Potential Identification of Mine Openings Using Remote Sensing Topographic LiDAR, Montague Gold District (NTS 11D/12), Halifax Regional Municipality

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Introduction

Nova Scotia has a long history of gold mining dating back to the 1800s. Most gold mines operated prior to modern environmental standards, which often resulted in unsecured abandoned mine openings and tailings that were not reclaimed following recovery of gold from ore. These vestiges may be a hazard to the local environment or to visitors to the sites. A critical component for evaluation of hazardous conditions is having an accurate location of these features.

Current methods to identify possible hazardous mine openings include reviewing archival maps and field visits to suspected areas of former mining which have provided a comprehensive database of abandoned mine openings in the province with over 7000 mine openings identified to date. Topographic LiDAR (Light Detection and Ranging) presents an opportunity to increase the accuracy of the location of these features, and to potentially identify previously unknown ones. In this report we examine LiDAR imagery from the Montague Gold District in an area of previously known openings to test the feasibility of this method (Fig. 1). Montague is one of many historical gold mining districts in the province; Oldham, Minesville, Waverley, South Uniacke and Mount Uniacke are also located within, or partially within, the LiDAR survey which was commissioned by the Halifax Regional Municipality (HRM) and the Geological Survey of Canada.

Topographic LiDAR has been used by Roik *et al.* (2009) to identify potential illegal, ‘bootleg’ coal-pits in the Sydney Coalfield, Cape Breton. The method successfully identified depressions approximately 1-3 m in size, similar in size to many of the known mine openings in the gold districts. In Alberta, LiDAR has been used to identify surface subsidence over underground coal mine workings. These features were identified on the LiDAR hillshade imagery and could not be identified using air photographs alone (Froese and Mei, 2008).

In this paper we use the term ‘depression’ for any topographic low that may be a natural feature or a man-made excavation which is the result of mining activity. Former mine openings may be infilled or partially infilled shafts, slopes, raises or ‘exploration pits’ (shallow, 2-3 m deep trenches dug into bedrock or till).

Geological Setting

Montague is located within the Taylors Head Formation of the Goldenville Group, a primarily grey metasandstone with interbedded metasiltstone and slate of Late Neoproterozoic to Middle Cambrian age (White *et al*., 2008). These rocks are folded, with gold found primarily in bedding-parallel quartz veins on the southern limb of the northeasterly-trending anticline.

