Analysis of the Efficacy of LiDAR Data as a Tool for Archaeological Prospection at the Highland Valley Copper Mine

by

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Abstract

As heritage resource management and Indigenous heritage stewardship moves into the forefront of project design and operational planning in British Columbia, researchers look for innovative ways to foster impact assessment efficiency without sacrificing quality. In this study I explore methods for employing LiDAR-derived digital elevation models as a tool for archaeological prospection within the Highland Valley Copper Mine. A review of contemporary and formative LiDAR-analysis archaeological prospection research was conducted to identify the most appropriate visualization techniques and data management workflow. Specific methods for the identification of microtopographic relief with the potential to contain archaeological resources were developed. The efficacy of LiDAR-based topographic analysis using manual feature extraction is validated through comparison with georeferenced survey and ground-truthing data provided by my research partners at the Nlaka'pamux Nation Tribal Council. The LiDAR analysis method identified a high percentage of recorded archaeological sites and meets provincial requirements for a moderately effective predictive model. Results of LiDAR analysis are presented along with recommendations for improved performance using best practices and an interpolation workflow. An analysis of the cost implications of incorporating LiDAR-survey into the heritage management workflow in the study area identified a significant benefit during survey. These savings would allow for redistribution of resources and potentially a greater focus on mitigative systematic data recovery. The use of remote sensing technologies and methods can have a positive impact on heritage resource management industry in BC by decreasing program costs while maintaining quality.

Keywords: LiDAR (Light Detection and Ranging); Highland Valley Copper Mine; Nlaka'pamux Nation Tribal Council; Heritage Resource Management (HRM); Manual Feature Extraction (MFE); Archaeological Prospection

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List of Acronyms

AFE	Automated Feature Extraction
ALS	Airborne Laser Scanning
AOI	Area of Potential
asl	Above Sea Level
BC	British Columbia
BP	Before Present
BSA	Blind Study Area
CMT	Culturally Modified Tree
DEM	Digital Elevation Model
FP	False Positive
GIS	Geographic Information System
GPS	Global Positioning System
ha	Hectare
HRM	Heritage Resource Management
HVC	Highland Valley Copper Mine
LiDAR	Light Detection and Ranging
LRM	Local Relief Model
LTA	Lornex Test Area
m	metre
MFE	Manual Feature Extraction
MTF	Missed Target Feature
NNTC	Nlaka’pamux Nation Tribal Council
NTA	Nicola Tribal Association
NTTA	North Tailings Test Area
P	Precision
PARL	Provincial Archaeological Report Library
ppm	Pulse Per Meter
R	Sensitivity
R1	Review 1
R2	Review 2
RAAD	Remote Access to Archaeological Database
RViT	Relief Visualization Toolbox

SFU	Simon Fraser University
STA	Subsurface Test Area
STTA	South Tailings Test Area
Teck	Teck Resources Limited
TP	True Positive
TRIM	Terrain Resources Information Management

Glossary

Area of Interest (AOI)	Area assessed in-field or digitally as having attributes indicative of archaeological potential, microtopographic landform suspected of containing surface and/or subsurface archaeological materials.
Automated feature extraction (AFE)	Uses data processing algorithms to apply objective criteria or variables to automated landscape analysis (Freeland et al. 2016; Howey et al. 2016; Cowley 2012:417).
BareEarth	A topographic representation of the ground surface with vegetation and structures removed by filtering LiDAR-collected point cloud data. Available as a layer in the ArcGIS platform.
LiDAR/ALS	Light detection and ranging (LiDAR) also called airborne laser scanning (ALS), is acquired when an aircraft surveys an area, emitting near-infrared laser pulses toward the ground surface, and measuring the time and intensity of the returning light using a specialized receiver (Glennie et al. 2013; Wehr and Lohr 1999).
Digital Elevation Model (DEM)	A set of data points organized into a matrix with elevation attributes as well as x and y axis ascribed. A subset of a Digital Terrain Model, these data points are often filtered for bare-earth returns (Kokalj and Hesse 2017:76)
False Positive (FP)	LiDAR-derived AOI not recorded in-field as an NNTC target feature
Hillshade Model	Standard hillshading is a raster data visualization method that assumes an elevation and angle for sunlight and illuminates a digital elevation model to provide contrast through grey-scale shading.
Local Relief Model (LRM)	LRM is a visualization method that presents localized, small-scale elevation differences after removing large-scale landscape forms from the data set. LRM is suitable for viewing low-profile topographic features such as knolls and small ridges isolated from the larger terrain where they occur (Hesse 2010).
Manual Feature Extraction (MFE)	Process of manually delineating areas of archaeological interest or suspected anthropogenic landscape alteration (Quintus et al 2017:352).
Missed Target Feature (MTF)	NNTC-identified target feature not identified during LiDAR-derived MFE review
Multi-azimuth hillshading	A hillshade raster data visualization technique that overlays minimally three images rendered in various hillshade directions (Kokalj and Somrak 2019).

Precision (P)	Portion of LiDAR-derived AOIs that are confirmed in-field or are True Positives (TPs); calculated as TP/(TP+FP) (Quintus et al. 2017:355)
Principal Component Analysis	Raster data visualization technique which involves processing the highest resolution views from minimally sixteen azimuth directions through multivariate statistical analysis and rendering them as a single image (Devereux et al. 2008).
Relief Visualization Toolbox[1] (RViT)	Software application developed to visualize raster elevation model data, specifically focusing on techniques for identifying small-scale anthropogenic features (Kokalj and Somrak 2019).
Sensitivity (R)	Also known as resonance this denotes the rate of detection success, calculated as TP/(TP+FN) (Quintus et al. 2017:355)
Sky-view Factor	A raster data visualization technique that illuminates the ground surface based on an estimate of what portion of the sky is visible from the surface, taking into consideration the relief horizon based on terrain and/or surface (Kokalj et al. 2011).
Subsurface Test Area (STA)	Location within the study area that has been subject to systematic subsurface inspection during archaeological prospection
Target Feature (TF)	Area of interest, subsurface test area and/or archaeological site recorded by NNTC or other consultants within the study area
True Positive (TP)	NNTC target feature that was also identified by LiDAR-derived MFE (Quintus et al. 2017:355)

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[1] https://iaps.zrc-sazu.si/en/rvt#v Accessed January 31, 2021

Executive Summary

The objective of this study was to evaluate the efficacy of using available LiDAR data as a tool to identify landforms with the potential to contain subsurface, precontact archaeological lithic scatter sites within the Highland Valley Copper Mine permitted area of operation in the Southern Interior of BC. Based on the results, best practices for using LiDAR imagery to prospect for areas of interest (AOIs) and archaeological sites in the Heritage Resource Management (HRM) industry in BC are proposed.

LiDAR data are produced when aircraft survey an area emitting laser pulses and record the time and intensity of the returning light to create a point cloud data set that contains positional and elevation information for the ground surface. These point clouds can be processed to create a detailed visual representation of the ground surface free of vegetation or structures. The ability to view bare-earth digital elevation models (DEMs) is what makes LiDAR such a valuable tool for the field of archaeological prospection, which is often plagued by the difficulties of visually identifying surficial expressions indicative of buried archaeological material or deposits.

To accomplish the study objectives, LiDAR imagery was visualized using a variety of techniques and reviewed using the process of manual feature extraction (MFE) to select landforms assessed as having archaeological potential. MFE is the process of delineating areas of archaeological interest during LiDAR-derived imagery interpolation and was chosen for this study due to the nature of the landscape and target features as well as the minimal geoprocessing requirements involved. The most efficient and intuitive visualization techniques for the interpretation of LiDAR data were identified based on the results of a literature review of contemporary studies into the use of LiDAR for archaeological prospection in a variety of environments.

Existing archaeological survey and assessment data collected between 2016 and 2020 by my research partners the Nlaka'pamux Nation Tribal Council (NNTC) and Teck, as well as data collected by HRM consultants, were utilized as a comparative data set for this study. To inform the research strategy the recorded target features (i.e., areas of interest, subsurface test areas and recorded archaeological sites) were subject to quantitative analysis to identify mean objective criteria for slope and aspect. These

target feature landscape characteristics were used to assess the results of MFE analysis and identify ways that the remote sensing process can be improved.

After visualizing the data, a series of DEMs was created that were layered and blended with variations in transparency to enhance contrast and allow for visual identification of microtopographic landforms indicative of archaeological potential. The MFE-method LiDAR imagery interpolation results were compared with the existing data set from traditional survey within eight test locations and two blind study areas. Existing traditional survey data included geospatially recorded AOIs, subsurface test locations (STAs) and recorded archaeological site polygons. The methods were compared analytically based on five factors including: i) true positives; ii) false positives; iii) missed target features; iv) overall intersection of area; and, v) the binary result of intersection.

The study results indicate 75-92% of recorded archaeological sites are captured using the LiDAR-derived imagery manual feature extraction method. Between 6% and 14% of the manual feature extraction area AOIs were false positives, and 18-39% of target features were missed during LiDAR analysis. Between 85 and 94% of the manual feature extraction AOIs at least partially intersected with the target feature polygons. These results align with other LiDAR-derived archaeological potential model testing in BC (Arcas and Millennia 2010; Millennia 2006) and recent analysis of the effectiveness of LiDAR-data for manual and automated anthropogenic feature extraction (Bennett et al. 2012; Crowley 2012; Freeland et al. 2016; Quintus et al. 2017).

Missed target features were re-evaluated to identify landscape characteristics that may have contributed to their selection. Several factors contributed to the identification of false positives including: i) resolution of the LiDAR data; ii) reviewer experience with the study area terrain; iii) landscape alterations from mining activities; and, iv) NNTC-specific feature recording strategies that take into account traditional knowledge.

The results of LiDAR-analysis for archaeological prospection using manual feature extraction are contrasted with alternate methods such as predictive potential modelling, automated feature extraction and GIS-based analysis of landform criteria. It was not the purpose of this study to develop a potential model, but rather to examine different techniques for visualizing LiDAR data and the associated success rate of target feature detection. The methods, workflow and best practices presented can be implemented in a variety of environments and are a baseline component for the development of study area-specific remote sensing strategies for archaeological prospection.

The study results suggest that LiDAR would be effective as a tool for guiding a field prospection program, during which the results could be judgementally adapted at the discretion of the field crew. This should be an iterative process in which the ground-truthing results from LiDAR-derived AOIs are provided to the reviewer so that adjustments can be made in the methods used for in-office AOI interpolation. Overall, the manual feature extraction LiDAR-analysis method is assessed as being highly effective for identifying archaeological resources within the study area and would be considered a moderate efficiency predictive model by the provincial regulator. The implementation of this tool in the archaeological prospecting strategy for the project area would result in cost savings during traditional survey. It would allow for a more holistic approach to operational planning to ensure the most efficient process for the preservation of archaeological resources as part of the NNTC heritage stewardship strategy.

More broadly, the use of LiDAR-derived DEMs for the prospection of archaeological sites in the HRM industry in BC is becoming more accessible. The availability of both opensource LiDAR data and software for processing and visualizations means that these innovative techniques are being employed by more researchers to identify paleoenvironmental landscape attributes and areas of archaeological interest within small and large-scale study areas. These techniques allow field programs to be planned effectively and efficiently, while providing cost savings opportunities for industry stakeholders.

Chapter 1. Introduction and Research Context

1.1. Introduction

This research presents the objectives, methods and strategy employed to investigate whether the analysis of LiDAR (light detection and ranging) data can effectively be utilized as a tool to prospect for archaeological sites within the Highland Valley Copper Mine (HVC), owned by Teck Resources Limited (Teck). HVC operation area covers 30,000 ha and is located in the southwestern interior of British Columbia, Canada, 14 km south of the community of Logan Lake (Figure 1).

Several key variables created an ideal opportunity for conducting this research; specifically, the availability of existing 50 cm-resolution LiDAR data to analyze and compare with abundant georeferenced data from the ongoing heritage impact assessment program at HVC. Additionally, the support of my research partners at the Nlaka'pamux Nation Tribal Council (NNTC) and their corporate entity A.E.W.LP as well as the facility owner Teck was essential in completing this research. The results of this study are compared with the assessed effectiveness of LiDAR-based potential modelling in BC and other contemporary LiDAR-derived heritage prospection studies. The efficacy of the methods employed during this study are also assessed more broadly through their implications for the heritage resource management industry in BC.

1.2. Research Problem and Goals

The research problem derives from the current heritage resource management (HRM) program underway in the Highland Valley Copper mine. Traditional survey methods are not financially or logistically feasible for assessing such a large project area. The seemingly insurmountable task of ground-truthing a development area measuring over 30,000 ha, which has seen significant land alterations from mining operations, is exacerbated by limited funding and strict schedule constraints inherent in the heritage management industry.

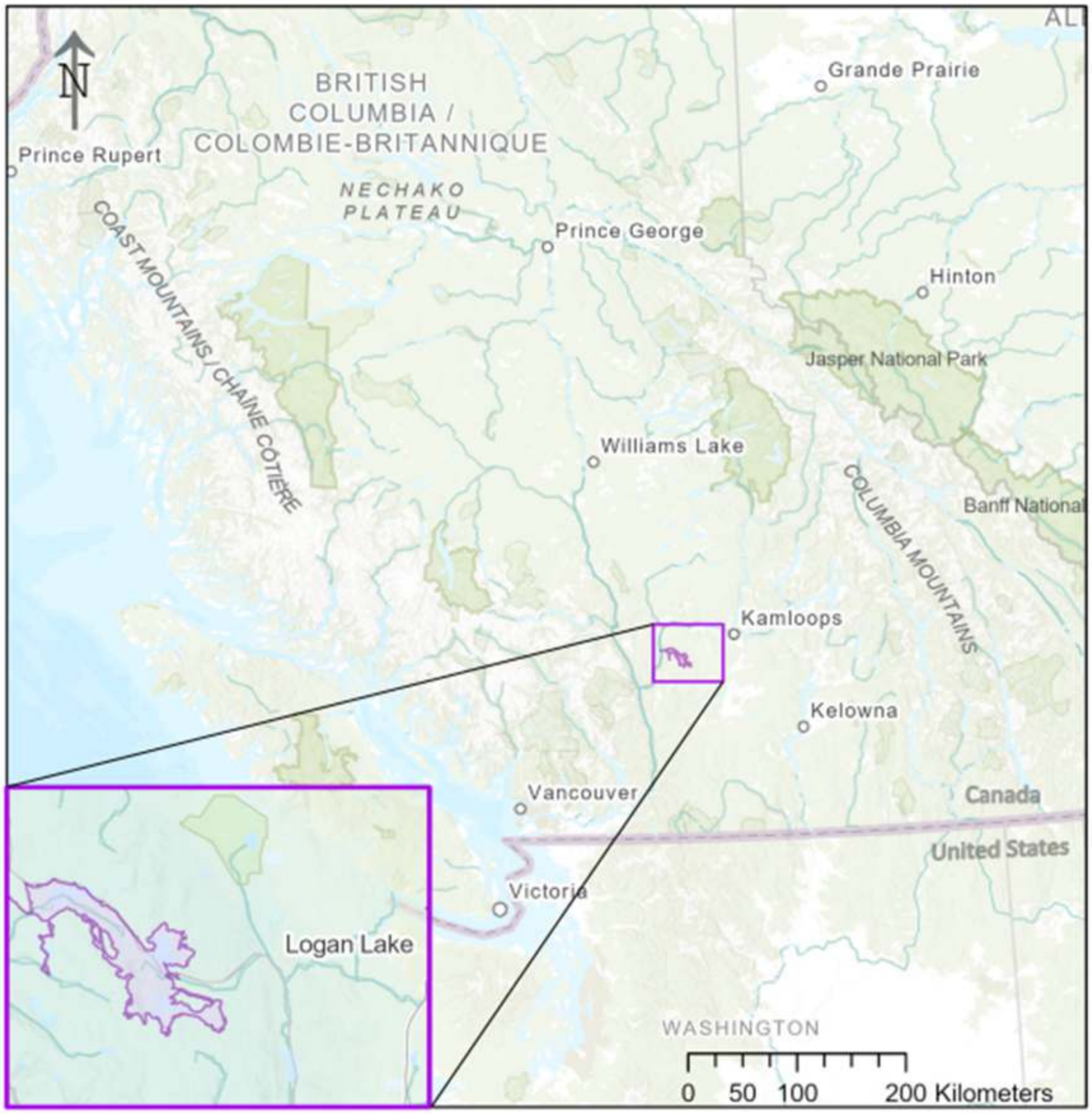

Figure 1. Location of the Highland Valley Copper Mine, British Columbia, Canada
Data Source: Esri Canada, Airbus DS, USGS, NGA, NASA, CGIAR, NCEAS, GSA, Geoland, Geodatastyrelsen, FEMA, Intermap and the GIS user community

Alternative methods and technologies could provide options for identifying a high percentage of archaeological resources present in a large project area without expending the time, labour and financial resources required to complete the assessment relying solely on traditional survey and ground-truthing methods. A.E.W.LP is the corporate development arm of NNTC and implements decisions related to sovereignty. As such, they are involved with executing heritage assessment programs within Nlaka'pamux traditional territory, including the HVC study area. The Nlaka'pamux Nation

Tribal Council and Teck have identified specific research goals associated with improving the quality of heritage stewardship within the project area. Stakeholder-specific research goals that can be addressed by this study include:

- contribute to improving heritage stewardship;
- analyze collected but incompletely studied heritage program data;
- apply new techniques and technologies to address critical issues in heritage stewardship; and,
- enhance the effectiveness of site identification, recording, assessment, preservation, and mitigation.

1.3. Research Questions

How do we as archaeologists use innovation in technology to adapt traditional field methods and plan more efficient and effective field programs with a focus on identification, impact management and avoidance through project redesign? Further, how can LiDAR analysis methods be incorporated within the archaeological tool-kit to facilitate Indigenous heritage stewardship goals, compliance-based heritage management and add value for development proponents? In pursuit of the research goals and broader questions, the following specific research questions were posed:

- **Question 1:** How effective is LiDAR data as a tool for planning field inventories and for the prospection of archaeological sites within the HVC study area?
    - **Sub-question:** In a blind study, would areas of archaeological interest identified by reviewing LiDAR data correlate with target features identified during a traditional field assessment of the same area?
- **Question 2:** Does LiDAR analysis allow for more refined landform selection than traditional methods?
- **Question 3:** What criteria and guidelines would be most effective for the interpretation of LiDAR data for site inventory work within the study area?
- **Question 4:** What, if any, is the cost-benefit associated with utilizing LiDAR to plan and execute field inventories at HVC?

1.4. Research Strategy and Methods

In collaboration with my research partners, eight areas previously subject to archaeological assessment were selected to develop and test LiDAR survey methods. Additionally, two blind study areas were identified to provide a controlled evaluation of the efficacy of the LiDAR-analysis methods once developed. The areas used in the study were selected based on the level of previous assessment completed and the data sets available. Geospatially referenced data sets for the HVC study area, consisting of areas of archaeological interest (AOIs), subsurface test areas (STAs) and recorded archaeological sites were provided by A.E.W.LP. This comparative data set was quantitatively analyzed and used to inform the LiDAR data visualization techniques and LiDAR-data analysis method selected.

Current methods employed by researchers for the analysis of LiDAR data for archaeological site prospection were reviewed to identify appropriate methods and criteria for conducting LiDAR analysis for archaeological site prospection at HVC. The test areas and blind study areas were assessed using the manual feature extraction (MFE) process to delineate AOIs through LiDAR-imagery interpolation. A variety of visualization techniques are employed to enhance the contrast of the LiDAR-derived imagery and increase the likelihood of target feature detection. Best practice and workflow for conducting LiDAR imagery interpolation using MFE for archaeological prospection are identified.

The results of the manual feature extraction method were measured against field data collected by NNTC over the past five seasons using traditional survey methods to prospect for surface and subsurface pre-contact archaeological sites. The results of the LiDAR-analysis were subject to statistical analysis to define the F_1-score and assign a Kvamme's gain[2] to assess accuracy and statistical relevance. After comparing the LiDAR-analysis AOIs with the baseline NNTC data set, the results are interpreted and contextualized to identify differences in effectiveness, efficiency and associated cost-benefits of the manual feature extraction method.

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[2] Kvamme's gain = 1 – (percentage of total area covered by the predictive model/percentage of total sites within the model area)

This research is timely as the volume of heritage resource management projects in BC is higher than ever due to industry demand and increased regulatory requirements. Innovative technical solutions can provide the required confidence for compliance-based assessments and meet the schedule and financial demands of the proponent, particularly for large-scale projects requiring survey and ground-truthing.

1.5. Research Results

Based on a comparison of LiDAR-analysis results with baseline NNTC data, the manual feature extraction method identified between 75% and 92% of recorded archaeological sites. Between 6 and 14% of manual feature extraction-selected AOIs were false positives and 85 to 94% at least partially intersected with target features. Between 18 and 39% of target features were missed by the manual feature extraction method, specifically landforms that were low-profile and elevated less that 1 m above surrounding terrain or areas that had been heavily impacted by mining activities. Statistical analysis indicates that the LiDAR-derived imagery manual feature extraction results are accurate and would be assessed as a moderately efficient predictive modelling technique by the Provincial regulatory standards (Archaeology Branch 2009).

1.6. Research Context

To develop the most accurate remote sensing strategy for the study area, the research context of HVC, specifically, and the Southern Interior Plateau cultural area, more generally, are examined. The background research includes a summary of past and current heritage research. Consideration of the regional cultural heritage context allows for a more detailed understanding of the target features within the study area, increasing the likelihood of detection success and providing context to negative results and data variances. To understand the research context, the history of Indigenous past land use in the region is contrasted with attributes of the biophysical environment as they are inherently linked aspects of heritage research. Existing research results provide a baseline of data against which the effectiveness of LiDAR imagery analysis as a planning tool for conducting and archaeological inventory can be compared.

