Settlement for EPBM Driven Soft Ground Tunnels Using Probabilistic Methods." Keynote Paper, Conference on Tunnels and Deep Excavations, Jakarta, Indonesia, April, 1996.
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- Breeds C.D. and Schreiber S., "Evaluation of Potential Effects of Abandoned Coal Mines on Landfill Design and Construction". Paper to be presented at the 1992 Pacific Northwest Mining and Metals Conference, Bellevue, WA. April, 1992.
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- Breeds, C.D. and B.N. Whittaker. "A Critical Analysis of Contemporary Methods of Controlling Mine Subsidence Damage", 6th International School of Rock Mechanics, Kracow, Poland, February, 1979.
- Whittaker, B.N., and Breeds, C.D. "The Influence of Surface Geology on the Character of Mining Subsidence", Proc. Association Geotechnica Itiliana, Capri, Italy, 1977.