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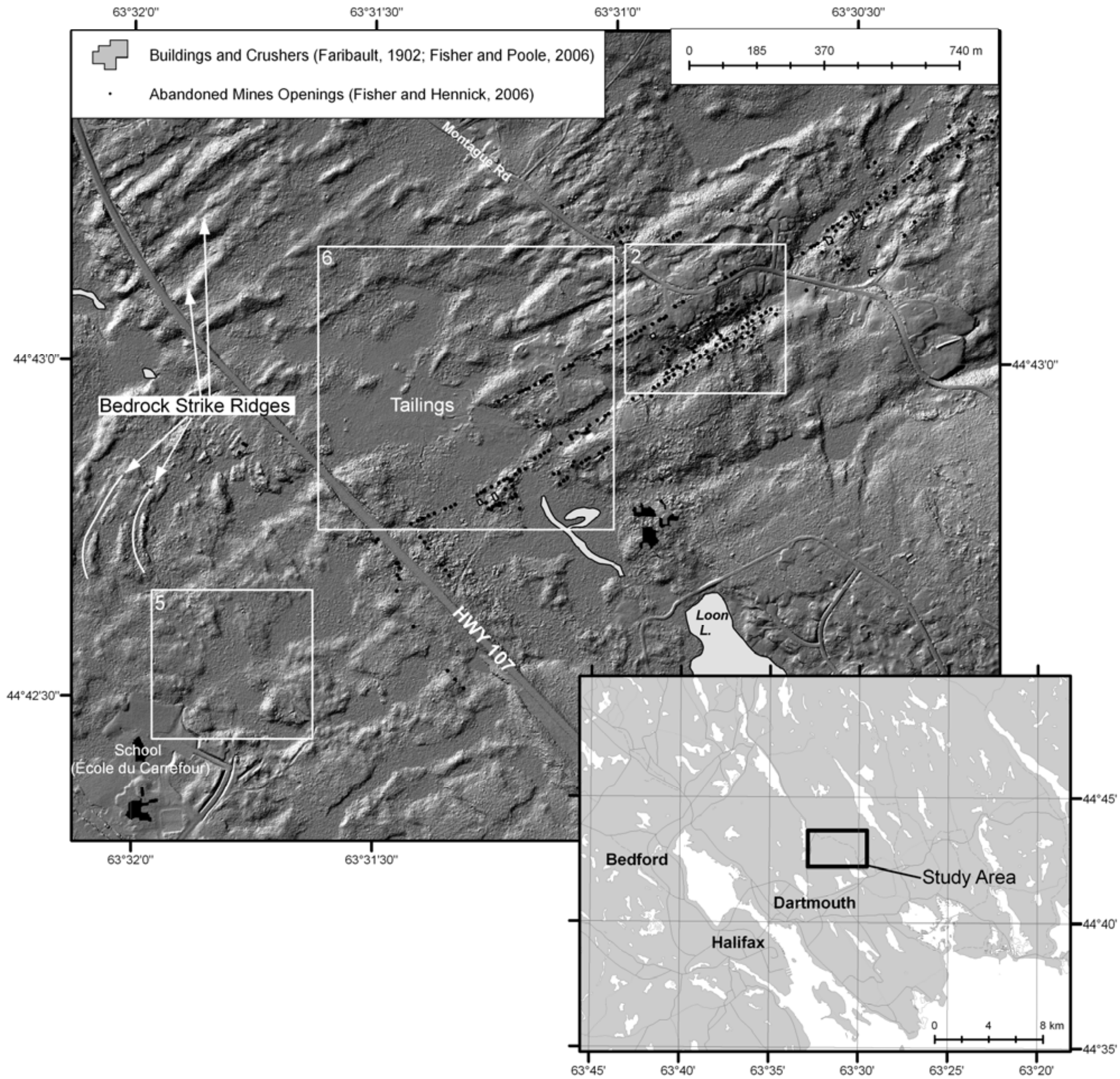

Figure 1. LiDAR hillshade image of the Montague area with numbered boxes indicating locations of Figures 2, 5 and 6. Location of abandoned mine openings shown from Nova Scotia Department of Natural Resources database (Fisher and Hennick, 2006).

Surficial materials of the area are typically locally derived silty to sandy, metasandstone facies of the Beaver River Till, averaging 3 m in thickness (Stea and Fowler, 1981; Finck and Stea, 1995). Ice flow and transport were generally towards the southeast.

Mining History

Gold was first discovered in Montague in 1861 when several auriferous quartz boulders were examined by prospectors (Malcolm, 1929). Surface and underground mining operations commenced in 1863 and the first steam crusher began operating in the district in 1865 (Malcolm, 1929). The Montague Gold District was operated almost continuously from 1863-1939 and produced over 65,000 ounces of gold placing it as the fifth largest producer in the province (Bates, 1987; Gillespie-Wood, 1987). Gold occurs typically as free gold in quartz, although it also occurs as auriferous arsenopyrite (Brunton, 1928; Malcolm, 1929). Arsenopyrite is commonly found in quartz veins and disseminated throughout the metasandstone and slate host rocks.

Typical of all historic gold districts in Nova Scotia, once an auriferous quartz boulder(s) was located, prospectors dug pits and trenches in order to locate the bedrock source. Once the bedrock source was located, then vertical shafts were used to access the narrow, bedding-parallel mineralized quartz veins (referred to as ‘leads’ by prospectors) at depth. Underground mining operations included drifts driven along the quartz veins and crosscuts driven perpendicular to bedding in order to locate and access additional bedding-parallel veins.

Detailed surveying and mapping of the Montague Gold District by Faribault (1902) accurately identified shafts and individual quartz veins, crushers/stamp mills, and related mining infrastructure. From 1863-1902, the vast majority of the shafts and associated underground mine development took place on the steeply dipping to near-vertical southern limb of the Montague Anticline (Faribault, 1902, 1908). Most of the infrastructure, including crushers, engine houses and mine offices used to support the mining operations, was located south of the anticlinal axis (Faribault, 1902). Faribault’s 1902 map indicates that at least 172 shafts were located on the southern limb of the anticline compared to only six on the northern limb. However, a plan showing the location of shafts constructed for the period 1903-1939 does not exist, despite the fact that mining continued virtually uninterrupted for that time period (Bates, 1987; Brunton, 1928; Gillespie-Wood, 1987 and references therein). Therefore, the 178 shafts depicted on Faribault’s 1902 plan map is a minimum number, because mining continued within the Montague Gold District for an additional 28 years. In the Nova Scotia Department of Natural Resources (DNR) Abandoned Mine Openings Database there are 228 shafts and 308 openings identified in the Montague Gold District (Fisher and Hennick, 2006).