1.6.1. Biophysical Setting

The Highland Valley study area is in the Thompson Plateau Region of the Southern Interior of British Columbia. The HVC operation encompasses the Highland Valley just east of the Thompson River and is located 14 km west of the community of Logan Lake and 19 km southeast of the community of Ashcroft (Figure 1). The area is within the Lower Jurassic Guichon Creek batholith, which is a high concentration mineral deposit including gold, silver, copper and molybdenum (BCDOM 1969). Prior to mining operations, the valley bottom consisted of rolling terrain with glacial drift soils, interspersed by small lakes and creek channels (Ryder 1976). Big Divide and Twenty-Four Mile Lakes drained westward to the Thompson River via Pukaist Creek and Quiltanton Lake drained eastward to the Nicola River via Witches Brook and Guichon Creek.

In his 1981 field survey, Brolly (1981:27) noted that the western side of the valley above two of the main lake bodies was characterized by complex glacio-fluvial terraces deeply incised by tributary and meltwater streams. Additionally, a natural wetland area had already been used as a drainage sump for tailings from the nearby Lornex Mining operation at the time of the field assessment (Brolly 1981). The landscape is rugged and typical of high elevation, formerly glaciated settings on the Interior Plateau. Because of the watershed divide in the valley, sediment texture and drainage were observed by Brolly (1981:29) to change from silty clay around Quiltanton Lake transitioning to sandy dry loam near Big Divide and Twenty-Four Mile lakes.

The study area is within the Thompson Plateau Very Dry Montane Douglas fir biogeoclimatic subzone (IDFb1) (MFRB 2003). This zone is characterized by arid grasslands and open forests, which create an ideal environment for ungulates (MFRB 2003). Where present, forest cover is moderately dense and comprised of mixtures of lodgepole pine, ponderosa pine, Engelmann spruce, Douglas fir and subalpine fir with a sparse shrub understorey consisting of huckleberry, soap berry, and pinegrass. Cottonwood and aspen are also present in some wetland areas with higher levels of moisture in the soil. Migratory birds are also drawn to this area as they take advantage of the warmer temperatures and wetlands around lakes and waterways (ERM 2017).

1.6.2. Ancient Environment

Paleoenvironmental research in the Southern Interior has established that the Cordilleran Ice Sheet covered southern British Columbia until 11,000-12,000 years Before Present (BP) (Clague 1991; Fulton 1975; Hebda 1982, 1995). The glacial obstruction of this region existed between about 25,000 and 12,000 BP (Roed and Greenough 2004) and reached south into modern Washington state around 15,000 BP (Carrara et al. 1996). In the Mid Fraser-Thompson area, deglaciation began around 12,000 BP and was essentially complete by 10,000 BP (Johnsen 2004). Deglaciation proceeded more quickly in the high summits and crests, which would have opened the Highland Valley early for the propagation of new plant and animal species (Johnsen 2004; Ryder 1976).

At the end of this period (approximately 10,000 BP), a shift to a significantly warmer and drier climate began, accompanied by increases in ponderosa pine, grasses and sage, and a corresponding decrease in lodgepole pine and spruce (Mathewes 1985). This interval is referred to as the Hypsithermal, and between 10,000 and 7,500 BP sage grasslands became widespread throughout the southern Interior Plateau, especially at lower elevations (Hebda 1982, 1995). In the arid setting that existed in the region at this time, valley-bottom grasslands likely expanded upwards to merge with alpine grasslands (Dyke 2006; Hebda 1982).

Glacial outwash drainages shaped the valley walls with deep incised troughs depositing sediments around the lakes on the valley floor (Tribe 2005; Johnsen 2004). This process left elevated fluvial terraces (Ryder 1976) suitable for human occupation in the early cultural periods. The rivers of the Southern Interior became stable around 5000 BP when this melt run-off process was nearly complete, creating an environment which encouraged salmon populations to drastically increase (Dyke 2006). These erosional and depositional processes are important to the current study as the associated linear landforms and terraces are used as indicators of human land use in the modern environment (e.g., Hiller and Smith 2008:2266).

The end of the Hypsithermal interval coincided with a massive fall of tephra (volcanic ash) from the catastrophic eruption of Mount Mazama (now Crater Lake, in

Oregon) around 6,900 BP, an event which is often used to date stratigraphy in the Southern Interior region (Zdanowicz et al. 1999).

1.6.3. Ethnographic Setting

The study area is within the traditional territory of two different Indigenous groups: the Nlaka’pamux and the Secwepemc (Shuswap). The Nlaka’pamux are speakers of the Thompson language which is part of the Interior Salish division of the Salish Language Family (Bouchard 1973a). The Secwepemc are speakers of the Shuswap language, the northernmost of the Interior Salishan languages (Bouchard 1973b).

The Nlaka’pamux Nation Tribal Council represents six member nations (Boothroyd, Lytton, Boston Bar, Skuppah, Oregon Jack Creek and Spuzzum First Nations.) The HVC study area is also within the traditional territory of other Nlaka’pamux peoples, specifically the Nooaitch, Lower Nicola, Cook’s Ferry, Nicomen, Siska, Coldwater and Shackan First Nations as well as the Ashcroft First Nation which represents both Nlaka’pamux and Secwepemc peoples. Finally, the study area is within the consultative area of Qwelminte Secwepemc, Skeetchestn and Tk'emlups te Secwepemc.

A traditional semi-nomadic seasonal round of activities, which included hunting, fishing and plant collecting for subsistence, would have characterized the traditional precontact Nlaka’pamux economy (Bouchard and Kennedy 1979). As temperatures cooled in the fall, Indigenous communities moved into more permanent winter villages where stored foods would sustain them through the cold winter months (Bouchard and Kennedy 1979). These winter villages consisted of collections of semi-subterranean pithouses and associated cache pits for stored supplies (Alexander 1992a). Cache pits were an important mechanism used by semi-nomadic populations to modify the landscape they inhabited to protect their population from resource scarcity (Howe et al. 2016:1). Pithouse excavations and cache pits would infill with sediment after abandonment, leaving sub-rectangular to circular depressions. Clusters of pithouses were often located near main waterways or fishing stations (Alexander 1992a, 1992b, 2000).

Nlaka'pamux people resided in temporary pole and tule mat structures called matlodges in warmer seasons when seasonal resource procurement activities required regular movement across the landscape. Matlodges would usually have been built along lakeshores, on the banks of rivers, or associated with seasonal resource procurement camps (Alexander 2000). Other constructed features used by Nlaka'pamux and Shuswap peoples that leave archaeological evidence include hearths, storage pits, food roasting ovens and berry drying pits (Bouchard and Kennedy 1979). Resource procurement activities in the summer months included fishing on lakes and rivers, root and berry collecting, and ungulate hunting in highland meadow lands (Alexander 1992a, 1992b).

Nlaka'pamux material culture consisted of chipped and ground tools produced from bone, antler and stone (Stryd and Rousseau 1996). The bow and arrow was the primary hunting weapon in the late pre-contact period; replacing the earlier technology of spears or shorter darts hurled with an atlatl (Arcas 1988). Additional ethnographic and historic descriptions of the Nlaka'pamux and Shuswap culture, language and resource procurement activities can be found in Alexander (1992a, 1992b, 2000), Bouchard and Kennedy (1979), Bouchard (1973a, 1973b), Teit (1909), Kuijt and Prentiss (2004), Lepofsky and Peacock (2004) and Turner (1978, 1979).

1.6.4. Historic Setting

Gold was discovered in the Fraser River region in 1859 which attracted a variety of European settlers and entrepreneurs (Edwards 1978). The Fraser and Cariboo gold rushes ended in approximately 1863, giving way to other industries in the Southern Interior and Thompson Plateau regions, including ranching, mining and forestry (Harris 1977; Wynton 2009). The Highland Valley was not included in lands set aside for Nlaka'pamux peoples during the colonial period when Indigenous communities were marginalized and prevented from accessing their traditional subsistence areas as property was sold to European settlers. In ethnographic literature, Highland Valley is first mentioned in 1889 when the Pukaist First Nation (Cook's Ferry Band) requested land in the area to support plant resource harvesting along the shores and wetlands of the great divide lake (Arcas 1985:17). Dawson (1895) mapped the Highland Valley originally and noted Indigenous trails along Pukaist Creek and Witches Brook. In the BC Ministry of Mines Annual Report from 1916, the mineral claims in the Highland Valley area are discussed and the Chataway Ranch is mapped between Quiltanton and Big Divide Lake. Cawker (1978) contends that historic ranching and cattle grazing has affected the modern abundance of sagebrush at the expense of native grasses and trees. Land clearing for farming would have had an adverse impact on surface and subsurface archaeological sites and deposits.

1.6.5. Highland Valley Copper Mine

The HVC area of operation measures 30,347.2 ha, predominately provincial Crown land but with some private parcels as well (Figure 1). Initial development of mining in the area began with the Bethlehem Mine Corporation opening the East Jersey and Jersey pits between 1951 and 1979. In 1981 Cominco, which owned the Valley Copper deposit, purchased the Jersey Pits and consolidated operations. Mining ended in the Jersey Pits in 1983 and mining of the Valley Copper pits began. Cominco joined with the Lornex Mining Corporation to form the Highland Valley Copper Mine joint venture in 1986 (Valley Copper 1979; MPS, DMMR 1983). Because the ore deposit was below the valley bottom, rather than the side-valleys or ridges as in other nearby mine sites, it required the draining of the Quiltanton, Big Divide and Twenty-Four Mile Lakes (Valley Copper 1979). Two of four First Nation reserves located within Highland Valle, Cooks Ferry IR#13 and Chilthneaux IR#12, were expropriated by Valley Copper in the early 1960s to facilitate future mine development (Duff 1964).

Early smaller-scale mining claims within the study area in the late-1800s would have created significant surface and subsurface impacts in the valley bottom (BCMOM 1916). HVC mining development activities which may impact archaeological resources include tree falling, levelling and grading, inundation from tailings pond accumulation, reservoir spillway and dam installation and upgrading excavations, quarries, borrow pits and aggregate extraction, dumping waste rock overburden, and installation of utilities and structures.

1.6.6. Regional Cultural Chronology

Although minimal investigation for prehistoric archaeological sites had been conducted within the Highland Valley prior to the 1981 survey by Brolly, there was extensive research in the nearby Thompson and Nicola River valleys (Sanger 1970;

Chatters and Pokotylo 1998; Fladmark 1982). As well, the Plateau peoples of the Pacific Northwest have been extensively studied and specific cultural correlates are used to define prehistoric periods of occupation from the end of the last glacial period 12,000 BP to European contact (Richards and Rousseau 1987; Chatters and Pokotylo 1998). Previous archaeological research regarding site distribution, site type and the development of a cultural chronological sequence has added greatly to the current understanding of Indigenous history in the region (see Bussey 1995; Cybulski et al. 1981; Fladmark 1982; Magne and Matson 2008; Pokotylo and Mitchell 1998; Prentiss and Kuijt 2004; Richards and Rousseau 1987; Rousseau 2004; Stryd and Rousseau 1996; Wright 1995a, 1995b, 1999). This chronology is briefly reviewed.

Early Prehistoric Period (12,000 - 7,000 BP)

Indigenous people initially moved into the Thompson Plateau region of BC around 11,000 years BP after deglaciation had opened the landscape and allowed for suitable plant and animal species capable of sustaining human populations to propagate (Rousseau 2004; Stryd and Rousseau 1996). The initial wet, cool climate after deglaciation was replaced by warmer and drier weather during the Hypsithermal. This transition would have greatly affected the hunting and foraging strategies of early people (Hebda 1995). Stryd and Rousseau (1996) contend that these specific environmental factors contributed to an optimal climate that would have encouraged new technologies to develop in association with shifting hunting practices. In the project area, the earliest manifestations of this occupation may have been associated with mid-elevation grasslands, away from the glacial lakes that filled the valley. These glacial lakes drained around 8,900 BP, but their basins would have remained significant sources of potable water during the dry period (Johnsen 2004).

There are only a few examples of archaeological sites yielding radiocarbon dates earlier than about 7,000 BP in the Interior Plateau. These include two temporary hunting camps with lithic scatters near Spences Bridge (7,530 years BP) and Ashcroft (8,240 years BP) and the Gore Creek burial near Chase dated to 8,240 years BP (Cybulski et al. 1981, Rousseau 2004; Rousseau et al. 1991). There is also a temporary occupation camp at Stirling Creek in the Similkameen River valley southeast of Hedley dated to 7,400 BP (Copp 2006). More recently, a site has been identified at HVC with a cultural deposit dated to 9100 years BP.

Middle Prehistoric Period (7,000 - 3,500 BP)

The Middle Prehistoric period in the Southern Interior is thought to coincide with the end of the Hypsithermal period when the climate returned to a cooler, more temperate state (Hebda 1995). The beginning of this period is correlated with the 6,900 BP ashfall from the catastrophic eruption of Mt. Mazama, which provides a stratigraphically distinct volcanic ash layer and temporal marker for the region (Zdanowicz et al. 1999). Hunting continued as a main subsistence activity during this period, but the importance of salmon and other freshwater resources became more prominent (Prentiss and Kuijt 2004).

The middle period is broken down further into three cultural traditions based on artifact type and site distribution. The Nesikep Tradition is the earliest cultural phase being further divided into Early Nesikep Phase (7,000 to 6,000 BP) and Lehman Phase (6,000 to 4,500 BP) (Stryd and Rousseau 1996). Both phases are characterized by low population density and small nomadic foraging camps. The lithic assemblage from the Early Nesikep phase has a high concentration of oval-shaped scrapers and lanceolate, shoulder-notched and corner-notched bifaces (Stryd and Rousseau 1996). The Lehman phase saw the introduction of microblade technology, moderately increased population density and an abundance of leaf-shaped dacite knives (Stryd and Rousseau 1996). Once thought to be restricted to the Fraser-Thompson drainage (Stryd and Rousseau 1996), characteristic Nesikep Tradition artifacts are now reported for the Similkameen River valley (Copp 2006) as well as the Central Interior Plateau (Magne and Matson 2008). Nesikep Phase sites have been identified in association with high-elevation benches and terraces in settings like the Highland Valley (Arcas Associates 1986).

The Lochnore Tradition appears in the Fraser-Thompson drainage between 5,500 BP and 3,500 BP (Prentiss and Kuijt 2004; Stryd and Rousseau 1996). This tradition is associated with the exploitation of stable salmon populations in riverine environments (Stryd and Rousseau 1996). As a result, the artifact assemblages include technology focused on fishing activities which dominate the larger lithic artifacts associated with terrestrial hunting.

Sites dated to the Lehman phase and Lochnore tradition have been identified in the Highland Valley (Arcas Associates 1983, 1986), Rattlesnake Hill (Arcas Associates 1985) and in Savona (Bussey 1995).

Late Prehistoric Period (3,500 - 200 BP)

Beginning 3,500 BP, the Canadian Plateau Pithouse Tradition is indicative of an increased population, more sedentary lifestyle and a stable economy characterized by a well-established seasonal round of subsistence procurement activities (Rousseau 2004). As with the Lehman tradition, salmon fishing along major rivers was the staple resource procurement activity and likely contributed to the collection of pithouses along major waterways as well as the increase in population (Prentiss and Kuijt 2004; Stryd and Rousseau 1996).

The Late Prehistoric period is divided into three cultural horizons based on artifact styles, technology utilized, landscape use and site distribution (Richards and Rousseau 1987; Rousseau 2004; Pokotylo and Mitchell 1998). The three horizons are the: (1) Shuswap Horizon (3,500 to 2,400 BP); (2) Plateau Horizon (2,400 to 1,200 BP); and (3) Kamloops Horizon (1,200 to 200 BP) (Stryd and Rousseau 1996). Because of the prolific nature of these cultural horizons and the increase in population, these sites are regularly identified through archaeological investigation throughout the Thompson Plateau region and the Highland Valley.

1.6.7. Previous Archaeological Research in Highland Valley

Preliminary archaeological research was conducted in the HVC study area by Kautz and Routley (1974) as part of an archaeological site survey conducted for the Archaeological Sites Advisory Board and the BC Ministry of Highways. This survey project was focused on identifying and recording archaeological sites as well as providing management recommendations for preserving archaeological resources in conflict with Provincial Highways. Since that initial assessment, archaeological research and survey in Highland Valley has been conducted in response to planned mine development and expansion activities. These early investigations focused primarily on lands in proximity to significant waterways and lake shores, while more recent development impact-based investigation has begun to identify sites on the rocky valley slopes and upland alpine settings (Golder 2016; ERM 2017). There has been no research-directed investigation of the archaeological record in the study area. However, early investigations by Arcas (1985, 1988) were used in combination with other sites to define the overarching regional chronology.

In 1980, contract negotiations between the BC government and the Highland mine proponent allowed development to proceed without input from the provincial Heritage Branch or First Nations regarding heritage management or mitigation (Brolly 1981:27). The government subsequently sponsored an inventory survey in 1981 focused primarily on the valley bottom zone. Twenty-one archaeological sites were recorded in association with the three lakes (Brolly 1981). The archaeological inventory recorded an additional 29 archaeological sites within the Highland Valley, consisting of surface and subsurface lithic scatters "usually located on the tops of ridges, on flat landforms, and along the creeks and lakes" (Arcas 1986:iv). A systematic data recovery program at 32 recorded archaeological sites was undertaken by Arcas (1982, 1986) on behalf of Cominco Ltd. to inform a mitigation strategy for future impacts from mine development. It was determined that cultural deposits were present to a maximum depth of 45 cm below surface and occasional archaeological features (i.e. hearths and matlodge post-holes) were also present in association with the artifact scatters (Arcas 1986:v). Analysis of seven radiocarbon samples collected during these studies placed the occupation period of the sites between 5,500 and 250 years BP (Arcas 1986:v).

Occupation dates for individual sites were assigned based on the seven radiocarbon measurements and temporally diagnostic stone tools. The latter are part of an assemblage of over 8,000 artifacts collected between the 1981 survey and 1986 mitigative investigations (Arcas 1981, 1986). The three lakes were drained in 1988 to facilitate the development of Valley Pit and the associated tailings facility (Arcas 1986). A machine operator recovered a preserved wooden atlatl from the Quiltanton Lake bottom from which a radiocarbon date of 2,000 +/- 100 years BP was acquired (Arcas 1988:2).

Further archaeological studies were conducted in the Highland Valley area by Altamira Consulting (2001) in relation to forestry resource management. A single lithic scatter site was identified during this study on a small bench above Pukaist Creek (Altamira 2001). The artifact assemblage included a Lochnore Phase projectile point dating site occupation to between 5,000 and 3,500 BP (Altamira 2001). The Nicola Tribal Association (NTA) conducted an archaeological study of a proposed dewatering facility at HVC in 2004 and identified a single lithic scatter site above Witches Brook and several heritage resource sites not protected under provincial legislation. These non-protected sites included traditional trails and post-1846 culturally modified trees (CMTs). NNTC involvement in archaeological assessment at HVC began in 2011 and they began directing the heritage management program in 2016; the research goals that form the foundation of this study subsequently were defined.

From 2007 to 2009 Arcas Associates conducted several archaeological studies for proposed facility construction and upgrades within HVC. Three new lithic scatter sites were recorded, two on the valley bottom and one along a northwest-southeast oriented ridge on the lower southern slope of the valley (Arcas 2007, 2008, AMEC 2010a, 2010b). Various archaeological studies were conducted by other consulting firms between 2010 and 2015 (Bonner and Cameron 2011; Ursus 2014; Golder 2016; ERM 2017). Since 2016 the NNTC has led the heritage program at HVC, leading to the identification and recording of more than 100 archaeological sites within the HVC operating area, including several low-density lithic scatter sites in the rocky highlands south of the valley (Figure 2).

Additional archaeological sites have been recorded in the upper Pukaist Creek Valley on small benches or disturbed relict landforms associated with gently elevated terrain within a disturbed meadow system (Ursus 2014). Several sites also have been identified in surficial contexts where past mining activities have impacted the landscape (Golder 2016). This suggests the need for post-impact assessment of previously disturbed areas and facilities. Temporally diagnostic artifact types documented throughout these studies have corroborated the occupation period of the valley to between 6,000 and 250 years BP, including an abundance of later period (3,500 to 200 years BP) sites. Continued survey into the present not only has identified new sites, but site revisits have expanded site boundaries at several with new finds in surface and subsurface contexts (Golder 2016).

From 2016 to 2019, 24 proposed development components were surveyed and/or tested within the HVC operating area, resulting in the identification of 132 new sites (personal comm M. Klassen March 2020). Many of the new sites are located on the slopes of Highland Valley or in high elevation upland settings, in areas that were not typically assessed in the past (Figures 2 and 3). Under provincial heritage investigation permit 2016-0277, another 10 sites were revisited, and three of these sites were expanded (EdRh-93, EdRh-97, EcRh-97). Reporting for the most recent provincial heritage investigation permits (2016-0277 and 2018-0191) is ongoing, and final results are not yet available (personal comm. M. Klassen March 2020).