The District Today

Today, the district is sparsely inhabited and most of the surface is forest covered. Evidence of former mining activity, including shafts, pits, trenches, waste rock piles and dilapidated buildings, is still present in 2009 despite the fact mining operations ceased in 1940. However, most shafts, pits and trenches are barely recognizable today, nothing more than an aligned series of depressions casting back on a time when prospectors and miners toiled along the strike of the numerous auriferous quartz veins throughout the district. These depressions are often filled with forest litter and in many instances have mature trees growing within and around the edges.

In some cases, however, shafts are ‘open’ and pose a physical hazard to humans. The Nova Scotia Department of Natural Resources has, in addition to posting warning signs, been actively filling in, capping and/or fencing many underground workings located on Crown land on a priority basis. This work is conducted as part of DNR’s ongoing Abandoned Mine Openings Program.

Methods/Existing Data

The LiDAR survey was completed through a contract to PHB Lasermap using an Optech 2050® survey system. The data were gridded using the nearest-neighbour interpolation method to 1 m and 2 m resolutions and a sun-illuminated hillshade model produced from these digital elevation models (DEM). The digital elevation model used for this study represents vertical heights from mean sea level based on the Canadian Geodetic Vertical Datum from 1928 (CGVD28). The LiDAR was groundtruthed using high resolution RTK-GPS surveys. A total of 1500 points were chosen over flat, nonvegetated areas to give the most accurate results. Comparing GPS derived vertical and horizontal positions to the 1 m grid generated a total mean difference of -0.04 m with a RMS error of 0.33 m; this falls within the accuracy of most LiDAR systems.

A database of Abandoned Mine Openings is maintained by DNR (Fisher and Hennick, 2006). The feature coordinates were originally determined by plotting survey field notes of the location of mine openings on 1:10 000 scale topographic maps, and then measuring the coordinates from this map. The accuracy of the coordinates was improved by subsequent site visits using GPS surveying techniques.

Results

Abandoned Mine Openings

An area of known abandoned mine openings was visited in May 2009 to determine the characteristics of those that can be detected on LiDAR imagery. Abandoned mine openings that are not infilled can sometimes be successfully identified from LiDAR imagery (Fig. 2). Because these are represented on the DEM as drops in elevation, compared to the surrounding topography, on the hillshade model they appear as black spots. A GIS query of the hillshade surface at the location of the feature provides an accurate geodetic location for it.

The 'base' of these openings might be infilled material covering workings below, or bedrock, so from the imagery alone it is not possible to identify the level of risk associated with an opening.

Where openings have been filled to the level of the surrounding topography they cannot be detected easily using the 'hillshade method'. However, at one previously infilled location visited in the field a subtle 'settling' feature was observed (Fig. 3). This feature is expressed on the LiDAR imagery as a bedding-parallel depression (Fig. 2), but it would be unlikely this feature could be delineated on LiDAR alone without prior knowledge of its location. This raises the potential of mapping infilled abandoned mine openings by identifying subtle elevation changes by comparing LiDAR data collected from multiple time periods. Advantages of the potential LiDAR comparison technique are that it could cover large areas and areas where infilled features were not known.