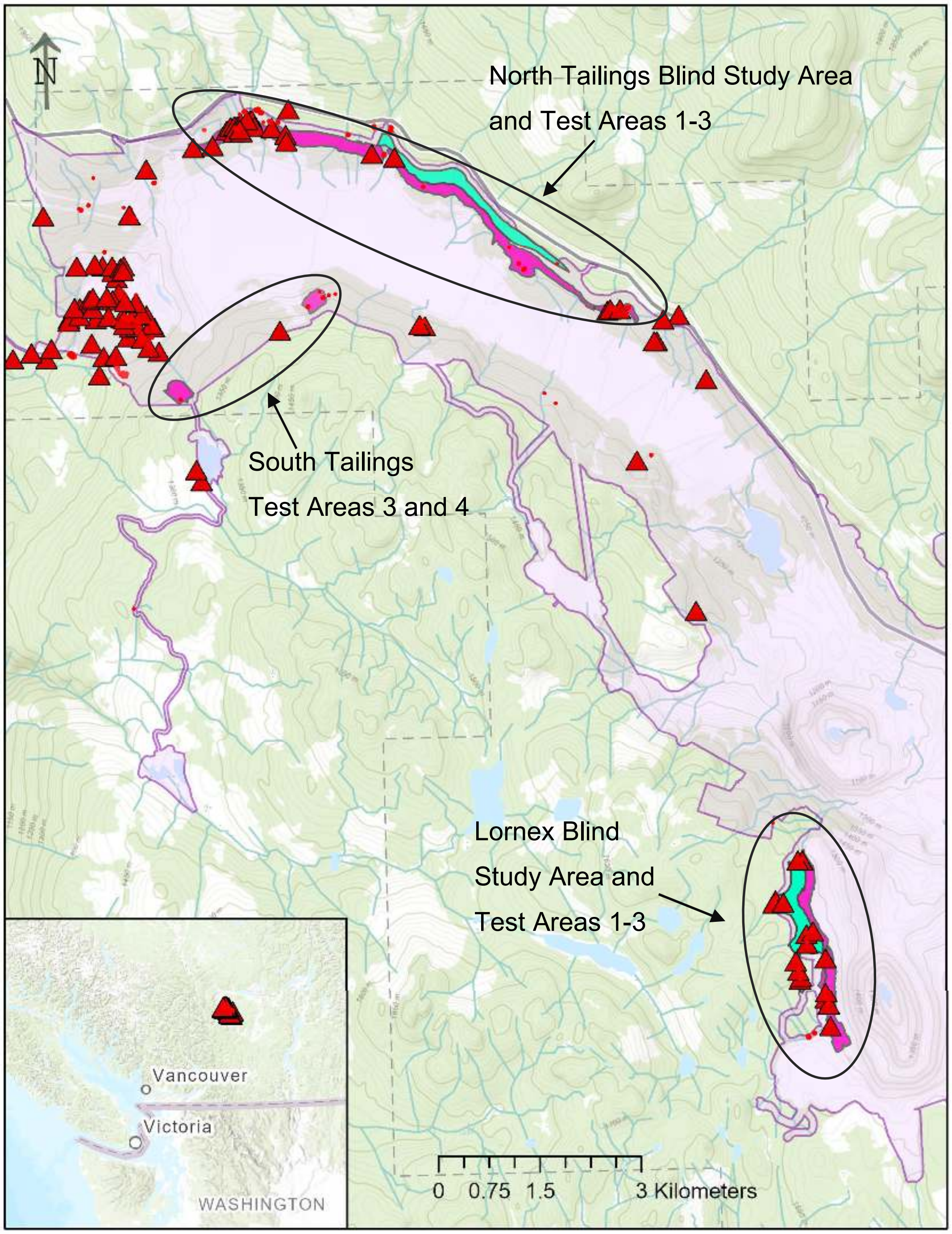

Figure 2. **Highland Valley Copper Mine operating area (purple), showing recorded archaeological sites (red triangles); study test areas (fuschia), blind study areas (blue)**

Data Sources: HVC permit boundary spatial data provided by NNTC, archaeological site spatial data acquired from RAAD and NNTC, Arc GIS Basemap (NRCan, Esri Canada, and Canadian Maps contributors., Esri Canada)

Figure 3. **View northeast to northern extent of the Lornex blind study area showing moderate to steep terrain in foreground and access road in background**

Photo credit: A.E.W.LP field photograph July 4, 2018

Since 2016, several heritage management projects have been undertaken at HVC with additional sites being recorded each year. The data sets provided by NNTC for this study, thus, are substantial and represent all recorded archaeological sites, AOIs and STAs within HVC as of March 31, 2020. It is therefore anticipated that by the time this study is complete the total number of recorded archaeological sites, AOIs and STAs will have increased, particularly in portions of the study area that were only subject to field survey but where systematic subsurface testing had not been completed. This provides an opportunity to continue evaluating the results of my analysis against the most recent heritage program data.

1.6.8. Recorded Archaeological Sites within the Study Area

At the time this study was started in March 2020, a total of 147 archaeological sites had been recorded within the HVC operating area (Table 1; Figure 2). The majority of these sites are comprised of lithic artifact scatters in surface exposures or with a subsurface component. A single petroform site is recorded, consisting of a cairn comprised of stones placed in a small tower shape, one traditional trail is registered, and several provisional sites are identified. The latter have yet to be submitted to the

Provincial Heritage Register. A single CMT site is recorded within the study area although additional CMT sites have been identified outside of the HVC operating area along creeks and travel corridors (Ursus 2014).

Table 1. Recorded Archaeological Sites within the HVC Operating Area by Type

Site Type	Attributes	Quantity
Lithic scatter	Surface	51
Lithic scatter	Subsurface	41
Lithic scatter	Surface and Subsurface	17
Lithic scatter, CMT	Subsurface	1
Lithic scatter	Undefined	6
Lithic scatter; Trail	Surface and Subsurface	1
Lithic scatter	Provisional Site	29
Petroform	Cairn	1
	Total	**147**

For the purpose of this study only recorded archaeological sites which occur within the spatial limits of the available LiDAR digital elevation model and which are comprised of surface or subsurface lithic scatters were included in the dataset. As a result of data trimming, discussed further in Section 3.2.2, a total of 115 recorded archaeological sites were examined using the ‘zonal statistics’ and ‘spatial analyst’ tools in ArcGIS.

Of the 115 archaeological sites spatially analyzed, the majority (n=48) are less than 100 m^2 and another 40 sites under 1000 m^2. Sixteen sites measure between 1000 and 5000 m^2 and the remaining eleven sites range between 5,500 and 27,000 m^2. This distribution obviously favours small, microtopographic relief on the landscape, where small lithic scatter sites are often observed in surface exposures or in shallow subsurface context (Figure 4). Using the zonal statistics’ geoprocessing tool the mean and range slope for each recorded archaeological site polygon was identified. The mean slope within the recorded archaeological sites dataset is 10° with a range of 10° and standard deviation of 2.76.

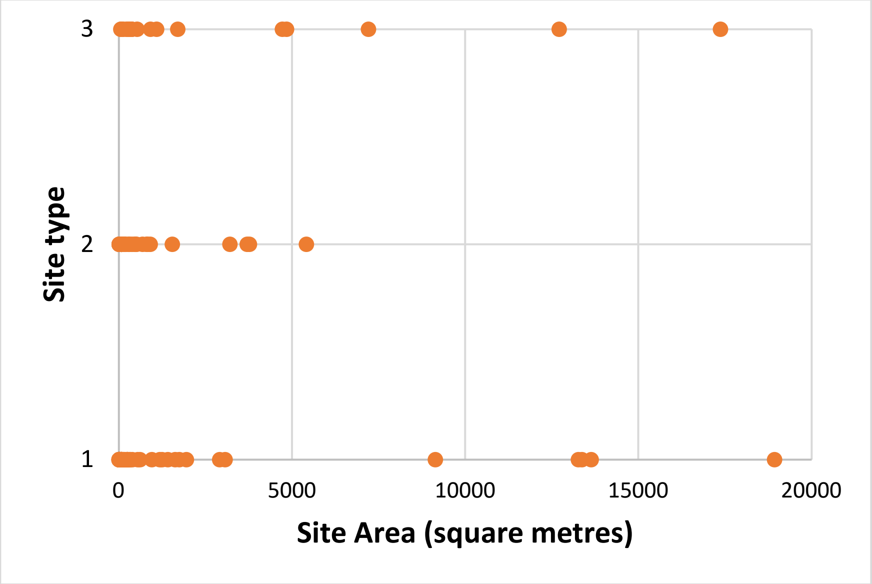

Figure 4. **Recorded archaeological site size by type: 1) surface lithic scatter; 2) subsurface lithic scatter; and 3) surface and subsurface lithic scatter**

1.6.9. Subsurface Test Area Dataset Slope Analysis

A subsurface test area slope percentage analysis was conducted by Golder (2016:56), which assessed the slope characteristics of STAs by comparing "the difference in slope between the dominant part of the landform and its surrounding terrain." This assessment required a comparison of slope degrees within the STA and that of the surrounding terrain by reviewing site maps, which was not possible during this study as the latter data were not available. However, identifying the mean slope degrees within STAs and recorded sites does provide information regarding landscape characteristics most likely to be identified in-field as indicating archaeological potential and which attributes are present where sites are identified. Further studies at HVC could use automated kernel analysis of the LiDAR elevation data to conduct a larger-scale target feature slope analysis and identify if this method is effective in predicting the presence of archaeological resources.

A total of 554 STAs were analyzed using the 'zonal statistics' geoprocessing tool in ArcGIS to identify the distribution of total area and mean and range of slope within the data set. The subsurface test areas ranged in size from 11 to 4,742 m^2, displayed as a histogram in Figure 5. Approximately 60% of STAs measured 11 to 500 m^2 with the most frequent size in that range (11%) between 100 and 150 m^2. STAs measuring between

500 and 1000 m^2 were the next most frequent at 21% and the remaining 19% of STAs were distributed generally evenly to the largest subsurface test area. The mean slope within the STAs is 9° with a range of 21° and standard deviation of 3.11.

The minimum slope within STAs was 1° and the highest was 64°. Slope analysis is pertinent to manual feature extraction as the selected AOIs can be overlaid with a slope characterization model and trimmed to remove terrain outside of the typical range. Further, if a potential model was developed in the future for implementation during the heritage management program at HVC the slope degrees (mean and range) will be input variables for digital visualization of archaeological potential.

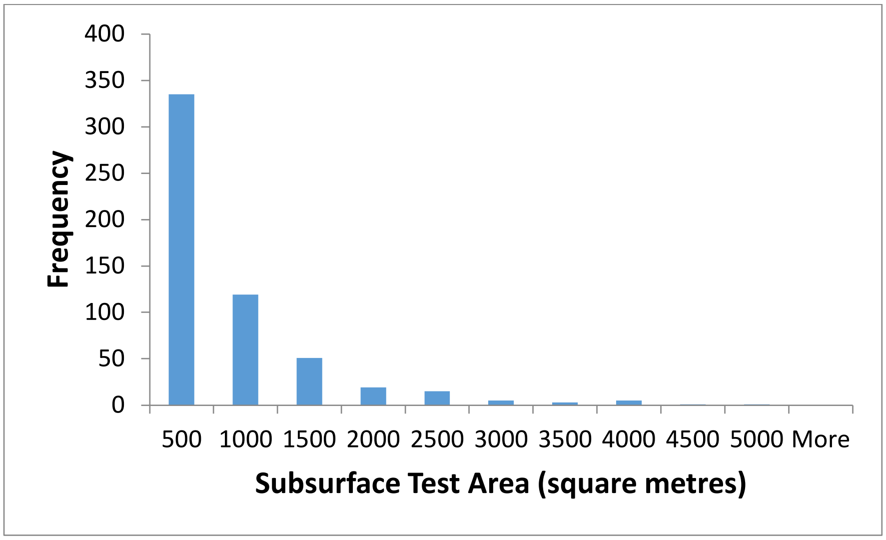

Figure 5. **Histogram showing area (m^2) frequency of subsurface test areas within HVC**

1.6.10. Heritage Protection Standards in British Columbia

In British Columbia archaeological sites determined or suspected of being from before 1846 are automatically protected under the *Heritage Conservation Act (HCA)* (HCAA 2019). Heritage prospection and protection is regulated by the Archaeology Branch of the Ministry of Forests, Lands, Natural Resource Operations and Rural Development. The Archaeology Branch has identified requirements for conducting archaeological overview assessments (AOA) to determine the archaeological potential of a landscape as well as impact assessments (AIAs) to identify archaeological sites within a proposed development area. These requirements are presented in the *British Columbia Archaeological Impact Assessment Guidelines* (Archaeology Branch 1998).

Specific regulations and standards for remote sensing and archaeological potential mapping are presented in the *Archaeological Overview Assessments as General Land Use Planning Tools - Provincial Standards and Guidelines* (Archaeology Branch 2009).

Any remote sensing method for identifying archaeological potential must minimally meet the criteria laid out in these standards and guidelines. Specifically, thresholds for assessing predictive model and AOA mapping effectiveness are presented. “AOA models must capture at least 70% of known archaeological site locations within areas of archaeological potential to be accepted by the Province” (Archaeology Branch 2009:2). In study areas that are less than 10,000 ha, overview assessments are conducted using traditional survey incorporating background research into the nature and distribution of sites, local knowledge regarding Indigenous landuse, geomorphological information and professional judgment. For large areas predictive models are often used which incorporate GIS-assisted analysis of recorded archaeological site criteria and location data to define and map terrain with attributes indicative of archaeological potential. The AOA standards (Archaeology Branch 2009:5) identify two levels of predictive models:

1) high efficiency models: capture 70% or greater of recorded archaeological sites in 10% of the terrain

2) moderate efficiency: capture 70% of known sites in 10-20% of study area terrain.

Kvamme’s gain is a statistical way to measure how much a predictive model differs from random distribution (Kvamme 1988). To meet regulator requirements the results of a predictive model must have a Kvamme gain of 0.90 for a high efficiency model or at least 0.80 for a moderately efficient model. Although it is not the purpose of this study to create a true potential model, this Provincial requirements and standards for remote sensing for archaeological prospection can be used to assess the effectiveness of the methods employed. Finally, in an effort to continually improve predictive modelling methods, it is expected that AOA reports include recommendations for improving efficiency (Archaeology Branch 2009:6).

1.6.11. Research Context Discussion

Significant environmental changes have taken place in the Interior Plateau, including the Thompson Plateau Region in the past 12,000 years BP (Ryder 1979). Changing environments and weather would have affected the availability of wild game, fish, edible plant and other resources essential in the daily lives of Indigenous peoples. Although the natural environmental setting of Highland Valley would have encouraged Indigenous exploitation of game (i.e., ungulates and waterfowl), the rugged, high elevation terrain would not have been ideal for year-round intensive occupancy. As such identified habitation sites likely represent seasonal occupation areas associated with the round of semi-nomadic resource procurement by Indigenous peoples.

A great deal of compliance-driven archaeological assessment has been conducted within the Highland Valley Copper Mine, resulting in the identification of almost 150 archaeological sites ranging in age of occupation from 9,100 to 250 years BP. The bracketing dates are inferred from three sites with temporally diagnostic projectile points ranging from 5,500 to 2,000 years BP and more recent land use information from ethnographic accounts, historic settlements and a cemetery. Additionally, one site (EdRh-105) has an early radiocarbon date of 9100 +/- 30 years BP and the cultural occupation deposit occurs below the Mazama Ash layer dated to 6900 years BP (Richards and Rousseau 1987).

The various cultural heritage management assessments in the project area have created a large volume of georeferenced spatial data associated with microtopographic landform selection for AOIs and ground-truthing volumes as well as results associated with STAs. These data were used during this study to compare with the results of LiDAR-derived image analysis to determine the effectiveness of this innovative technology as a prospection tool for use in HVC.

Archaeological sites occur in various environmental settings, most often in association with past waterways and lakes, on benches overlooking creek or ephemeral and relict drainage channels (Altamira 2011; Arcas 1982, 1986, 1988, 2007, 2008; AMEC 2010a, 2010b; Bonner and Cameron 2011; Brolly 1981; Golder 2016; ERM 2017; NTA 2004; Ursus 2014). The most common site types identified within the study area are surface and subsurface lithic artifact scatters although archaeological features including a matlodge depression, hearth and cache pits are identified at a few (ERM 2017). The majority of recorded sites are on landforms elevated above surrounding terrain, measuring less than 500 m^2, with a mean slope of 9-10° and a range of 10-21°. The preliminary analysis and characterization of the digital dataset facilitated a structured LiDAR-analysis of test areas and comparison of results with existing data.

It is worth noting that recent field results have identified archaeological lithic scatter sites in eroded slopes below the dominant portion of microtopographic landforms (personal comm M. Klassen March 2020). Further, archaeological sites have recently been recorded in swales between microtopographic areas, where the change in aspect would have provided shelter from the wind and view of game in the elevated alpine environment (Kim Christensen, personal communication 2020). These site locations would be difficult to identify using LiDAR-analysis methods as they are external to the standard microtopographic landform criteria usually used to prospect for archaeological sites at HVC. Apart from the recorded archaeological sites within the study area, NNTC maintains a confidential registry of information pertaining to traditional knowledge-based activities within the area. This includes site locations identified by ethnographic and historic accounts of landuse as well as intangible aspects of the cultural landscape such as place names and associated oral traditions. This deep connection to place is acknowledged and was respected throughout the course of this research.

Chapter 2. LiDAR Research for Archaeological Prospection

The use of LiDAR imagery as a tool for archaeological prospection is not new, having been employed by researchers for the last 20 years. However, as with any technological advancement, there is constant innovation in the application of LiDAR and current researchers suggest that data visualization techniques and drone-assisted LiDAR data collection for archaeological survey remain in the early stages of development (Risbøl and Gustavsen 2018; Opitz and Cowley 2013). It is an interesting time for technological innovation in archaeological research as upgrades and new software plug-ins are becoming available at an unparalleled pace and the application options are extensive (Boardman and Bryan 2018). Testing various software offerings and interpolation techniques is essential to identifying the most appropriate research methods and to understand the quality of any results produced (Kokalj and Hesse 2017:45).

Digital elevation data such as LiDAR-derived raster data, has been used to develop archaeological potential models in other regions in BC (Millennia 2006; Arcas and Millennia 2010). LiDAR-derived digital elevation models (DEMs), displayed in shaded-relief format, are sometimes used in the HRM industry as a tool for assessing the archaeological potential of proposed development areas. In HRM there is usually minimal budget available for exploring new software options and, as a result, existing and often out-dated methods for data visualization and interpretation are maintained. However, with the proliferation of opensource software and LiDAR data, it is worthwhile testing alternative methods to identify new efficiencies for archaeological prospection in BC (Carter 2019). The availability of existing 50 cm-resolution LiDAR data for the entire study area provides an excellent opportunity to examine the effectiveness of different data visualization using the manual feature extraction target identification technique.

Apart from understanding how LiDAR data is collected and processed, it is important to understand what visualization techniques will work best for the unique terrain within the area under study as well as the attributes of the target features (Kokalj and Hesse 2017; Mayoral et al. 2017). Hesse (2012) assessed the effectiveness of different LiDAR DEM visualization techniques in varying terrain and with a variety of target feature attributes. Primary terrain characteristics that impact visualization methods include the presence of steeply sloping microtopography contrasted with low-profile settings (Hesse 2012; Kokalj and Hesse 2017:34). High-relief features and landscapes tend to mask the visibility of more subtle features. This can be corrected slightly during visualization with colour ramps selected to enhance contrast as well as through local-relief modelling, which subtracts the macro-environmental ‘noise’ allowing more subtle landscape attributes to appear (Hesse 2010:285). The contrast in elevation, either positive or negative, between the target feature and surrounding terrain also has a significant impact on detection success. This is particularly important when prospecting for anthropogenic features such as deep circular pits and angled walls (Hesse 2010). The selection of specific visualization techniques for this study is discussed further in Chapter 3.

To frame this work within the field of HRM in British Columbia specifically I queried the Provincial Archaeological Report Library (PARL) for grey literature and consultant reports that utilize or make reference to LiDAR data. This task was aimed at identifying trends in the use of LiDAR data in HRM in over the past two decades. Comparing the results from this study with that of past studies locally, regionally and internationally provides a framework in which process accuracy can be validated and contextualized.

2.1. LiDAR & Orthophotograph Imagery

LiDAR, also called airborne laser scanning (ALS), is acquired when an aircraft surveys an area, emitting near-infrared laser pulses toward the ground surface, and measuring the time and intensity of the returning light using a specialized receiver (Glennie et al. 2013; Wehr and Lohr 1999). The LiDAR survey records the distance from the laser-source to different ground surfaces (i.e., bare-earth, vegetation, buildings, structures) based on measuring the reflectance and return of laser pulses (Wehr and Lohr 1999). All data points are georeferenced using an integrated geographic position system (GPS) which assigns an ‘x and y’ spatial position, as well as a ‘z’ elevation orientation to each measurement point. In the case of the study area, spatial coordinates relate to the NAD 1983 CRS UTM Zone 10N.

Each returning laser pulse is measured for amplitude. Full-waveform ALS categorizes each return as a portion of the pulse which bounces back when passing through upper canopy vegetation (first return) and ground vegetation (second return) before reaching the bare-earth (Crow et al. 2007; Doneus et al. 2008; Figure 6). The benefit of using full-waveform ALS is that multiple laser returns of varying intensities can provide additional ground points, even in dense vegetation, to facilitate the visualization of a more accurate bare-earth morphology during processing (Coluzzi et al. 2010).

At the conclusion of a LiDAR survey a data point cloud is created which requires filtering and processing to determine which data points represent different types of surface returns (Figure 6). As a result of point filtering, a bare-earth representation of the terrain can be developed, eliminating all vegetation and structures so that topographic attributes can be viewed and analyzed (Horňák and Zachar 2017).