Limitations to identifying openings using LiDAR are that the surface depression must have a large enough 'footprint' and enough depth to be resolved. The minimum detectable size depends on the resolution of the imagery. Visual comparisons of hillshade models produced from the 1 m and 2 m resolution DEMs are slightly different, with the 1 m version appearing better at identifying abandoned mine openings. For comparison, we also produced topographic profiles over an area of openings, using the 1 m and 2 m resolution DEMs

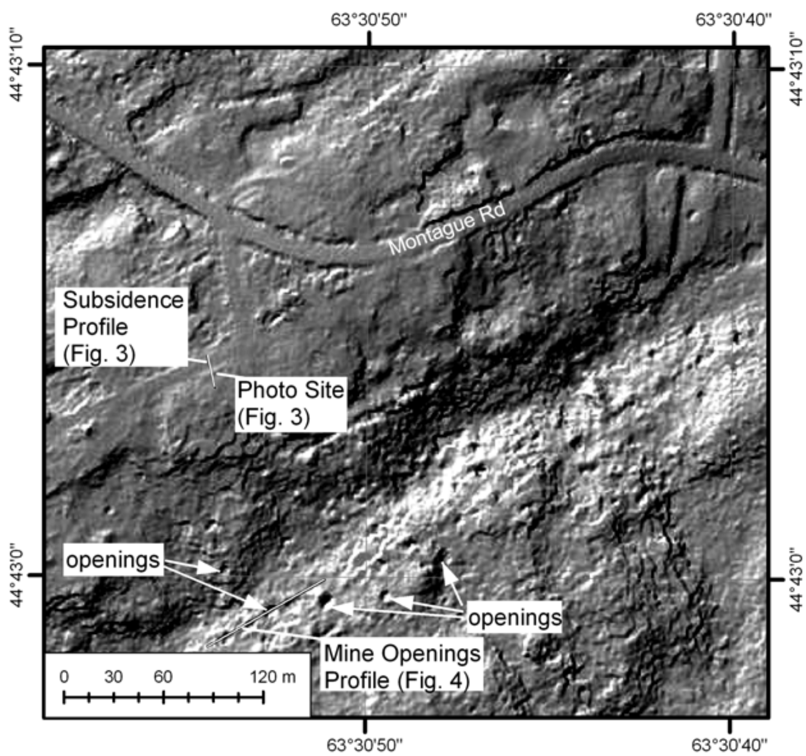

Figure 2. Closeup view of LiDAR 'bare-earth' hillshade image (1 m grid) with some abandoned mine openings, labelled as 'openings' (location shown on Figure 1). Note that numerous openings are obvious on the image, but for simplicity only five are indicated. Locations of subsidence profile and photo (Fig. 3) and mine openings profile (Fig. 4) are labelled.

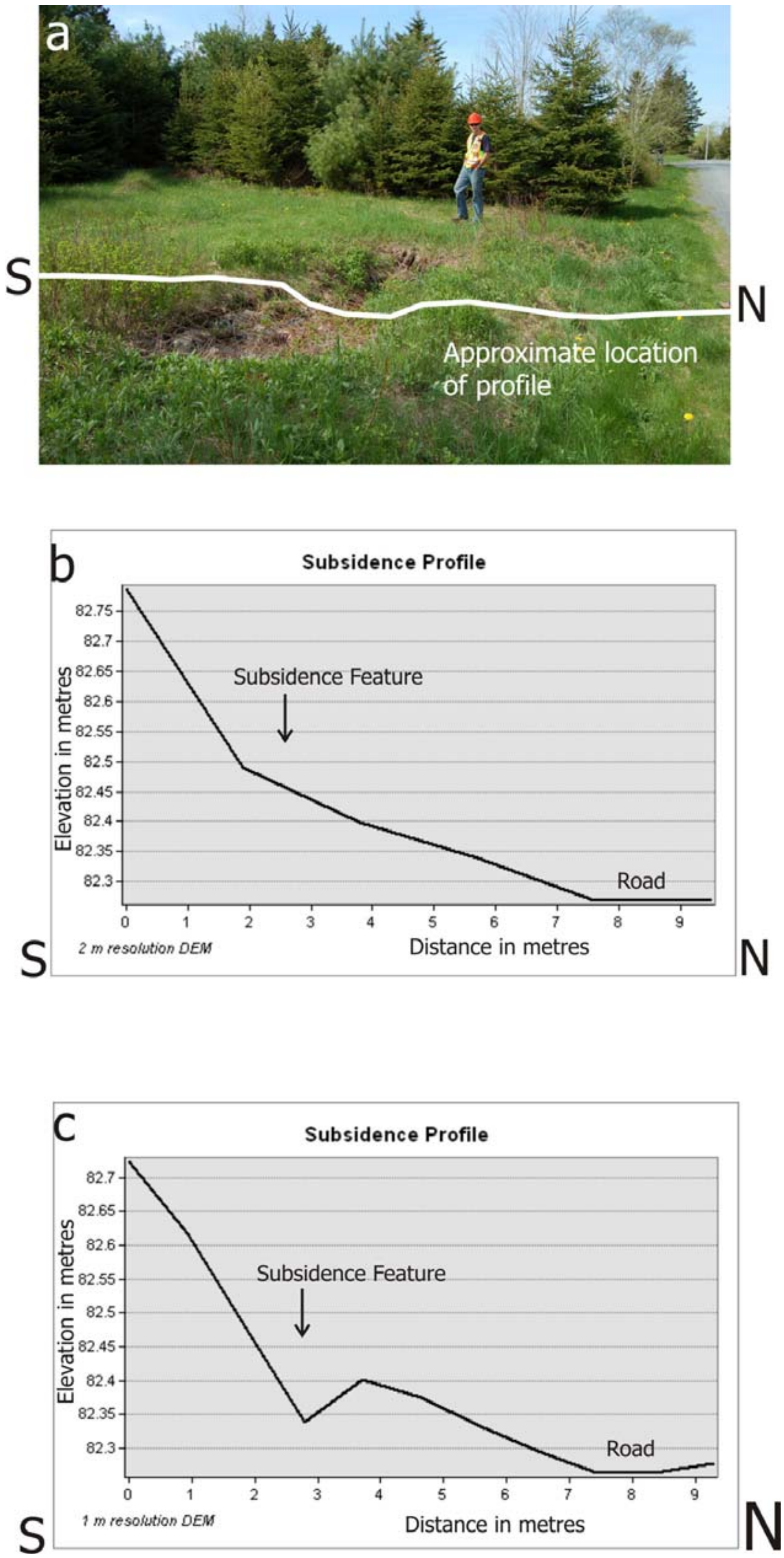

Figure 3. (a) Photograph of settling feature identified during fieldwork (location shown on Figure 2). (b) Profile created using 2 m resolution DEM. (c) Profile created using 1 m resolution DEM.

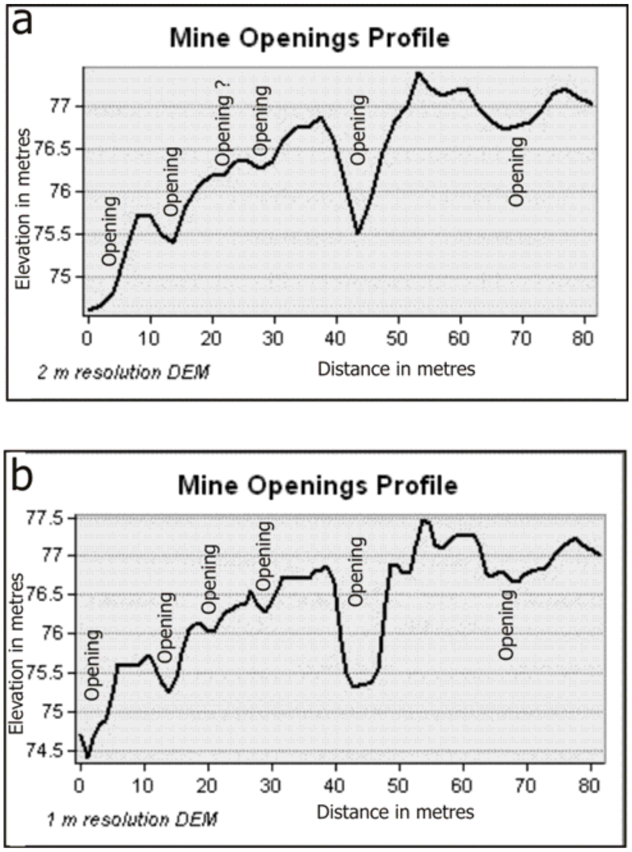

Figure 4. Profiles across abandoned mine openings (location shown on Figure 2). (a) Profile created using 2 m resolution DEM. (b) Profile created using 1 m resolution DEM.

(Fig. 4). The 1 m profile shows greater detail, measuring relief as subtle as 0.1 m. This resolution is maximized in flat areas with less vegetation. Thick forest cover reduces the accuracy.