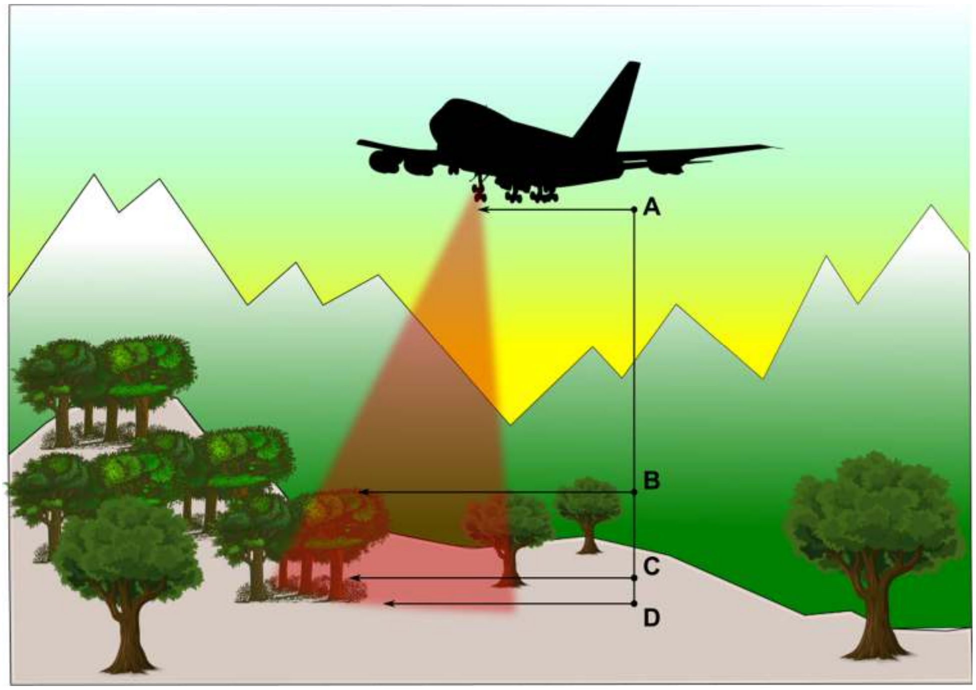

Figure 6. **Image depicting a LiDAR data collection flight: A) oscillating receiver measurement device collecting data on distance, geospatial location, time and amplitude of laser pulse return; B) first return; C) second return; and D) bare-earth final return**

The data collected using LiDAR is converted to imagery files. These contain recorded positional data that can be processed, filtered and viewed in a geographic information system (GIS), such as GRASS GIS or ArcGIS. This creates a relational database to store and analyze information from different sources (Koch and Mather 2011:326). Challis and others (2011:281) present a list of different software options and their corresponding analysis functions, which assists in the selection of the most appropriate for specific study parameters.

When converting the point cloud to a DEM, a triangular irregular network is often used to make contiguous triangles with the three closest points (Carter 2019:436). A DEM surface is a grid of pixels of a defined size (usually 0.5 m minimum to maintain resolution) with each assigned a ‘z value’ for the data points that fall within it (Opitz 2013:24). In low-resolution DEMs there are gaps between data points and the processing algorithm must assign elevation based on the closest pixel, causing loss of topographic definition. The parameters of the target feature’s resolution can have a significant impact on detection success.

LiDAR survey can be a very effective means of visualizing the ground surface in remote, difficult to reach areas, particularly forested environments where microtopographic landforms or anthropogenic features may be obscured by dense vegetation (Krasinski et al. 2016; Risbøl and Gustavsen 2018). LiDAR survey takes advantage of the preservative effect that forest cover can have on archaeological remains (Schindling and Gibbes 2014). However, depending on the type and density of vegetation within a survey area, the resulting LiDAR-derived DEM may be of varying quality. As shown by Crow and others (2007:245) a rapid survey of the vegetation of a study area can allow for a density score to be attributed to the terrain, which will inform the LiDAR penetration success and the resulting quality and accuracy of any DEMs created from the filtered ground points.

HVC forest cover, where present, consists of moderately dense to sparse coverage with a sparse shrub understory vegetation. For the most part, the forest cover in the study area is moderately well-spaced alpine conifer. The ideal time for LiDAR collection is weather dependent with minimal cloud cover and snow-free ground conditions. The vegetation and canopy score for HVC is assessed as medium to good, which allows for a 41 to 80% penetration range during LiDAR survey (Crow et al. 2007:245).

It is important to understand how the canopy density in a particular study area will impact the LiDAR penetration during survey so that appropriate laser pulses per metre squared (ppm^2) can be applied to gain sufficient point cloud data to achieve the imagery quality required for target feature identification. Various researchers (Bennett et al. 2012, Risbøl et al. 2013, Doneus and Kühteiber 2013) have identified the optimal laser ppm^2 to derive the best resolution data for various archaeological studies. It has been shown (Bennett et al. 2012) that when increasing from 1 ppm^2 to 5 ppm^2 there is an increase in accuracy of feature detection. However, increases in point density beyond 5 ppm^2 have had a negligible effect on results (Risbøl et al. 2013).

In the HRM industry in BC it is unlikely that ALS survey will be conducted under the direction of an archaeological researcher and be tailored to capture data for archaeological prospection. Often the HRM archaeologist is provided previously captured data by a developer or government entity, as with this study. Golden and others (2016) identify methods for utilizing and reanalyzing DEMs created for environmental studies for archaeological site survey. When archaeological site selection criteria are included in the LiDAR data collection and sampling strategy the results can favour known site locations, orientations and anthropogenic attributes and miss new finds (Golden et al. 2016:295). This type of bias is excluded from LiDAR data sets collected by other industries, which may lead to unexpected positive results during LiDAR-assisted archaeological prospection projects.

One of the defining features of LiDAR data is that it “records landscape in an indiscriminate way, every place, every feature, every trace, and every square metre is in principle treated with the same attention and resolution” (Mlekuž 2013:119). For this reason, LiDAR-derived DEMs are referred to as the ultimate representation of the ‘palimpsestic’ nature of complex cultural landscapes (Henry et al. 2019). Palimpsest in this case refers to how a landscape is used by past people and altered by the environment over long periods of time, but where anthropogenic traces remain (Mlekuž 2013:122). The study area is an excellent example of this concept, as there is an active mine tailings pond present, creating islands and beaches where previously there were only alpine glacio-fluvial terraces.

2.2. Formative and Current LiDAR Research

The majority of LiDAR-assisted archaeological studies have taken place in Europe, including in the United Kingdom (Opitz and Cowley 2013; Cowley et al. 2020), Scandinavia (Risbøl et al. 2020), Austria (Doneus et al. 2008), Germany (Schneider et al. 2015), the Mediterranean (Coluzzi et al. 2010; Grammer et al. 2017), and Eastern Europe (Kokalj et al. 2011; Roman et al. 2015; Štular et al. 2012). LiDAR data are available for many European countries, either commercially or as opensource public data and as such is often used as an archaeological prospection tool in this region (Horňák et al. 2017; Risbøl et al. 2020). Terrain that is remote, inaccessible and has dense forest cover is ideal for the implementation of LiDAR as in Mesoamerica (Chase et al. 2011; Chase et al. 2012) where large, previously unmapped urban centres have been uncovered, and in Cambodia (Evans et al. 2014) where ancient urban areas are being studied.

LiDAR-analysis for archaeological survey and feature detection has been less prevalent in North America where Indigenous archaeological remains such as lithic sites have limited to no surficial expression. Several studies have prospected for earthworks in the southern United States (e.g., Henry et al. 2019) while LiDAR also has been used to document cultural depressions in forested environments in Alaska (Krasinski et al. 2016) and the Upper Great Lakes region (Howey et al. 2016; Gallagher and Josephs 2008). In historical archaeology of the eastern US (Harmon et al. 2006; Johnson and Ouimet 2014) LiDAR has been used to identify a range of more recent features.

Recent research projects (Zhang et al. 2016; Horňák and Zachar 2017) focus on the most effective ways to conduct post-collection processing of LiDAR 3D point cloud data. This is not relevant to this research, as the LiDAR data were provided after processing and point filtration had been completed by the GIS department at HVC. However, it is important to understand the nature of the data to make informed decisions about which visualization techniques to employ during analysis. Furthermore, future researchers may want to design a LiDAR collection and processing program that is tailored to the specific terrain and target features found in a study area. Data analysis criteria for archaeological site prospection is terrain specific and can use various raster data visualization techniques including: Standard Hillshade, Sky View Factor and Topographic Openness (Horňák and Zachar 2017). Identifying which of these sets of criteria is the most appropriate for terrain characteristic visualization at HVC was a major component this study.

With the advent of new techniques and uses for LiDAR imagery in archaeological research there is also a more cautious approach, which involves assessing methods in terms of accuracy, detection success, cost and practicality of implementation to verify research quality and results (Ainsworth et al. 2013, Risbøl and Gustavsen 2018, Harmon et al. 2006, Horňák and Zachar 2017; Parcak 2009). Kokalj and Hesse (2017) test different visualization techniques to quantify the imagery contrast optimized by each in a variety of topographies. Best practices are suggested for data processing and visualization based on terrain complexity, slope percentage, forest cover and target feature characteristics. The results of these studies were used to select methods for my analysis (Challis et al. 2011, Kokalj and Hesse 2017; Mayoral et al. 2017).

Current research using LiDAR as a tool for archaeological prospection often focuses on large areas to identify general patterns and distribution of anthropogenic features (Ainsworth et al. 2013; Bennett, et al. 2012; Chase et al. 2011; Chase et al. 2012; Freeland et al. 2016; Grammer et al. 2017; Wiseman and El-Baz 2007). LiDAR was originally developed for hydrological and geological survey and has been identified by archaeologists as an indispensable tool for surveying large, remote terrain to identify archaeological features and to conduct cultural landscape analysis to answer questions regarding ancient socio-political integration and catchment capacity and resource productivity (Martinez-del-Pozo et al. 2013). During their study in the Great Lakes region, Howey and colleagues (2016) identify a much higher number of cache pit features than previously recorded, even in areas where extensive field survey had occurred. These results indicate that researchers can “utilize tools like lidar to expand …. our interpretations of past social and economic developments among these relatively low-density, mobile societies” (Howey et al. 2016:9).

Chase and others (2017) use LiDAR to better understand the overall layout and activity centres of ancient urban centres as well as the relationship between those centres. Research in Hawaii have used LiDAR to map farm terracing and landuse practices over time to answer questions about population and settlement segmentation and intensification (Ladefoged et al. 2011). Additionally, LiDAR is utilized as a tool for conducting large-scale national inventories of heritage resources to facilitate management and protection and impact monitoring (Hesse 2013; Risbøl et al. 2015). This final application may be a useful method in BC for monitoring erosion of recorded archaeological sites along shorelines as well as impacts to known sites through unsanctioned development.

Automated feature extraction (AFE), which applies objective criteria or variables to landscape analysis such as elevation for feature identification over large areas, is increasing the efficiency of survey and analysis of imagery (Freeland et al. 2016; Howey et al. 2016; Cowley 2012:417). Several formative LiDAR research projects have used AFE to analyze high-resolution LiDAR imagery to identify anthropogenic objects or landscape alterations which meet specific criteria with varying success (Freeland et al. 2016; Krasinski et al. 2016; Howey et al. 2016; Trier and Pilo 2012; Wang et al. 2017). AFE has most effectively been used by archaeologists in Europe to identify archaeological sites which have above ground expressions such as stone walls, kilns, roads and enclosures (Chase et al. 2017; Horňák et al. 2017; Kokalj et al. 2011). Unlike these European studies, this research focuses on identifying natural landforms that have the potential to contain surface and subsurface archaeological materials, rather than anthropogenic landscape features. These natural relief landforms may be identifiable more effectively through imagery analysis methods employed in hydrological modelling or geomorphometry (Smith and Clark 2005). Additionally, not all anthropogenic target features are suitable for AFE, particularly features that are naturally occurring, as in this study, and those which are non-homogenous in their characteristics and/or have a negligible surface expression (Quintus et al. 2017).

Manual feature extraction is the process of manually delineating suspected anthropogenic target features or areas of interest using LiDAR-derived DEMs or aerial photographs (Quintus et al. 2017). Results of MFE are often subject to in-field ground-truthing to identify the effectiveness of the interpolation (Krasinski et al. 2016). Quintus and others (2017:357) found that 77% of confirmed target features were identified by at least one of the reviewers and that contrast between the feature and surrounding terrain was the main factor which led to successful identification during MFE review.

2.3. LiDAR Analysis for Archaeological Research in BC

LiDAR survey can cover immense areas in a matter of hours and provide bare-earth topographic models that “help researcher[s] to develop quantitative models explaining how terrain evolved to its present form, and how it will likely change over time” (Glennie et al. 2013:1). For this reason, LiDAR data have recently been used as a tool for paleoenvironmental research in the northwest coast region of BC, where sea-level change data has been contrasted with DEMs to locate Holocene aged sites on ancient beaches, elevated above the modern shoreline (Letham et al. 2018; Sanders 2009; Eamer et al. 2018). The accuracy of LiDAR derived elevation models has proven invaluable during these studies and has allowed for a previous gap in the archaeological record of occupation to be uncovered and recorded, adding to the understanding of land use by ancient peoples in the region (Letham et al. 2018:194).

LiDAR additionally has been used as a tool to create archaeological potential models in BC and Alberta (Millennia 2006; Woywitka and Froese 2018, Arcas and Millennia 2010) but manual feature extraction of microtopographic landforms with archaeological potential has not been systematically examined. In northern Alberta the use of LiDAR-derived potential modelling to plan archaeological surveys for development is standard practice and a more recent study by Woywitka and Froese (2018) attempts to use LiDAR DEMs to predict ‘a process-depositional model’ for deeply buried Holocene sites with positive results. An analysis of the efficacy of using a LiDAR-derived potential model to identify areas of high archaeological potential in northeast BC was conducted using 5 m-pixels to assign a potential rating of low to medium based on slope and landform criteria specific to the study area (Millennia 2006). Centroid points were calculated for each high potential pixel using ArcGIS and these points were input into a handheld GPS unit to ground truth the locations and confirm the potential assessment (Millennia 2006:8). The study concluded that the model identified 85% of previously recorded archaeological sites in 1% of the project area, and 95% of sites in 10% of the project area (Millennia 2006:32). Adjusting the potential criteria of the model resulted in the identification of 9% more land rated as having high potential but also the identified 5% more archaeological sites.

A follow-up study was conducted between 2007 and 2010 to create a predictive GIS model of the Peace Forest District. The model was intended to increase efficiency in heritage resource management without sacrificing the ability to protect and manage archaeological resources effectively (Arcas and Millennia 2010:iii). This model was based in the BC Terrain Resources Information Management (TRIM) maps available for the region, which incorporate geospatially referenced elevation points spaced 50 to 100 m (Arcas and Millennia 2010:iv). A custom macro language was used to analyze the elevation raster data and assign landform types based on specific criteria such as slope percentage and elevation relative to surrounding pixels (Arcas and Millennia 2010:iv). Efficacy of the TRIM-based model was assessed using Kvamme's gain statistics and analysis of the percentage of known sites captured. In terrain with high relief, the success rate was 80%. In lower areas with smaller-microtopographic landforms, however, the TRIM data did not have a high enough resolution for site capture (Arcas and Millennia 2010:v; Kvamme 1988:329).

The majority of contemporary researchers note that LiDAR-derived models should not be used in isolation but rather as a tool implemented as part of a multi-scale research program involving ground-truthing, extensive background research into site characteristics and geomorphology as well as other data sources such as orthophotos, historical aerial photographs and traditional use information (Arcas and Millennia 2010; Doneus and Kühteiber 2013; Hesse 2012; Koch and Mather 2011) Ainsworth and others (2013) confirm that LiDAR analysis methods should be employed collaboratively with a systematic ground-truthing program to gain full confidence in results. Freeland and others (2016:73) conclude that LiDAR analysis techniques "provide us with patterns, concentrations, and specific locations to target for more intensive field study." The output of LiDAR analysis can be a very useful tool for directing and supporting traditional survey, potentially saving time and resources by facilitating the most efficient access to project locations and in turn increasing program safety (Gallagher and Josephs 2008).

HRM companies in BC often use the ArcGIS 'BareEarth' layer to review proposed development footprints and identify the potential for extant paleochannels or microtopographic landforms indicative of past human activity (SRRMC 2017). Projects with large scale landscapes requiring survey in short time periods such as hydroelectric reservoir heritage management projects in BC, benefit greatly from the data collection capabilities of LiDAR survey (Tipi Mountain 2019). A search of the Provincial Archaeological Report Library using the keyword 'lidar' identified 95 reports that reference LiDAR data between 2005 and 2018, although more recent and current projects are yet to submit reports. Figure 7 shows the number of HRM permit reports that mention LiDAR by year, either as an employed method or as a recommendation for a future research strategy. The objective of this task was to identify the ways in which LiDAR data is being implemented in BC HRM and the popularity of this remote sensing method over the past two decades. Understanding the ways in which LiDAR is currently being utilized for archaeological potential assessment and prospection in BC is key to identifying ways in which innovative techniques and new methods can be employed to achieve the highest target detection success rate.

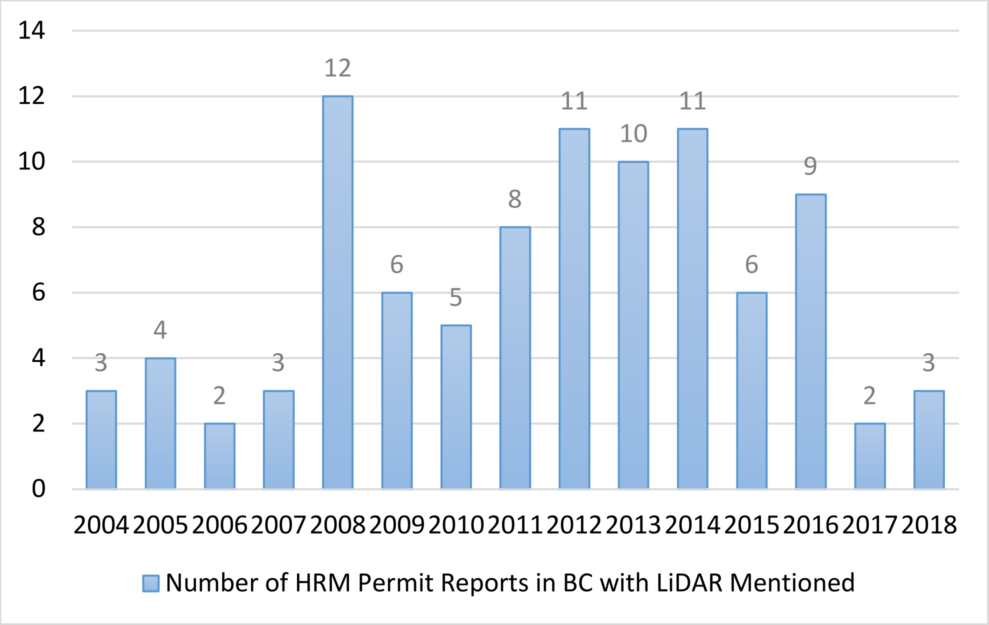

Figure 7. LiDAR mentioned in BC heritage resource management permit reports by year (PARL search results)

Chapter 3. Research Methods, Data Acquisition, and Interpretation

This study seeks to address NNTC-specific research goals by analyzing existing data sets using innovative technology and methods to enhance the effectiveness of site identification, recording, assessment, preservation, and mitigation. The overarching objective of this research is to contribute to improving heritage stewardship within HVC.

After identifying specific research goals and questions a research design was developed in partnership with NNTC to assess the efficacy of LiDAR-derived imagery analysis using MFE to identify target features within HVC. Eight test areas and two blind study areas were selected by NNTC to capture terrain where one or all phases of traditional archaeological prospection had been completed. Georeferenced spatial data representing all identified archaeological sites, AOIs and STAs within HVC operations area was provided at the commencement of this project, with the exception of target feature data associated with two blind study areas. These were withheld until the test area assessment workflow and process were developed, and two reviews of all test areas had been completed (Figure 2). A review of each blind study area was then conducted prior to receiving the target feature data from NNTC to avoid bias in the results. The NNTC subsequently provided the final spatial data for these locations for comparative analysis between traditional survey and LiDAR-derived AOI results.

The results of manual feature extraction using LiDAR data were compared with the NNTC-provided target feature data based on five factors:

- true positive (TP): target features (AOIs, STAs and recorded archaeological sites) identified by both methods
- false positives (FP): AOIs only identified by MFE
- missed target features (MTF): target features only identified by traditional survey
- intersection of area selected (m^2)
- binary result intersection: percentage of MFE AOIs that intersect with target features

The results were coded into the five categories allowing for a quantitative assessment of accuracy. The topographic attributes of the target feature categories were subject to review using ArcGIS software geoprocessing to identify objective criteria. At the conclusion of the methods comparison, an error matrix was reviewed to identify factors which contributed to false positives and missed target features. The purpose of this analysis and error review was to assess efficacy of the MFE process and identify ways in which it can be improved to increase target feature detection success.

3.1. Research Methods

3.1.1. Traditional Survey Methodology at HVC

For each season of field work, Teck provided the consultant archaeologist with a georeferenced map identifying areas where proposed project developments require archaeological assessment. The NNTC has a three-phase process to assess these areas for archaeological potential and clear areas where operational impacts are anticipated. The core objective of these assessments is to identify archaeological sites and areas of archaeological potential to facilitate avoidance of impacts through redesign of proposed developments, wherever practicable. Where avoidance of impacts to archaeological resources through redesign is not feasible, a secondary objective is to mitigate impacts from mining activities through the collection and recording of data and cultural artifacts.

Archaeological Potential Assessment

The natural and modern industrial impacts to the study area have significantly altered the general landscape integrity as well as site preservation and distribution within HVC. Understanding how factors such as geology, hydrology, paleoenvironmental conditions and landscape integrity may affect the archaeological record can aid in designing an effective archaeological inventory program. These key factors contribute to the archaeological context of the study area and influence the methods and outcome of archaeological site prospecting in relation to ongoing mining development activities.