A profile across the subsidence feature using the 1 m resolution data reveals the depth of the feature to be <0.1 m (Fig. 3). This corresponds with field observations at the site. Based on these results, we recommend using the 1 m resolution DEM for analysis of abandoned openings.

LiDAR imagery was used to identify a series of depressions in an area where no mine openings were previously known and no detailed historical mapping is available (Fig. 5). The openings are located along strike with the other known geological features, but not reported on previous mapping or in databases. Based on field investigations, it was determined that the features were former exploration pits that pose a minimal

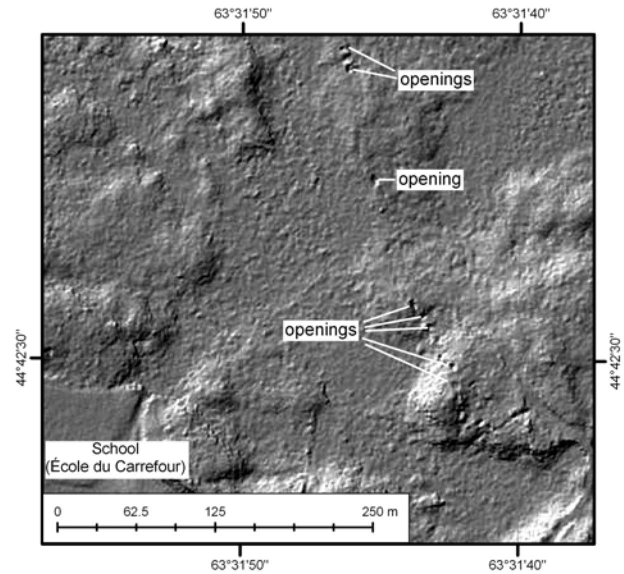

Figure 5. Close up view of LiDAR 'bare-earth' hillshade image (1 m grid) with previously unknown abandoned mine openings identified (location shown on Figure 1).

hazard, but identification of these previously unknown features highlights the potential value of this technique to identify previously undetected mine features. This may be especially helpful given the expanding urban population in HRM and plans for new transportation infrastructure in the expanding areas. Other previously unknown openings (not shown) were identified west of the Oldham Gold District and confirmed by a site survey of the area.

Tailings

Another potential benefit of the LiDAR imagery is for mapping the location of mine tailings. A GPS survey of the distribution of tailings compared with the LiDAR hillshade imagery indicates that the potential exists for delineating areas of tailings (Fig. 6). Tailings deposited in topographic lows create a flat, smooth surface, so mapping this surface provides a predictive map of the distribution of tailings. However, smooth surfaces can be created by natural processes in the environment (e.g. alluvial plains, wetlands), so geochemical sampling must be completed to determine the existence and actual distribution of tailings.

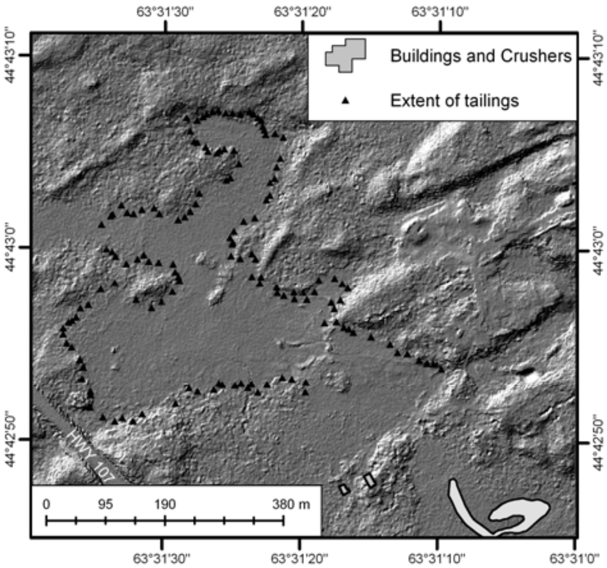

Figure 6. Montague area showing extent of tailings, based on ground surveying (location shown on Figure 1).

Summary

DEMs and hillshade models derived from topographic LiDAR are potentially useful tools to identify the location of possible abandoned mine openings. Field checking is required to confirm their locations and determine the potential risk posed by identified features. The location of infilled features, that may pose a risk due to collapse, might be identified by areas of subsidence by comparing multiple series of LiDAR surveys.

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