Since archaeological site locations are often correlated with particular microtopographic attributes, the presence or absence of these variables is used during archaeological prospecting in BC to identify lands with greater or lesser archaeological potential. These variables include: i) modern vegetation/forest cover; ii) proximity to documented archaeological resources; iii) presence of traditional resources; iv) proximity to waterways; v) aspect; vi) paleoenvironmental data; vii) environmental setting of archaeological sites within the region/study area; and, viii) landscape integrity.

As an alternative method the current NNTC archaeology program eliminates all other AOI selection criteria other than:

- Landscape integrity
- Landform attributes
    - degree of slope (median and range)
    - difference of slope to that of surrounding terrain
    - elevation above surrounding terrain

Phase 1: Heritage Field Reconnaissance

The current survey program begins with an in-office assessment of the landscape including factors such as topography, geology, vegetation, slope and presence of ephemeral, relict or perennial waterways. Various sources of data are currently utilized by NNTC to plan archaeological surveys and identify areas of cultural concerns. The NNTC has undertaken ethnographic and historical research to produce extensive traditional land-use and occupancy mapping. This information is shared with HVC and archaeologists conducting the field program by the NNTC on an as-needed basis and according to confidentiality agreements. Archival maps dating from 1888 onwards are available from HVC and other sources, which provide information on trails and habitation locations.

With the information collected during the in-office landscape potential assessment, a crew comprised of one senior and two junior NNTC community field technicians conduct a pedestrian survey of the development component. The survey is not systematic but is intended to visit areas of cultural concern such as modern and extant waterways, traditional trails, spiritual/named places and/or resource procurement areas. Additionally, locations are georeferenced with a hand-held GPS unit to record points of interest from a heritage or archaeological perspective. These data are provided to the team of archaeologists at NNTC, who then plan the next stage of assessment based on the information from the field reconnaissance and in-office review.

Phase 2: AOI Field Survey

A field survey is the next stage of assessment and is conducted in accordance with the NNTC Survey Standards (NNTC 2018). The following methods are summarized from the standard and alternative methods presented in the *Heritage Conservation Act* Section 12.2 heritage inspection permit application. The permit application was submitted by A.E.W.LP to the Archaeology Branch for review in February 2020.The permit application and NNTC standards identify that survey will be conducted within 100% of a project component apart from areas that have been identified to have poor landscape integrity, low potential or waterlogged/inaccessible terrain during the field reconnaissance and in-office review phase.

A field crew is comprised of one field director level archaeologist, one A.E.W.LP assistant archaeologist or field supervisor and two field technicians, and up to three First Nation representatives from communities with traditional interest in the study area. Crew members are spaced at 10-15 m intervals and a pedestrian survey is conducted in parallel transects, where possible. In areas where Holocene and late Pleistocene sediment deposits have been removed or extensively disturbed by development, survey transect intervals may be increased up to 50 m. In areas lightly impacted by development activities such as road surfaces, where redeposited materials from adjacent landforms are present and/or surface visibility is improved from disturbance, spacing intervals may be decreased to 1.5 m to facilitate surface inspection. Disturbance and biophysical landscape attributes are recorded for the entire survey area and AOI points from the Phase 1 reconnaissance are revisited and assessed. Field survey covers up to 7 ha per day and involves recording any surface artifact scatters and other heritage sites (i.e., pre-1846 CMTs or trails) as well as AOI landforms requiring further investigation.

Based on landscape attributes such as elevation above surrounding terrain and presence of level terrain, AOIs are identified by the crew and mapped as polygons using hand-held GPS units. The digital record of AOIs collected during field survey is then utilized by the A.E.W.LP project manager to determine, with an appropriate level of confidence, an estimate of shovel tests required to ground-truth the locations.

Phase 3: Archaeological Inventory Field Testing Program

The ‘level of effort’ estimate identified for each development component is used by the proponent to cost out design options and locations for required mining operation activities. The ‘level of effort’ estimate is then applied to the Phase 3 planning process and field programs are budgeted based on completing subsurface tests on a 5 m-grid across all AOIs, with a minimum of 5 shovel tests per 100 m^2. As per Provincial standards, shovel tests minimally measure 0.123 m^2 (e.g., 35 cm a side shovel test) (Archaeology Branch 1998). Sediments are screened through 6 mm-mesh or smaller. Tests are excavated by shovel until culturally sterile sediments are confirmed. A visual inspection of subsurface test area landforms is conducted with crew members spaced 1-5 m apart to identify any surface artifacts. Subsurface tests are placed systematically on a grid, and judgmentally, based on in-field observations. A typical AOI being subject to subsurface testing by A.E.W.LP is shown in Figure 8. At the conclusion of Phase 3 testing, mitigative recommendations are provided to the proponent including avoidance through project redesign, systematic data recovery and/or construction monitoring.

Figure 8. View south of A.E.W.LP crew on an area of interest in a previously logged portion of the north tailings area of HVC. (15-Sept-2020).

3.1.2. Manual vs Automated Feature Extraction

There are various methods for identifying and recording features using LiDAR-derived imagery, the majority of which have been influenced by the field of photogrammetry and aerial photography analysis (Historic England 2018; Opitz and Cowley 2013). While each researcher needs to determine the most appropriate methods and techniques for their study area and target feature criteria, it is also essential to understand the limits of available data, software and expertise. Manual feature extraction involves a reviewer visually inspecting LiDAR imagery and manually delineating the extent of suspected target features based on observed landscape criteria. For this study, all LiDAR visualizations were viewed in ArcGIS Pro 10.1 using the workflow described in Section 3.1.3, and polygons were manually drawn around each suspected AOI.

A growing number of researchers are using automated geoprocessing algorithms to select target features based on a set of prescribed characteristics (Freeland et al 2016; Howey et al. 2016). The algorithms are comprised of a set of classifications or rules that are used to distinguish features or three-dimensional data points of interest from the rest of the DEM, or alternatively ‘template-match’ landforms to prescribed target feature alignments and attributes (Schneider et al. 2014; Trier and Pilo 2012). These techniques have been shown to have positive results in association with features that have an above ground expression such as burial mounds or remnants of structure foundations (Freeland et al 2016; Luo et al 2014; Trier and Pilo 2012). However, AFE results associated with cache pit features in North America has been less successful in densely forested terrain where target features can often be confused with natural landscape attributes or modern impacts and as such ground-truthing is necessary to refine the results (Krasinski et al 2016).

For this study, manual feature extraction was selected as the preferred technique as it is a simple process that could be executed on any potential development component in a fairly short period of time. This efficiency and accessibility make manual feature extraction an excellent tool for the HRM industry, in which researchers are often pressed for time and financial support. The manual analysis method also required limited geoprocessing experience and could be undertaken without the development of complex algorithms, making it more accessible to a wider range of researchers.

An aspect of automated LiDAR analysis that would be beneficial for a large operational area like HVC would be potential modelling of terrain based on ascribed attributes such as mean slope, relative slope to surrounding terrain, proximity to waterways and traditional trails or resource procurement areas. While outside of the scope of this study, the information collected regarding target feature attributes should be able to provide the basis for future LiDAR-derived potential modelling within HVC, if desired by the NNTC to support their heritage stewardship goals.

3.1.3. LiDAR-Derived DEM Interpolation Best Practice and Workflow

Interpreting LiDAR imagery and defining criteria for automated geoprocessing methods is not a passive process but iterative, requiring continuous revision and updating based on a standardized review of results (Freeland et al. 2016). Several researchers identify process workflow and best practices for identifying archaeological features using LiDAR-derived DEMs (Grammar et al. 2017; Challis et al. 2011; Kokalj and Hesse 2017). After a review of the formative research for LiDAR data interpretation for archaeological survey, a target feature detection workflow was developed for this study (Figure 9). Since LiDAR data was received from HVC as a processed DEM, steps involving processing and evaluation of data and metadata are excluded here but would be of benefit for studies with access to unprocessed LiDAR data point clouds. Gallagher and Josephs (2008) suggest that participating in data acquisition and processing can tailor the resulting DEM to your research goals and study area environment for a more successful result to interpolation.

The following is the workflow implemented during this study for LiDAR-derived DEM interpolation using manual feature extraction for archaeological prospecting (Figure 9). This workflow was adapted from that presented by Doneus and Kühteiber (2013:33-35) and includes i) data collection (green); ii) data review and interpolation (blue); and, iii) data analysis and interpolation (yellow). Depending on the specifics of a particular study, various decisions will need to be made prior to commencing and during the implementation of this workflow.

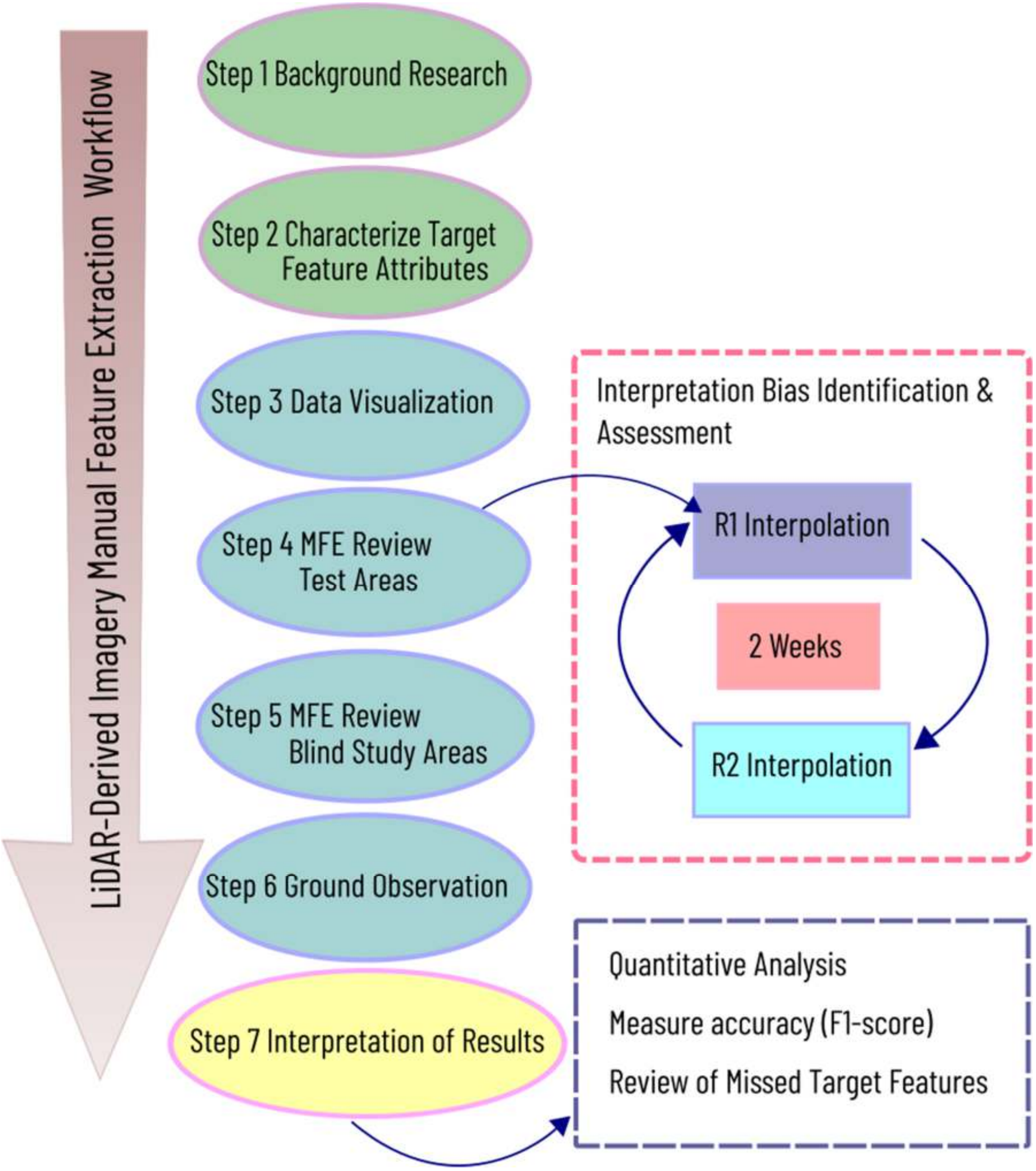

Figure 9. **Workflow for LiDAR-derived DEM interpretation using manual feature extraction for archaeological prospection**

Based on contemporary research (Grammar et al. 2017; Challis et al. 2011; Kokalj and Hesse 2017) the following best practices that should be considered when conducting LiDAR-derived imagery interpolation for archaeological prospection include:

- If not collected for your study, understand how LiDAR data was collected, processed and filtered
- Understand the types of imagery errors that may impact your target feature identification
- Use the highest resolution ppm data available
- Analytically identify the attributes of target features to inform the selection of the appropriate imagery analysis methods
- Identify study area topographic characteristics that may affect the type of data visualizations which will produce the highest contrast and best results
- Use multiple types of data such as orthophotography, historical aerial photography and traditional knowledge data to contrast with LiDAR imagery
- If possible, use more than one reviewer for the same study area and compare results, assign a confidence scale to MFE-selected features

3.2. Data Collection

3.2.1. Background Research (Step 1)

As with any research project the first step is to conduct a thorough review of available research materials available for the study area. Background research for this study included a review of past and current archaeological and ethnographic research in the southern interior region as well as the Highland Valley specifically. Topographic maps, environmental and geological data, historical aerial photography and information pertaining to past land altering activities were all reviewed. It is important to develop an understanding of how the modern environmental setting was achieved and how it relates to ancient environmental factors. Any traditional knowledge information relating to past and continuing land use by Indigenous peoples within a study area should also be reviewed to contextualize research goals and methods.

To understand current methods, best practice and available software applications in the field of archaeological prospection using ALS data, a thorough review of contemporary and formative peer-reviewed research was conducted. The field of LiDAR analysis is relatively new, particularly in its application in the archaeological sciences. However, substantial innovation has occurred in both the technology and the interpretation methods and process within the past two decades. The regional applications of LiDAR for archaeological prospection provide a framework to contextualize the results of this study and provide insight into best practice and knowledge gap requirements.

3.2.2. Target Feature Landform Attributes, Data Trimming and Zonal Statistics (Step 2)

At the commencement of research, NNTC provided geodatabase layers for three classes of target features: areas of interest, subsurface test areas and recorded archaeological sites. These layers form the comparative data set and are represented by georeferenced polygons that overlay the LiDAR DEM. Some of the recorded archaeological site locations are preliminary and were therefore represented by point data, likely identifying a single surface find or positive shovel test. These points were buffered by 10 m to create polygons, to ensure a uniform data format. The data were coded based on the type of polygon and permit under which they were recorded so that attributes associated with each could be catalogued for quantitative analysis. Additional supporting documents included provincial heritage register site inventory forms.

Digital shapefiles outlining the areas within HVC which had been subject to Phase 2 survey were overlaid on the DEM. This facilitated the delineation of test areas, in consultation with NNTC, based on quality of the terrain, volume of identified features, phase of archaeological prospection completed, and level of previous disturbance.[3] Two

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[3] There were originally ten test areas which were edited based on the quality of available data. The south tailings test areas retain the numbering from the original data set (i.e., there is no test area 1 or 2 in the south tailings area).

blind study locations were also selected based on the alignment of previous survey polygons and most recent data production (Figures 10 and 11).

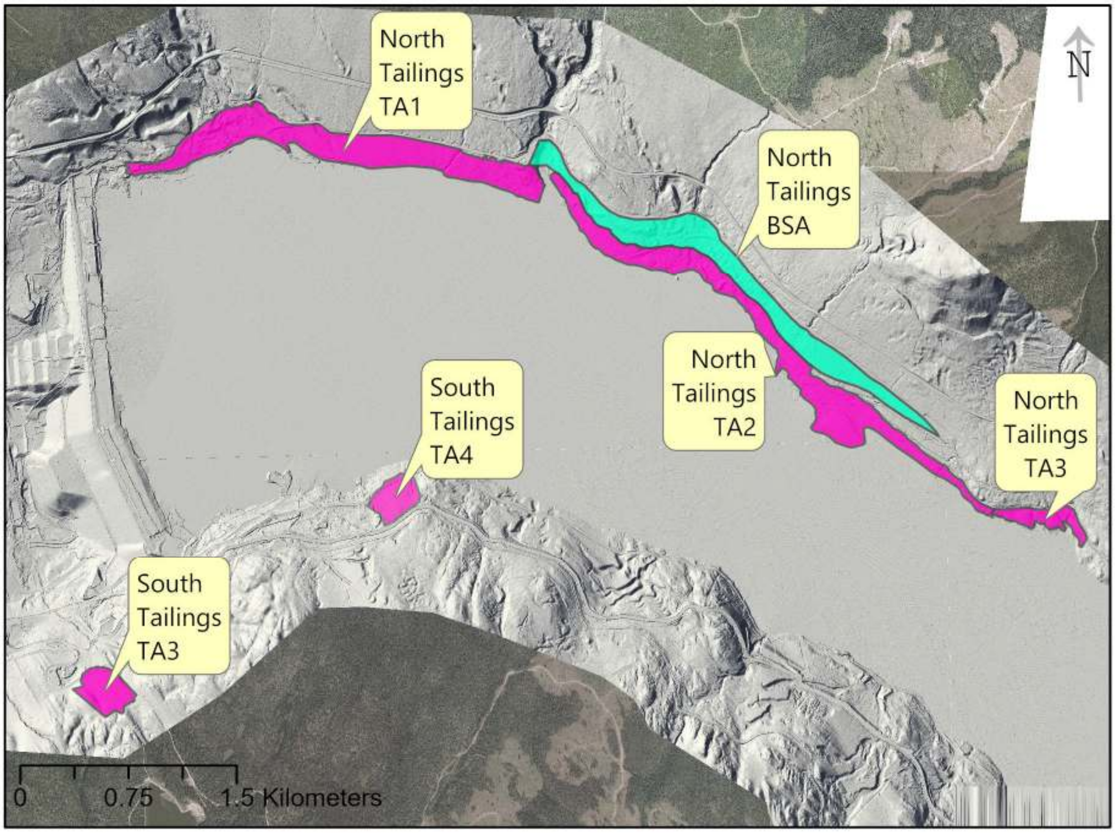


Figure 10. Location of north and south tailings test areas and blind study area
Data Source: Orthophotography and 2014 LiDAR data provided by Teck Resources Ltd; hillshade azimuth = 300, altitude = 45, z-factor = 2

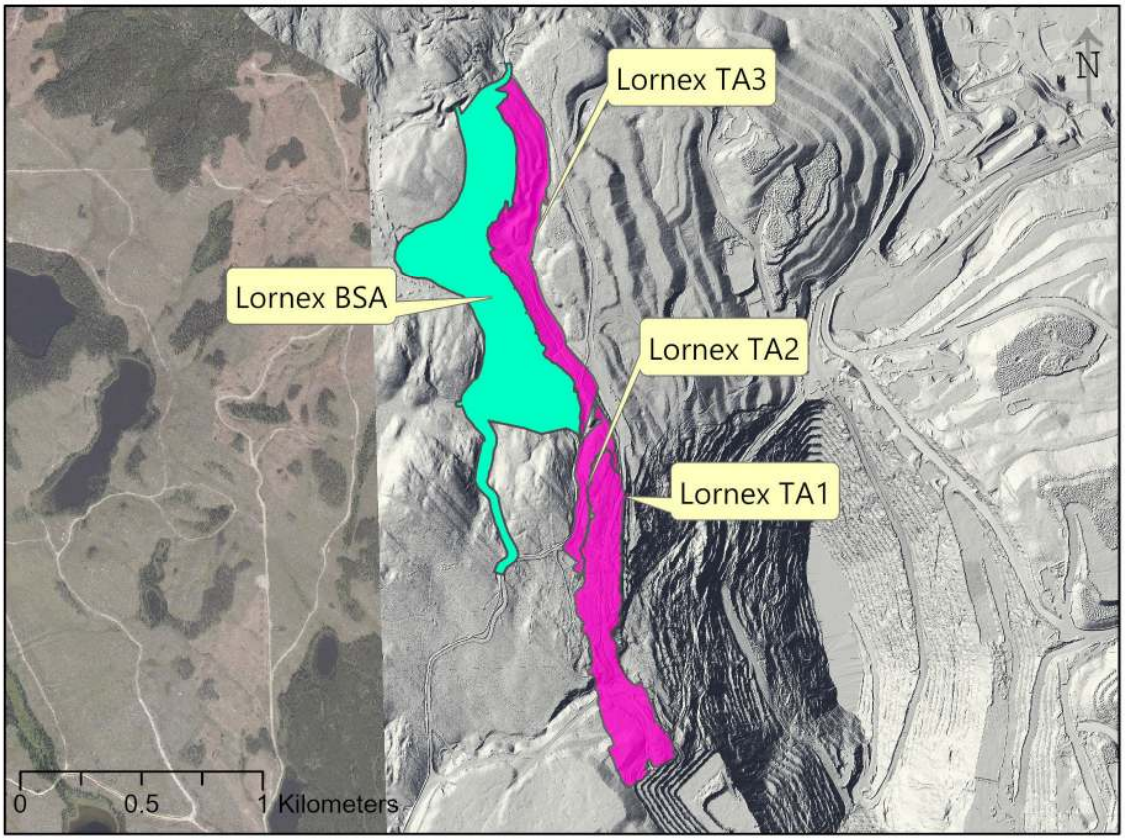


Figure 11. Location of Lornex test areas and blind study area
Data Source: Orthophotography and 2014 LiDAR DEM provided by Teck Resources Ltd; hillshade azimuth = 300, altitude = 45, z-factor = 2

The purpose of the test areas was to identify the best visualization techniques for the terrain and target features as well as developing a workflow for imagery interpolation using manual feature extraction. The blind study areas were included as a control variable in the research strategy to test the manual feature extraction method once developed without prior access to the target feature data. Results from all test areas are examined as one data set and contrasted with the results of the blind study area manual feature extraction review.

After the manual feature extraction review was complete, the ‘Spatial Join’ and ‘Intersect’ geoprocessing tools in ArcGIS Pro were used to identify the number of target features (AOI, STA and recorded archaeological sites) within each test area (Table 2). The features within the blind study areas were analyzed and catalogued after the study was complete so as not to influence the LiDAR-derived DEM analysis (Table 3).

Table 2. **Test area target features: areas of interest, subsurface test areas and recorded archaeological sites**

Test Area ID	Area (m^2)	Number of AOIs[1]	Number of STAs[2]	Archaeological Sites
Lornex Test Area 1	217,594	38	54	4
Lornex Test Area 2	45,669	18	null	1
Lornex Test Area 3	168,045	45	null	0
South Tailings Test Area 3	88,753	null[3]	21	1
South Tailings Test Area 4	75,599	null	24	3
North Tailings Test Area 1	538,734	45	133	19
North Tailings Test Area 2	512,558	32	160	3
North Tailings Test Area 3	70,075	8	33	6
Totals	**1,717,027**	**186**	**425**	**37**

1) AOI = Area of Interest
2) STA = Subsurface Test Area
3) null = this phase of survey not completed for the test area

Table 3. **Blind study area target features: areas of interest, subsurface test areas and recorded sites**

Blind Study Area ID	Area (m2)	Number of AOIs[1]	Number of STAs[2]	Archaeological Sites
Lornex Blind Study Area	436,611	179	258	12
North Tailings Blind Study Area	471,722	112	null[3]	null
Totals	**908,333**	**291**	**258**	**12**

1) AOI = Area of Interest
2) STA = Subsurface Test Area
3) null = this phase of survey not completed for the blind study area

To understand more about the microtopographic features which are most likely to contain archaeological materials within HVC, the target feature topographic attributes (slope median and range, aspect, elevation), were analyzed. As a preliminary step, the data sets were reviewed and trimmed to remove any overlapping, duplicate or outlier data points that would skew the results. Often Phase 2 surveys overlapped and the same AOI may have been identified more than once as a different shape and extent. A single artifact may be recorded as a buffered point only to be expanded into a large-scale archaeological site during subsequent ground-truthing. Due to these factors, several different sized AOI or site polygons from various field programs often overlap.

An example of an anomalous recorded site polygon is EdRg-26, a small petroform site with no recorded lithic scatter or specific microtopographic attributes indicative of subsurface archaeological deposits. EcRg-2 represents an extremely large lithic scatter site recorded on the shore of Quiltanton Lake prior to valley disturbance.

This large site surpasses the next largest site area by a significant margin of almost 40,000 m^2. Both of these sites are not suitable for the current study and were removed from the dataset prior to analysis.

Once the data were vetted for accuracy and trimmed for relevance, the 'Spatial Join' geoprocessing tool in ArcGIS was used to combine the polygon data into three sets based on target feature type (i.e., AOI, STA, recorded site). Each set of target features were then analyzed using the "zonal statistics' geoprocessing tool in ArcGIS to identify the descriptive statistics associated with topographic attributes. The zonal statistics function summarizes specific values of a raster layer (i.e., DEM, slope model or aspect model) within the parameters of another layer (i.e., either raster, polygon or point data). As HVC has varied topography, a broad study area analysis was conducted as well as discrete test area-specific analysis to identify localized landscape attributes that can be used to assess the archaeological potential of topography.

A data set of 115 recorded archaeological sites were analyzed to identify variations in site type and size in comparison with topographic attributes. For this portion of the spatial analysis only sites that are recorded in the provincial register were reassessed to avoid duplication of temporary site polygons. When analyzing the topographic attributes, the target feature data set was trimmed to exclude sites recorded within active mining areas and outside the DEM. Only STA polygons were subject to slope analysis as the alignment of these target features is the result of ground-truthing rather than preliminary survey. All sites were minimally comprised of subsurface and/or surface lithic artifact scatters.

To facilitate landform attribute analysis all temporary and recorded sites remaining in the trimmed data set were merged into one polygon data layer using the 'Union' geoprocessing tool. This process ensured that any overlapping polygons were fused into a single layer so that slope for the same terrain was not calculated more than once. The final recorded archaeological site data set consisted of 96 polygons and had a cumulative area of 60,902 m^2. Similarly, the STA polygons were merged into a single layer consisting of 190 discrete polygons and measuring 176,757 m^2.

3.2.3. LiDAR Data Acquisition

Realistically, in the heritage management industry in BC, it is unlikely that a researcher will be able to acquire LiDAR data specifically collected for the purpose of their study. Similarly, for this project the LiDAR data was acquired by HVC in 2014 from Eagle Mapping to support operational planning as well as geological and hydrological analysis rather than archaeological studies (Figure 12). The LiDAR data was collected using a Riegl's Q1560 - 2015 laser scanner and the corresponding georeferenced orthophotography was captured using an Intergraph DMII230 – 2011 and Trimble R6 from a fix-wing Cessna 206 aircraft over a flightpath covering approximately 2290 km^2.

The point density achieved during the 2014 LiDAR survey was 2 ppm^2 with a flight overlap of at least 10%. Absolute horizontal accuracy of raw LiDAR data points was 50 cm, vertical accuracy was 15 cm or better at 95% confidence based on comparisons to ground survey points. The airborne GPS data is accurate to +/- 1.0 m at the required flying altitude for this project. The aerial photography was triangulated using Leica Photogrammatic Suite software with at least two target ground GPS checkpoints with dual frequency high quality receivers referenced to achieve 95% confidence.

After the initial 2014 LiDAR survey, Teck opted to acquire data using a different method than ALS, conducting annual stereo satellite surveys of the study area from PhotoSat. The PhotoSat survey produced a 1 m stereo satellite survey and 50 cm accuracy orthophotographs georeferenced with ground control points. This data is acquired by utilizing stereoscopy or multiple high-resolution georeferenced images acquired from various angles and overlaid to emulate a 3D elevation model. This data is then superimposed with other vector layer data such as the existing 2014 LiDAR grid and ground control points to create accurate DEMs. While the more recently collected stereo satellite-derived DEM data was made available for this study, the 2014 LiDAR survey data was utilized instead. This choice was made for a few reasons but predominantly because several of the test areas and one blind study area have been impacted by mining development since the archaeological survey was completed and more recent DEM data does not show the pre-impacted topography.

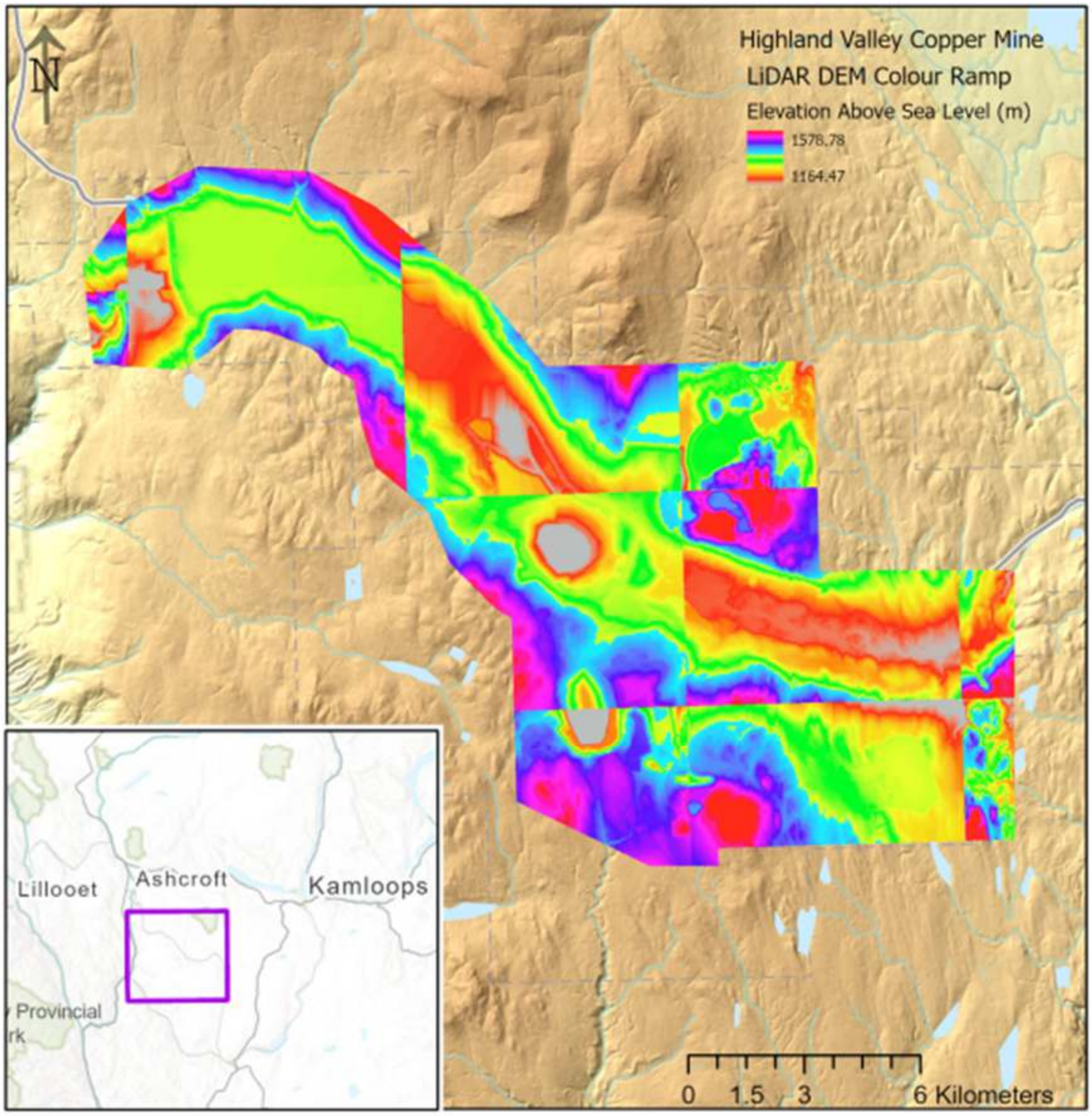


Figure 12. **LiDAR DEM produced from data points collected in 2014 provided by Teck Resources for the heritage management program**
Data Sources: 2014 LiDAR DEM property of Teck Resources; NR Can, Esri Canada, and Canadian Community Maps contributors.

Orthophotography is the process of acquiring aerial photographs of the landscape and orthorectifying them using a series of geospatially surveyed ground-points as datums to reference and adjust the imagery. Photographs can be collected as orthophotography, as with the more recent imagery form PhotoSat, or this process can be applied to older photography to understand changes in the landscape over time. Orthophotography from 1969 was provided to get an understanding of the natural topography of the study area, before major mine impacts occurred. Understanding the nature of the natural landscape provides context to the current study area and allows for a more informed interpretation of archaeological potential.

3.3. Data Review and Interpolation

Bennett and others (2012:41) point out that “many end-users of the data are not trained in remote sensing and visualization techniques and the lack of comparative assessment of techniques has increased the complexity of interpretation of the ALS-derived models.” In response to this knowledge deficit various researchers have conducted comparisons to determine the most effective methods for visualizing and interpreting LiDAR-derived elevation models for archaeological prospection in various terrains (Bennet et al 2012; Challis et al 2011 Horňák and Zachar 2017; Kokalj and Somrak 2019).

3.3.1. Imagery Visualization Techniques (Step 3)

The efficacy of a variety of imagery visualization techniques has been compared for archaeological prospection in studies in Europe and Central America (Kokalj and Hesse 2017; Štular et al 2012, Chase et al 2012). Each visualization technique has advantages and disadvantages based on the nature of the terrain and the characteristics of the target features (Mayoral et al. 2017).

The most common visualization technique utilized by archaeologists is hillshade also called shaded relief, which is available as a ‘spatial analyst’ function in ArcGIS and calculates the amount of shadow on a bare-earth topographic representation. A DEM is then rendered based on an artificial illumination azimuth and zenith angle and a grey-scale colour cast is applied to optimize contrast between dark and light. However, interpretation based solely on hillshade has the potential to miss archaeological features or potentially subtle microtopographic changes (Challis et al. 2011). Regardless of its limitations, hillshade remains the most commonly used visualization technique because it provides a visually intuitive representation of the ground surface.

The preference of a reviewer is also an important factor when selecting the visualization techniques that will have the greatest target detection success because intuitive imagery can have a significant impact for target identification (Kokalj and Hesse

2017:35). Krasinski and others (2016) compare the results of target feature identification between the different visualization techniques in a boreal forest environment, determining that sky-view factor had the best results for target feature identification in their study area. Harmon and colleagues (2006:654) contend that “[w]hile LiDAR is well-established as a technique for making fine-scale topographic maps, it is less certain how to present the data to the archaeologist in a form that allows for detection of the features of interest.”

To identify the most effective visualization technique for archaeological prospection in the study area Kokalj and Hesse (2017) suggest determining the preferred number of different visualization techniques required to accomplish the research goals and which visualization techniques are best suited to the specific study area terrain. The main factors that affect the selection of a data visualization method are the characteristics of the target features (size, shape, convexity/concavity) and the overall terrain characteristics (Kokalj and Hesse 2017:35). For flat terrain, a combination of shaded relief, local-relief modelling and openness is recommended, while better results in more complex topography are often seen using sky-view factor (Kokalj and Hesse 2017:34). Testing different software and interpolation techniques is essential to understand the quality of your results (Kokalj and Hesse 2017:45). Kokalj (2014) stresses that visualizations are especially important for LiDAR data not collected or optimized for archaeological detection as the specific requirements of the study and target feature attributes were not considered when collecting or processing the data which can lead to lower identification success.

Letham and others (2018) provide a workflow for implementing a predictive model to identify paleoshorelines with high archaeological potential. The software GRASS GIS is used to extract shoreline elevation contours, and lands with the potential to contain Holocene-aged archaeological sites are identified in the LIDAR-derived DEM using QGIS geoprocessing algorithms (Letham et al. 2018). Depending on the parameters of the research being undertaken, the tools available in current software platforms, including opensource options like QGIS, are incredibly robust. These can add a great deal of insight, particularly in the fields of landscape archaeology and site prospection studies.

Interpretation of visualization techniques requires the reviewer to search for "form-oriented factors of tone and brightness, shape as well as contextual factors of pattern, association and setting" (Grammar et al 2017:316). For this study, becoming familiar with microtopographic landform attributes that display archaeological potential and how they are represented in the various visualization techniques and orthophotographs was conducted during the reviews of the four test areas. Hiller and Smith (2008:2266) suggest looking for "topographic primitives, namely length, orientation and width." This was particularly useful during this study which focused on identifying naturally occurring landforms indicative of archaeological potential rather than anthropogenic surface expression.

Bennett and others (2012:43) conclude in their study that using a single visualization technique resulted in a 77% detection success rate, using two resulted in an 83% detection success rate and three different data visualization methods increased the detection success rate to 93%. Based on research conducted into which visualization technique is suitable in each type of terrain (Štular et al. 2012) eight different visualizations were selected for this study (Figure 13):

1. Standard hillshade
2. Multi-azimuth hillshade
3. Principal component analysis
4. Slope gradient
5. Local relief model
6. Sky-view factor
7. Positive openness
8. Slope characterization

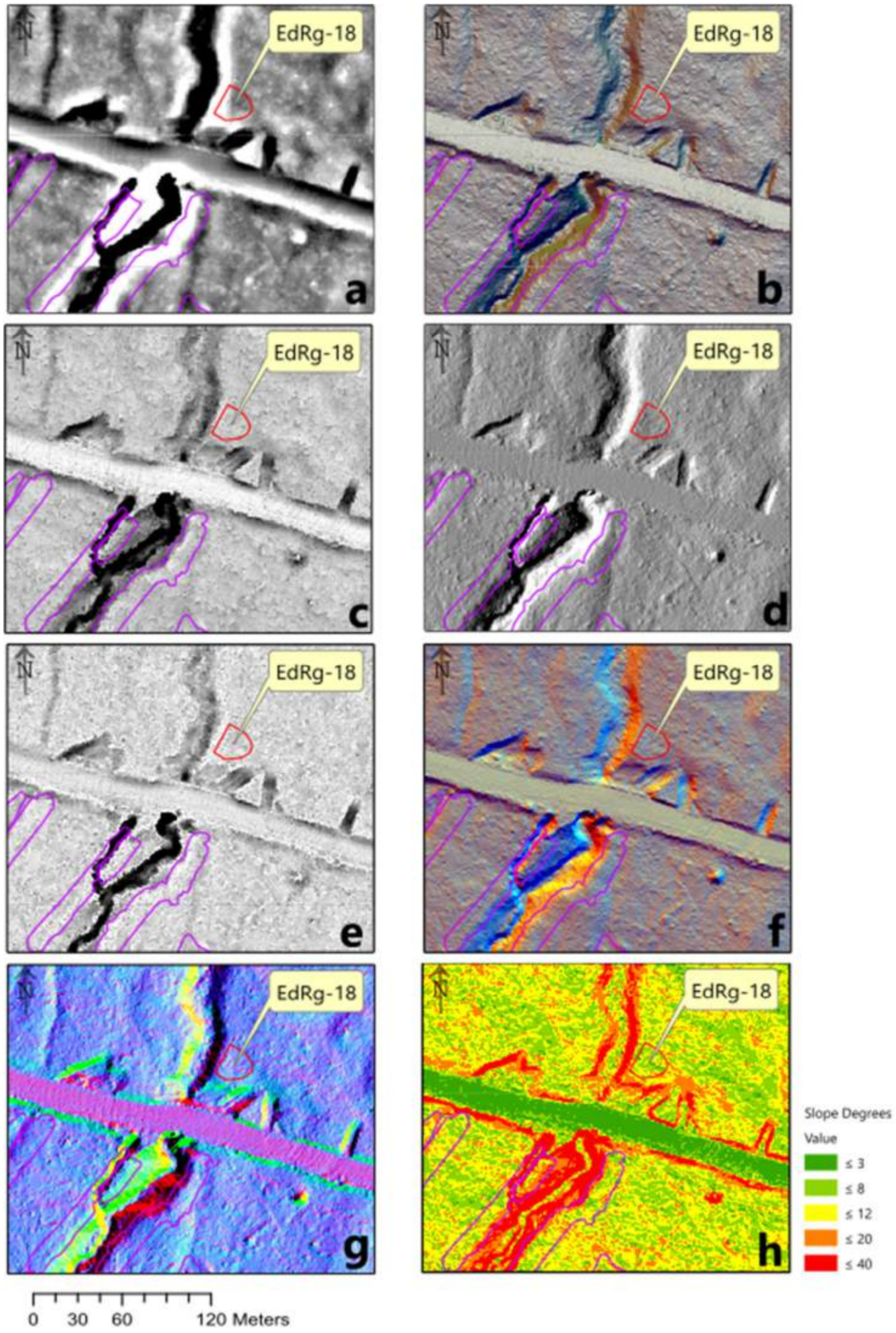


Figure 13. **Examples of LiDAR data visualization techniques used during the study, showing modern land alteration, creek, recorded archaeological site (red polygon), AOIs (purple): a) LRM; b) slope gradient; c) sky-view factor; d) standard hillshade (azimuth = 280; elevation angle = 25°; z-factor = 0); e) positive openness; f) multi-hillshade; g) principal component analysis; h) slope characterization (degrees)**

Data Source: Orthophotography and 2014 LiDAR data provided by Teck Resources

Standard hillshading is a raster data visualization method that assumes an elevation and angle for sunlight and illuminates the DEM to provide contrast through grey-scale shading. A standard hillshade visualization uses the azimuth of 315 degrees and elevation angle of 45 degrees. “An azimuth is an angular measurement in a spherical coordinate system. The vector from an observer to a point of interest is projected perpendicularly onto a reference plane; the angle between the projected vector and a reference vector on the reference plane is called the azimuth” (Kokalj and Hesse 2017:76). Adjusting the azimuth, angle and z-factor of a standard hillshade visualization can increase contrast and improve feature identification. The main disadvantage of hillshade is that if any archaeological features are aligned parallel to the direction of illumination, they may not be visible. This effect can be reduced by using multi-azimuth hillshading which overlays minimally three images rendered in various hillshade directions (Kokalj and Somrak 2019). Each image is adjusted using a red-green-blue (RGB) colour-cast to increase contrast and delineate convex and concave surfaces.

Principal component analysis takes the concept of multi-azimuth hillshade one-step further. This technique involves processing the highest resolution views from minimally sixteen azimuth directions through multivariate statistical analysis and rendering them as a single image (Devereux et al. 2008). Principal component analysis is computationally complex and therefore appropriate software needs to be employed to ensure accurate image projection.

Slope gradient is a data visualization method which is aspect independent and displays change in slope between each pixel as a percentage or degree of slope (Doneus et al. 2008; Challis et al. 2011). A colour gradient is then applied to the coded slope degrees to display contrast. Slope gradient maps can be produced using the geoprocessing toolkit in ArcGIS or equivalent software. Less detailed slope characterization maps can also be produced which visualize set slope ranges within a landscape. The later process is less refined but can be useful if prospecting for target features within a specific slope range. Slope characterization maps are also very useful for planning field survey to minimize risk of surveying through dangerous or inaccessible terrain and increase efficiency of terrain access.

Local relief model (LRM) visualization presents localized, small-scale elevation differences after removing large-scale landscape forms from the data set. LRM is suitable for viewing low-profile topographic features such as knolls and small ridges isolated from the larger terrain where they occur (Hesse 2010). A low-pass filter is added to the DEM which separates and displays a low-relief image. This low-relief model is then subtracted from the DEM point cloud and only low-relief features remain (Hesse 2010). This technique is intended to reduce the distraction of macrotopography of steep, mountainous landscapes by focusing in on microtopographic terrain changes (Bennett et al. 2012:42). Kernel density analysis measures the difference in a parameter, in this case elevation, between raster data in a prescribed area (ex. 25 m-diameter or 10 m^2). The kernel size of the low-pass LRM analysis determines the size of features visible (Bennet et al. 2012). This study used a 20 m-radius kernel size to produce the LRM which is the standard setting for the software employed.

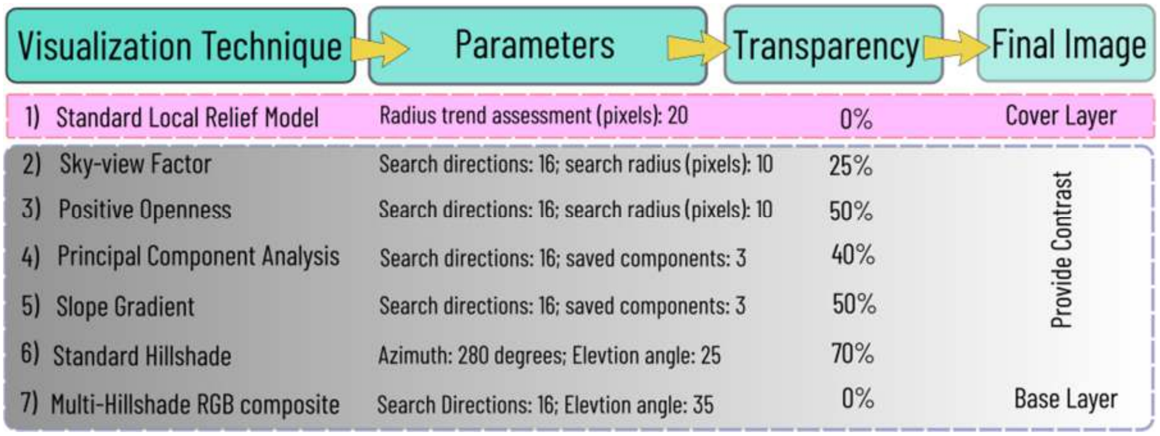
Sky-view factor is a visualization technique that illuminates the ground surface based on an estimate of what portion of the sky is visible from the surface, taking into consideration the relief horizon based on terrain and/or surface. Ridges and terraces of higher elevation are lighter in colour and illuminated as they receive more skylight than ditches and furrows. A histogram stretch is usually required to visualize the data most effectively (Kokalj et al. 2011:2).

Positive openness involves diffuse relief illumination and estimates the mean horizon elevation angle within a defined search radius. Negative openness is not the opposite of positive openness; while positive highlights topographic convexities, negative openness highlights the lowest elevation of concavities (Doneus 2013; Kokalj and Hesse 2017). Negative openness was determined to not be useful for the identification of target features within the terrain of this study and therefore only positive openness was visualized.

For this study each visualization technique, apart from standard hillshade, was created using the Relief Visualization Toolbox (RViT) opensource software created by Zakšek and colleagues (2011). The RViT tool allows uploaded raster data from the LiDAR-derived DEM to be output as multi-azimuth, principal component analysis, sky-view factor, local relief model and positive openness visualizations. These visualizations can be layered with orthophotography and viewed in ArcGIS or other software platforms such as QGIS or GRASS GIS. Figure 13 shows the same location in the study area visualized with each of the seven techniques plus a slope degree colour ramp map produced in ArcGIS.

Kokalj and Somrak (2019:2) contend that layering the visualizations with varying translucence and histogram stretch parameters increases contrast and can improve the identification of low-relief topographic landforms. Elevation differentiation is intended to increase the contrast between differing elevations and is achieved through applying a histogram stretch to enhance the contrast between pixels (Kokalj and Hesse 2017:21). Kokalj and Hesse (2017:34) suggest using “a histogram stretch of 0.65 to 1.0 for diverse terrain and 0.9 to 1.0 for very flat terrain”.

These techniques were selected based on the required parameters of the study objectives and landscape attributes of HVC. A set of blended visualizations was created with a specified workflow for viewing each layer during interpolation (Figure 14). The best results involved viewing a LRM image first, followed by layered sky-view factor, positive openness, principal component analysis, slope, standard hillshade and multi-hillshade. The LRM is more abstract and is helpful as a preliminary layer for identifying areas of elevation contrasted with low-lying and/or sloping terrain. The suspected AOIs were then compared to orthophotography to exclude any obvious disturbance or modern anthropogenic impacts (i.e., roads, ditches and areas of excavation or piled soil from mining activities). The eighth visualization technique, slope characterization, was not suitable for the blended method but was used as an additional data source during AOI interpolation.



Visualization Technique	Parameters	Transparency	Final Image
1) Standard Local Relief Model	Radius trend assessment (pixels): 20	0%	Cover Layer
2) Sky-view Factor	Search directions: 16; search radius (pixels): 10	25%	Provide Contrast
3) Positive Openness	Search directions: 16; search radius (pixels): 10	50%	
4) Principal Component Analysis	Search directions: 16; saved components: 3	40%	
5) Slope Gradient	Search directions: 16; saved components: 3	50%	
6) Standard Hillshade	Azimuth: 280 degrees; Elevtion angle: 25	70%	
7) Multi-Hillshade RGB composite	Search Directions: 16; Elevtion angle: 35	0%	Base Layer

Figure 14. **Raster data visualization technique image layering and blending process for interpolation**

3.3.2. Imagery Display Errors

During the data processing and filtering required to ascertain which points represent bare-earth there are gaps between the elevation points. These gaps are filled-in through the process of pyramid building using a triangular irregular network, or the ground surface is estimated based on connecting points to the nearest neighbour. As a result of this process, the ground surface where structures and dense vegetation points are filtered out there are often artificially fractal impressions in the visualized DEM. It is important to understand the types of errors that can occur when visualizing LiDAR data so that they do not confound the results of feature interpretation during review (Kokalj and Hesse 2017; Opitz 2013:26).

Other imagery errors that can be present in LiDAR data include elevation discrepancies where flight survey transects overlap resulting in the misclassification of ground points as vegetation or structures (Opitz 2013:26). Imagery errors from divergence in data collection or processing are often displayed as blurry lines, zig-zag patterns, waves and/or black star bursts (Kokalj et al. 2011:102). In Figure 10, for example, a blurry line made up of vertical stripes can be observed in the bottom right, likely the result of a missing flight path or gap in the data points filled-in by the triangular irregular network algorithm during processing.

A reviewer must be cognizant that shapes and images which appear to be anthropogenic modification or indicative of archaeological interest may be just a trick of the data. For this reason, understanding the method of data collection and processing is key to feature detection.

3.3.3. Manual Feature Extraction Review of Test Areas and Iterative Comparison of Results (Step 4)

The visualized LiDAR imagery for each test area was reviewed and areas suspected of exhibiting archaeological potential were outlined as polygons and saved as a layer in a geodatabase. These digitally produced AOIs were then compared with the existing NNTC georeferenced target feature data to assess intersection and variance.

Confounding factors for data collection and interpolation are present within both traditional survey and LiDAR-analysis methods, specifically due to differences between recorders/reviewers, a well-known source of interpretation bias (Bennett et al. 2012). To counteract reviewer bias, initial MFE review results for each test area were completed and a second review was conducted after a two-week period. The results were compared through an iterative process beginning with the first test area to identify and address interpretation bias incrementally during each subsequent MFE interpolation. Comparability and variance issues are often the result of differences in skill and experience. These factors can affect the archaeological features detection rate and by comparing LiDAR-analysis results from the same area over a period of time, reviewer bias can be identified and methods adjusted (Kokalj and Hesse 2017:35).

Quintus and others (2017:353) demonstrate that the results of MFE are more accurate when more than one researcher is involved in the review. Additionally, a researcher with more experience with target feature selection within the study area and/or interpretation of DEMs, will likely have a higher detection success rate (Bennett et al. 2012). The iterative comparison between the test area reviews (R1 and R2) sought to identify variations in the overall area of target features selected, archaeological site identification rate and intersectionality between the two reviews. The results of the first review were used only for comparison with the second review to identify interpretation bias. Evaluation of the overall efficacy of the visualization techniques and manual feature extraction process is based on a comparison of the second review and blind study area review results compared with NNTC traditional survey data set.

3.3.4. Interpretive Mapping of Blind Study Areas (Step 5)

AOIs were manually delineated for each of the blind study areas using the eight visualization techniques as described, as well as high resolution orthophotographs. Once the AOIs were identified and saved to a geodatabase, A.E.W.LP provide the ground-truthed data for comparison and evaluation of the MFE results.

3.3.5. Ground Observation/Field Visit (Step 6)

In mid-September 2020, a field visit was conducted to examine the north tailings and south tailings study area locations. In this I was led by an A.E.W.LP field supervisor who provided guidance and insight into different aspects of previous field methodologies. Survey recoding techniques for STA locations were reviewed as well as the personal preferences and bias of each field recorder and their general and regional experience. Here I hoped to identify any confounding variables that, potentially, would influence statistical analysis of AOI landform attributes. Individual contributions to the overall data set are to be expected, and professional judgement is a crucial component to a successful field program.

The LiDAR-derived AOI feature class layer was exported as a shapefile and uploaded to Avenza maps so that the georeferenced polygons could be identified in the field. The field visit focused on assessing false positives and missed target features. I also examined a sample of AOIs within test areas in the north and south tailings areas to visually observe and validate landform attributes. Understanding factors that affect the variance between the LiDAR-analysis and traditional survey methods will contribute to improving the processes associated with using DEMs for archaeological prospection.

3.4. Data Analysis and Interpretation

3.4.1. Interpretation and Contextualization of Results (Step 7)

Quantitative analysis of the total target feature area identified in test areas and blind study areas was conducted to compare traditional survey and LiDAR analysis methods. Landscape factors such as slope (median and range) of target features can be considered for comparing the results. Traditional survey and MFE methods were compared analytically based on the following five factors:

- true positive (TP): AOIs/STAs/archaeological sites identified by both methods
- false positives (FP): AOIs only identified by MFE
- missed target features (MTF): target features only identified by traditional survey
- intersection of area selected (m^2)
- binary result intersection: percentage of MFE AOIs that intersect with target features

The classification of ‘false positives’ assumes that areas of interest identified by LiDAR but overlooked in the traditional survey are likely incorrect, and therefore an actual ‘false positive’. Traditional survey data, thus, are considered accurate and provide an acceptable baseline for comparison. Time, and the scope of this study, did not allow us to ground-truth false positive locations. This type of assessment, however, could be undertaken in the future. Missed target features are locations where traditional survey identified test locations that were not identified during LiDAR analysis.

The AOIs identified through LiDAR-derived DEM analysis were compared to the layer of target features recorded through traditional survey methods. The above comparative factors were reviewed to quantitatively analyze the target feature detection success rate and accuracy of the LiDAR analysis MFE method. The total area of overlap as well as percentage of true positives and false positives identified by the LiDAR feature class layer were calculated for each test area and blind study area. The test area results are reviewed as a whole and contrasted with that of the blind study area.

3.4.2. Analytic Methods

Once all target features were coded, the data were compared using the zonal statistics geoprocessing tool in ArcGIS to identify patterns and potential expected values for topographic attributes such as aspect and slope. For the test area and blind study area results, an error matrix was used to assess detection success rates between different types of target features (Risbøl et al. 2013). By reviewing the landscape attributes of missed target features and false positives, errors in the review process can be identified along with potential methods for increasing future detection success rates.

The overlap of area or intersectionality between the survey-identified AOIs and the LiDAR-derived reviewer AOIs, as well as the difference between the two reviews was assessed using a Venn diagram equation[4]:

$$\mathrm{R1} \cap \mathrm{R2} = \text{ Review Overlap (R0)}$$

$$\mathrm{R1} \cup \mathrm{R2} = \text{ Total Area of R1, R2}$$

$$\mathrm{n}(\mathrm{R1} \cup \mathrm{R2}) = \mathrm{n}(\mathrm{R1}) + \mathrm{n}(\mathrm{R2}) - (\mathrm{R1} \cap \mathrm{R2})$$

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[4] https://prepinsta.com/venn-diagram/formulas. Accessed March 22, 2020

Intersectionality comparison assesses the level of interpretation bias between the two manual feature extraction reviews conducted for the same area two weeks apart. A comparison is made between the total overlap between the two reviews and differences in the total area identified by each (Figure 15). This analysis can also be used to compare the LiDAR results with traditional survey results to answer research questions associated with whether LiDAR-analysis is a more precise method or whether it identified a larger area of archaeological potential.

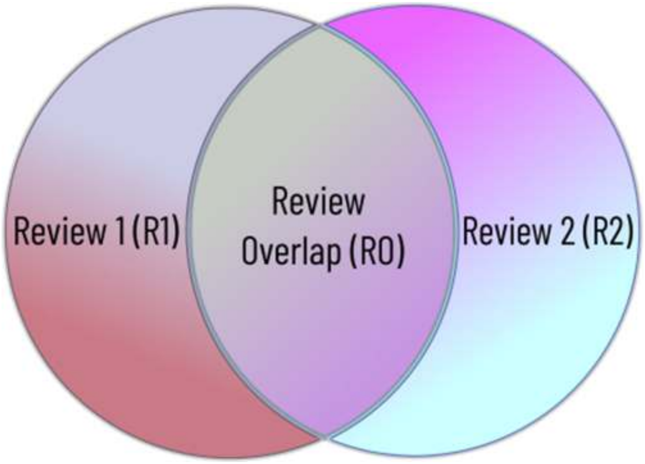

Figure 15. **Idealized Venn diagram showing the method for interpretation bias analysis - overlap in AOI area (RO) between review 1 and review 2**

While this study did not involve the creation of an automated predictive model, it does digitally identify all areas suspected of having archaeological potential within a development area. For this reason, Kvamme's (1988:329) gain statistics is useful to quantitatively assess the effectiveness of the manual feature extraction method. This statistical process "estimate[s] how far the model deviates from a random distribution or the model's level of improvement over chance" (Archaeology Branch 2009:6). According to the Archaeology Branch (2009:6), a high efficiency predictive model must have a gain of at least 0.90 and between 0.80 and 0.90 for moderately efficient. Kvamme's (1988:329) gain is calculated as follows:

$$1 - (percentage\ of\ total\ area\ covered\ by\ the\ predictive\ model \\ /percentage\ of\ total\ sites\ within\ the\ model\ area)$$

To analytically quantify the efficacy of using LiDAR-derived imagery, the results of manual feature extraction were quantitatively assessed using the F_1 measure, also called the F_1-score (Freeland et al 2016; Quintus et al. 2017). "This is a measure of the accuracy of a binary classification that relies on the calculation of the harmonic mean of sensitivity (R) and the precision (P)" (Quintus et al. 2017:355). The closer the F_1 measure is to 1, the more accurate the MFE classification of target features with F_1-scores closer to zero indicating poor target feature identification (Quintus et al. 2017:356). The following equations define how F_1-score is calculated and Table 4 defines the factors used to determine the efficiency of the predictive model.

Precision is calculated as:

$$\mathrm{TP}/(\mathrm{TP}+\mathrm{FP})$$

Sensitivity is calculated as:

$$\mathrm{TP}/(\mathrm{TP}+\mathrm{MTF})$$

F_1 score is calculated as:

$$\mathrm{F1\ Score} = 2\mathrm{PR}/(\mathrm{P}+\mathrm{R})$$

Table 4. Definition of analytical terms used to assess the F_1-score of manual feature extraction results

Factor	Acronym	Definition
True Positive	TP	Target features identified in-field during survey and in-office using LiDAR-derived manual feature extraction review
False Positive	FP	LiDAR-derived areas of interest that do not correlate to any recorded target features
Missed Target Feature	MTF	NNTC-identified AOIs, STAs, and archaeological sites that were not identified during LiDAR-derived manual feature extraction review
Sensitivity	R	The rate of True Positives (TP) or the rate of target features identified during LiDAR-derived manual feature extraction review
Precision	P	The portion of LiDAR-derived manual feature extraction features that correlate with NNTC-identified target features

3.4.3. Evaluation and Contextualization of Results

Assessing the success rate of the manual feature extraction process for detecting AOIs, STAs and recorded archaeological sites is important because it determines the efficacy of LiDAR-analysis remote sensing for planning archaeological prospection programs within HVC. Once the target feature detection success rate is identified, the blind study area results can be contextualized and the application of the manual feature extraction method compared to regulatory efficacy requirements.

The results of this study can be compared to detection success rates of similar projects by Bennett and others (2012) and Millennia (2006). Respectively these had success rates of 80 - 90% and 85 - 95% depending on method employed during LiDAR-derived potential modelling. The detectability of feature attributes can be assessed statistically by comparing the zonal statistics of slope (mean and range) of missed target features and false positives to improve our understanding of how and why certain features are identifiable in LiDAR data and why some are missed (Bennett et al. 2012:204).Validating results through site visits and ground-truthing can contextualize study results and facilitate meaningful recommendations for future project applications of LiDAR analysis.

Finally, a cost-benefit analysis of the LiDAR based survey is undertaken for HVC. Many decisions regarding which technology and methods to employ during HRM studies are directly correlated to available budget. It is, therefore, pertinent to examine the cost-implications of incorporating LiDAR-analysis into the toolkit for archaeological site prospection. To complete the cost-benefit analysis a hypothetical heritage management program was devised to assess the costs associated with incorporating LiDAR-analysis into the workflow (Appendix C). Program financial data and estimates of effort were acquired from NNTC to provide a hypothetical baseline for program execution per hectare.

Chapter 4. Analysis Results

Using available data from the ongoing HVC heritage management program provided by NNTC, LiDAR-derived areas of interest within eight test locations and two blind study areas were compared with the results of traditional survey. First, the DEM was processed using the visualization techniques most suited to the terrain of the study area. A multi-faceted approach was used which employed a comparison of layered visual data including orthophotographs, slope characterization mapping and blended visualization techniques. Manual feature extraction was used to designate AOI polygons based on the visual analysis of attributes indicative of archaeological potential (i.e., slope, aspect, integrity of the landscape, presence of discrete microtopographic features).

Interpretation bias was assessed by comparing the results of two manual feature extraction reviews (R1 and R2) of the eight test areas conducted by the same researcher, at least two weeks apart. The R1 results were used only to contrast with the R2 results to investigate the nature of interpretation bias. To evaluate the effectiveness of the LiDAR-analysis method, R2 test area results and blind study area results were contrasted with traditional survey data.

The results of the test area and blind study area manual feature extraction review were assessed for effectiveness in two ways; first, the detection success rate of identifying target features and secondly by the overall intersectionality of the two methods by total area (m^2). The former assesses how accurate the method is for capturing recorded archaeological sites. The latter assesses how effective manual feature extraction would be as a field program planning tool for NNTC and Teck within the HVC study area.

Missed target features and false positive results were identified and re-evaluated to determine factors that may have contributed to the discrepancy between traditional and LiDAR-analysis prospection methods. Finally, the accuracy of the manual feature extraction method as a predictive model was assessed using the Kvamme's gain analysis.

4.1. Interpretation Bias Analysis

As expected, the overall results of R2 were better than R1, with an increase in capturing recorded archaeological site locations, AOI/STA detection success and a decrease in missed target features (Table 5; Figure 16). The overlap in total area of interest (m^2) between reviews 1 and 2 was 50% (Table 5). In the individual test areas, the percentage of overlap by square metres between R1 and R2 was as low as 20% and as high as 69%. There is a substantial difference in the area identified during manual feature extraction between the two reviews. The primary factor which led to this variance was the experience of the reviewer with the LiDAR-analysis methods, software and the study area itself. As a reviewer becomes more experienced in using manual feature extraction to identify specific target features in a topographic landscape, the comparison between the reviewer results within an area will likely show greater correlation.

The second review identified 18% more area (m^2) during manual feature extraction than the first review (Table 5). This increase came with a 10% increase in target feature detection and an 11% increase in identified sites (Table 6; Figure 16). This increase included three additional archaeological sites captured by manual feature extraction in three of the test areas. These results correspond with the findings of the Millennia (2006:32) study which found a 9% increase in potential area identified resulting in a 10% increase in archaeological site identification. The overall intersection (m^2) of manual feature extraction AOI and traditional survey AOIs was 50% during R1 and 63% for R2, an increase of 13%.

Some of this increase has to do with reviewing the NNTC data in comparison with each review in an iterative process designed to educate the review on the nature of NNTC-selected AOIs. Once the NNTC target feature data set was used to compare with the results of R1 a two-week period elapsed before the completion of R2, but the location and orientation of target features had been observed during the analysis of the first review. Further, becoming more familiar with both the study area landscape and the software being used to conduct manual feature extraction likely had a significant impact on the increased interpolation success.

Table 5. **Interpretation bias – review 1 and review 2 comparison**

Test Area ID	Review 1: AOI Total (m^2)	Review 2: AOI Total (m^2)	R0 Overlap Area (m^2)	Total Area (m^2) [5]	Percentage of overlap
Lornex Test Area 1	22,823	30,036	16,301	36,558	45%
Lornex Test Area 2	5,079	4,051	1,526	7,604	20%
Lornex Test Area 3	8,097	14,053	4,875	17,275	28%
South Tailings Test Area 3	14,649	28,826	10,585	32,890	32%
South Tailings Test Area 4	10,051	11,582	4,529	17,104	26%
North Tailings Test Area 1	66,658	76,163	44,289	98,532	45%
North Tailings Test Area 2	94,158	95,080	77,586	111,652	69%
North Tailings Test Area 3	14,650	18,872	12,175	21,347	57%
Totals	**236,165**	**278,663**	**171,866**	**342,962**	**50%**

Table 6. **Results of test area manual feature extraction review 1 and review 2**

Test Area ID	True Positives		Missed Target Features		False Positives	
	R1	R2	R1	R2	R1	R2
Lornex Test Area 1	80	83	30	13	6	1
Lornex Test Area 2	9	10	11	9	5	4
Lornex Test Area 3	36	36	20	9	8	2
South Tailings Test Area 3	15	16	11	6	0	2
South Tailings Test Area 4	16	18	7	9	3	4
North Tailings Test Area 1	109	127	79	70	10	4
North Tailings Test Area 2	148	178	32	17	1	0
North Tailings Test Area 3	38	44	4	3	1	1
Totals	**478**	**512**	**147**	**136**	**34**	**18**

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[5] Calculated using venn diagram formula https://prepinsta.com/venn-diagram/formulas. Accessed March 22, 2020

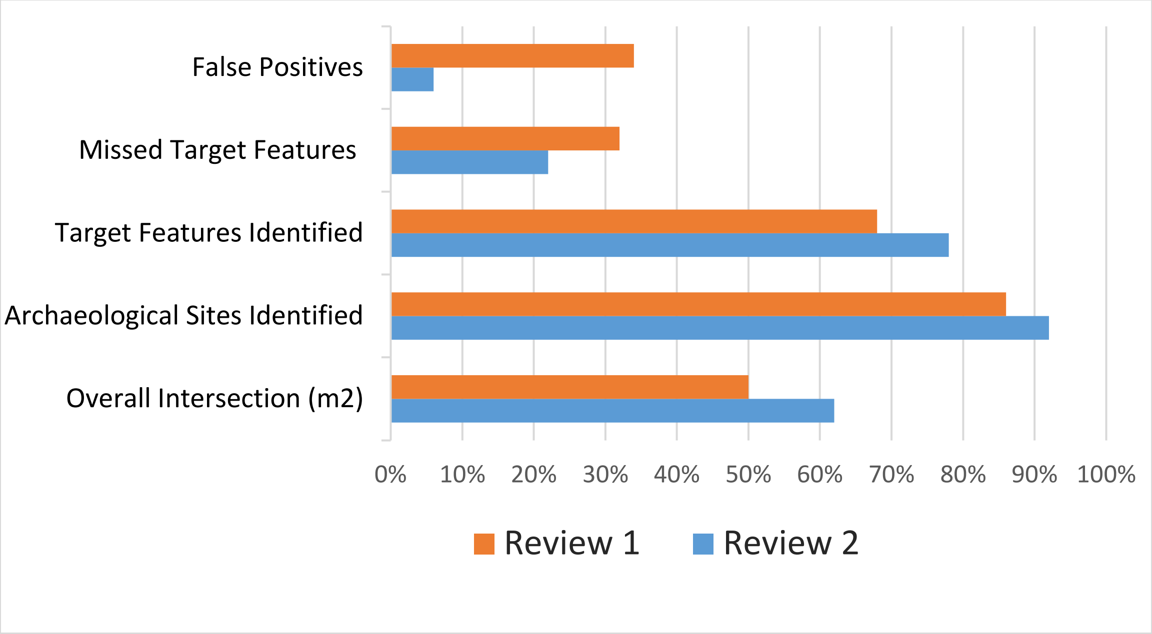

Figure 16. **Comparison of NNTC and LiDAR-derived data intersection within test areas: reviews 1 & 2**

4.2. Manual Feature Extraction Test Area Results

As a complete data set, results from the eight test areas showed that 92% of recorded archaeological sites were captured by the LiDAR-derived manual feature extraction method (Table 7). A total of 29% of the areas of interest and 2% of the subsurface test areas identified by traditional survey were missed by the LiDAR-analysis. This may indicate that certain landform attributes are more difficult to detect using LiDAR imagery analysis. To understand more about these factors all missed target features and false positive results were re-examined. Overall, 94% of the LiDAR-derived AOIs at least partially intersected with a target feature identified by traditional survey. Of the total 296 areas of interest delineated during manual feature extraction 6% (n=18) were false positives which did not intersect with any target features. The results of each individual test area are presented in Table 7 and assessed based on the five factors of success in Table 8.

Table 7. Test area manual feature extraction results

Test Area ID	NNTC AOIs	NNTC STAs	MFE AOIs	Recorded Archaeological Sites	Archaeological Sites Captured by MFE
Lornex Test Area 1	38	54	27	4	3
Lornex Test Area 2	18	n/a	17	1	1
Lornex Test Area 3	45	n/a	42	0	0
South Tailings Test Area 3	n/a	21	18	1	1
South Tailings Test Area 4	n/a	24	18	3	2
North Tailings Test Area 1	45	133	68	19	18
North Tailings Test Area 2	32	160	79	3	3
North Tailings Test Area 3	8	33	27	6	6
Totals	**186**	**425**	**296**	**37**	**34**

Table 8. Analysis of test area manual feature extraction results

Test Area ID	True Positives	Missed Target Features	False Positives	Intersection by Area (m^2)	Binary Result Intersection
Lornex Test Area 1	83	13	1	81%	96%
Lornex Test Area 2	10	9	4	33%	76%
Lornex Test Area 3	36	9	2	64%	95%
South Tailings Test Area 3	16	6	2	46%	89%
South Tailings Test Area 4	18	8	4	37%	78%
North Tailings Test Area 1	127	70	4	58%	94%
North Tailings Test Area 2	178	17	0	66%	100%
North Tailings Test Area 3	44	3	1	80%	96%
Totals	**512**	**135**	**18**	**62%**[1]	**94%**[2]

1) percent of combined data set area (m^2) overlap
2) percent of binary results for combined data set

4.2.1. South Tailings Test Areas

The south tailings test areas (STTAs) have been subject to Phase 3 traditional survey and the georeferenced data set of recorded STAs and archaeological sites was provided by NNTC. Elevation within the STTAs ranges from 1215 to 1310 m asl, mean slope is 12-13°, and the mean aspect is southwest in STTA3 and northwest in STTA4. Terrain is gently sloping for the most part with breaks-in-slope, ridges, and knolls indicative of archaeological potential. In STTA3, the single recorded archaeological site (EdRh-107) was captured although the LiDAR-derived AOIs only intersected 48% with the traditional survey STAs (Figures 17 and 18). The low-profile areas of potential identified in generally featureless terrain were not visible in the LiDAR-derived DEM visualization. STTA4 has similar terrain and the lowest intersect between manual feature extraction areas and traditional survey data at 37% (Figure 19). A single archaeological site (EdRg-23) in STTA4 was missed by the manual feature extraction review; however, the site represents a surface lithic find identified in a disturbed context from road construction.

Figure 17. View north toward recorded archaeological site EdRh-107 within the south tailings test area, captured during manual feature extraction review

Photo credit: A.E.W.LP field program November 1, 2019

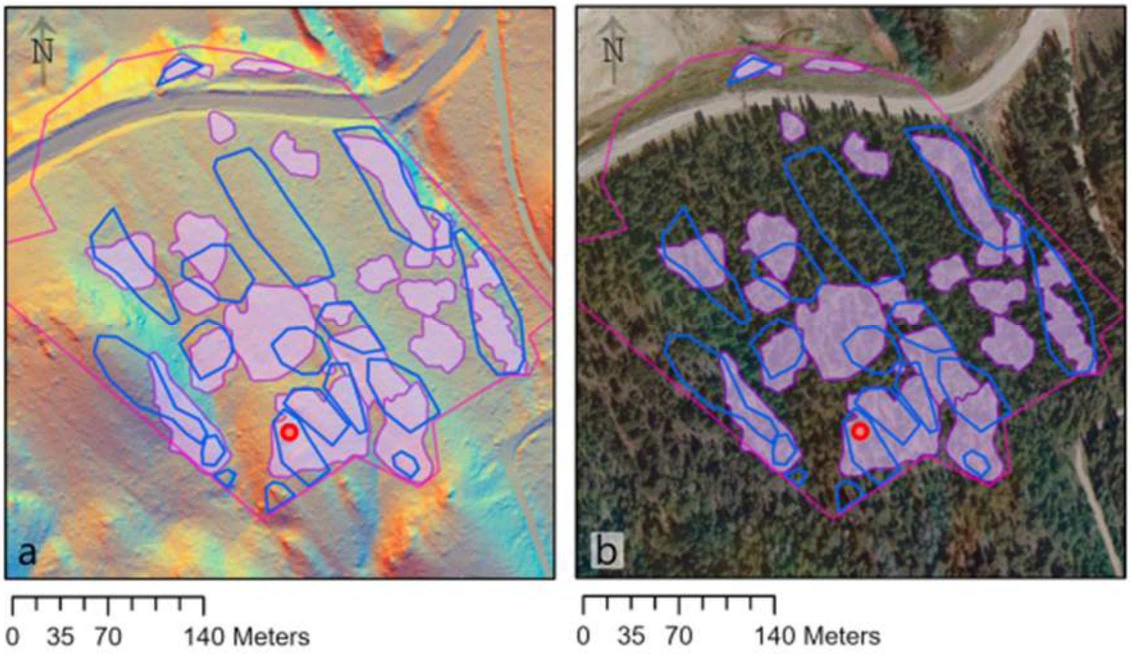

Figure 18. **South tailings test area 3 showing NNTC STA polygons (purple), MFE Review 2 AOIs (blue), recorded archaeological sites (red); a) multi-hillshade RBG composite; b) 2014 orthophotography**
Data Source: 2014 LiDAR DEM and 2014 Orthophotography property of Teck Resources

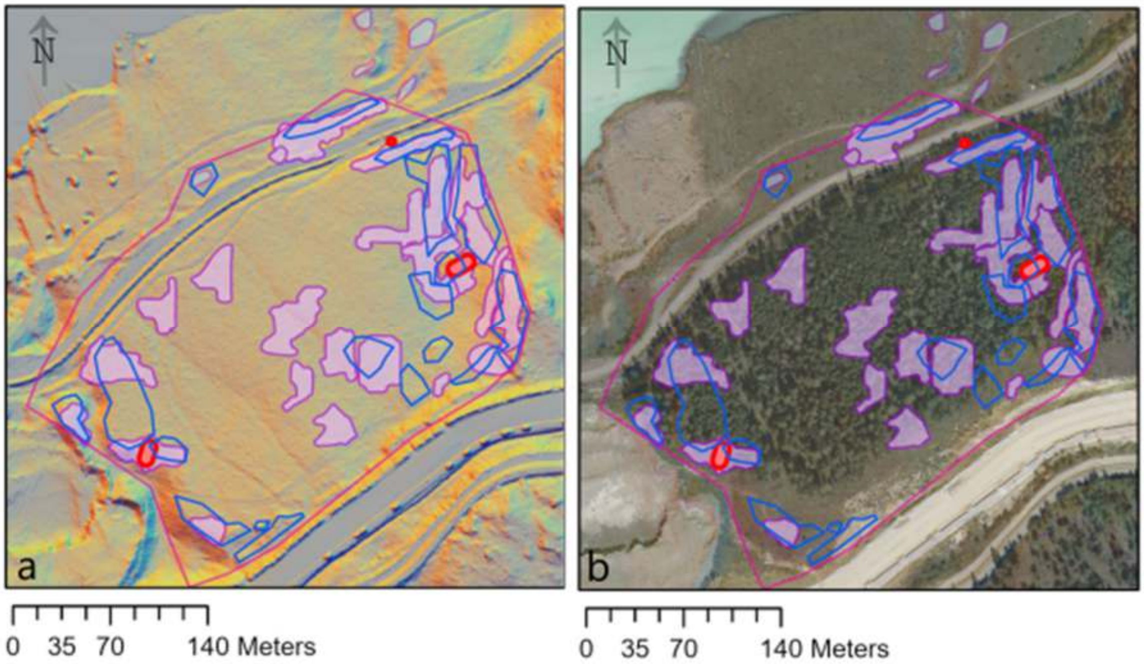

Figure 19. **South tailings test area 4 showing NNTC STA polygons (purple), MFE Review 2 AOIs (blue), recorded archaeological sites (red); a) multi-hillshade RBG composite; b) 2014 orthophotography**
Data Source: 2014 LiDAR DEM and 2014 Orthophotography property of Teck Resources

4.2.2. North Tailings Test Areas

The three north tailings test areas (NTTA) include a total of 112 ha of terrain on the north side of the HVC valley. Large drainages (extant, ephemeral, and abiding) are present within this portion of the study area, which has a general south/southeastern aspect and is dominated by rocky outcrops and breaks-in-slope (Figure A.1, Appendix A). The elevation in these locations ranges from 1202-1280 m asl with a mean slope ranging from 9-12° and a south-southwestern aspect. As with most lands within HVC, these areas have been subject to extensive land alteration activities from mine development including the construction of haul roads, drainages, pumphouse facilities and laydown areas. Forest cover is comprised of ponderosa pine, Engelmann spruce and alder. Archaeological sites typically consist of surface and subsurface lithic scatters on defined microtopographic landforms with south/southwest aspects as well as within low-lying swales between knolls and ridges.

Within the three north tailings test areas there were 28 recorded archaeological sites. These were distributed unevenly with the majority (n=19) of sites located in NNTA1 with three and six located in NTTA2 and NTTA3 respectively. Twenty-seven or 96% of these archaeological sites were captured during the manual feature extraction LiDAR-analysis. The target feature detection rate for AOIs/STAs ranged from 64% to 100%. The percentage of false positives ranged from 4% to 6%, with no false positives identified in the NTTA2. The overall intersection of the manual feature extraction and traditional survey AOIs by area (m^2) was between 40% and 88%. NNTA3 had the best results of any test area as all but one of the target features were identified (Table 7; Figure 20). Figures A.1 and A.2 show LiDAR-derived AOIs compared to traditional survey data for NTTA1 (Appendix A). Figures A.3 and A.4 show LiDAR-derived AOIs compared to traditional survey data for NTTA2 (Appendix A).

A false positive identified during the LiDAR review for NTTA3 was determined during post-analysis as a modern landscape modification. When undetected in the MFE process, disturbances of this type may present attributes suggesting archaeological potential (Figure 20). Gaining experience with a study area and the ways in which modern landscape modifications appear in visualized DEMs would greatly reduce this type of false positive.

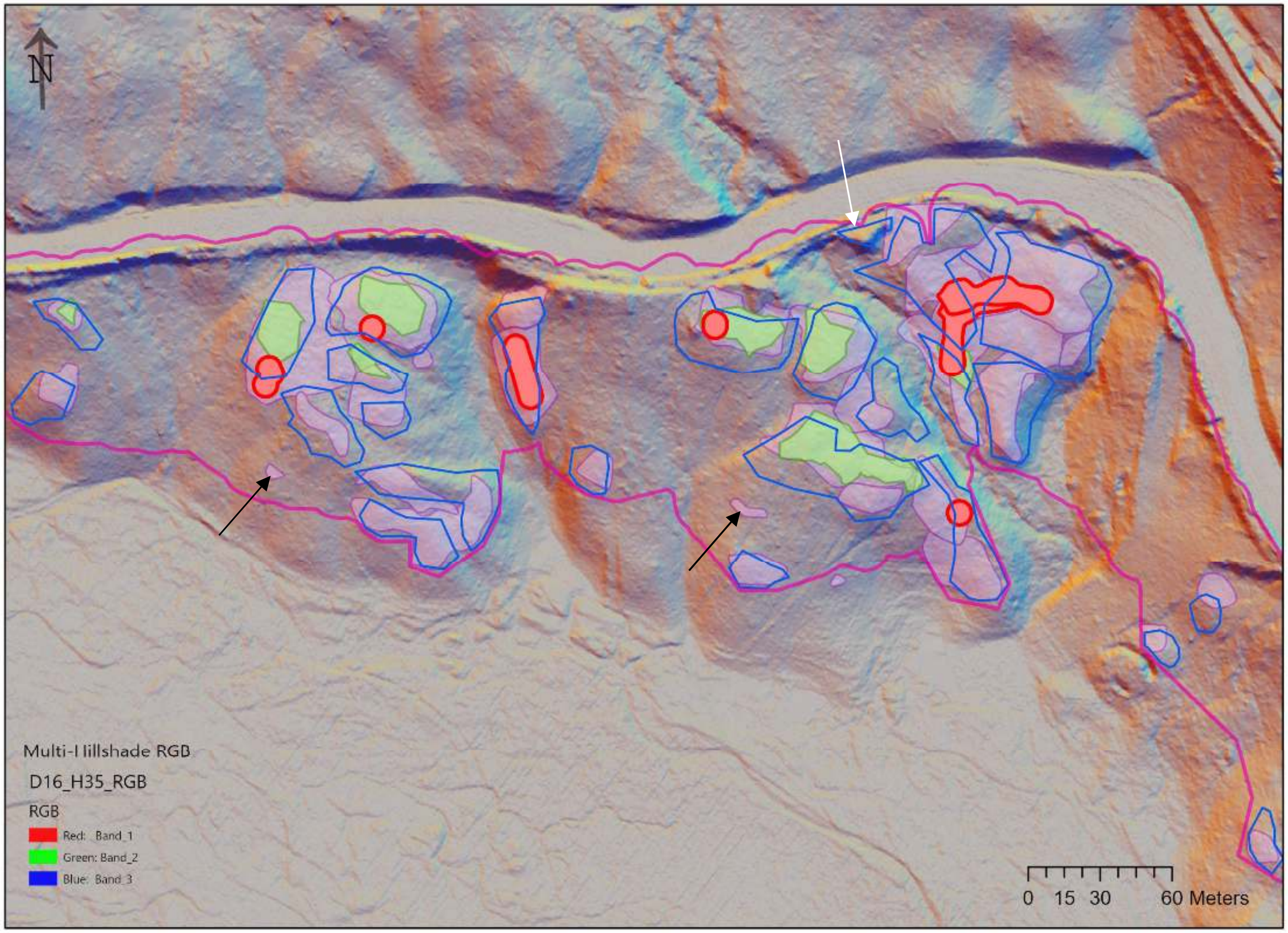

Figure 20. **North tailings test area 3 showing NNTC STA polygons (purple), AOI polygons (green), MFE Review 2 AOIs (blue), recorded archaeological sites (red); false positive (white arrow), missed target features (black arrows)**

Data Source: 2014 LiDAR DEM; Multi-Hillshade RGB (Directions = 16, Angle = 35°)

There are two missed target features identified in Figure 20 resulting from their relatively low profile. If low-profile landforms with archaeological potential are common in an area, the LiDAR point cloud data can be post-processed with a Gaussian low-pass filter. This smooths the DEM and reduces the noise created by macrotopography, amplifying the contrast of a target feature (Kokalj and Hesse 2017). This was not possible here as the LiDAR data was provided as a processed DEM.

4.2.3. Lornex Test Areas

The Lornex test areas (LTAs) are located on the southwest side of the main mine pit. Following initial impact assessment work, the pit was expanded to impact lands within LTA3 (Figure 21). The elevation within the LTAs ranges from 1539 to 1610 m asl, the mean slope is 12-18° and the mean aspect ranges from southwest to southeast. The landscape differs from the other test area locations in that microtopographic landforms in this terrain are represented by a series of curved lineaments and ridges caused by glacial erosion and run-off. All recorded archaeological sites were captured by the manual feature extraction review, which intersected with the original survey data between 33 and 86%, with the lowest intersection in LTA2 (Figures A.5 and A.6). Only 50% of the target features were identified within LTA2, while LTA1 and LTA3 had greater success in target detection ranging from 80-84%. The percentage of false positives for LTA1 and LTA3 were 18-24% with only 4% false positives identified in LTA2. The correlation between the quantity of target features identified and the rate of binary intersection and false positives is clear. This means, the more LiDAR-derived AOIs that are selected within a test area, the greater chance of intersecting with target features as well as having more false positives. The binary intersection rate of manual feature extraction AOIs, which at least partially intersect with target features is between 76 and 96% for the three LTAs.

Quintus and others (2017) implement a level of confidence rating during manual feature extraction, which may encourage the reviewer to be more liberal in assigning target features in areas where they are less certain or obvious. A level of confidence rating would allow the researcher to track the estimated likelihood that false positives are in fact target features.

Figure 21. Lornex test areas 1 and 2, showing NNTC AOI polygons (green), NNTC STA polygons (purple) and manual feature extraction review 2 AOIs (blue), recorded archaeological sites (red), missed target features (black arrows)

Data Source: 2019 orthophotography, property of Teck Resources

4.3. Manual Feature Extraction Blind Study Area Results

The blind study results are predictably lower than that of the test areas, as no NNTC-collected target feature data was reviewed for either area prior to the manual feature extraction process. In the Lornex blind study area, 75% of archaeological sites were captured during the manual feature extraction review, during which 85% of the LiDAR-selected AOIs intersected with target features (Table 9; Figure 22). However, only 50% of the pedestrian survey AOIs and 60% of the NNTC STAs were identified by manual feature extraction. At the time this study was conducted there were no archaeological sites recorded within the North Tailings blind study area as only preliminary survey has been completed. The review had an 85% success rate for LiDAR-derived AOIs intersecting with target features and all of the NNTC AOIs were identified. Only 68% of the total target features were identified by the manual feature extraction process and 75% of the recorded archaeological sites were captured (Tables 9 and 10). The results of each individual blind study area are presented in Table 9 and assessed based on the five factors of success in Table 10.

Table 9. Blind study area manual feature extraction results

Test Area ID	NNTC AOIs	NNTC STAs	MFE AOIs	Recorded Archaeological Sites	Archaeological Sites Captured by MFE
Lornex Blind Study Area	179	258	98	12	9
North Tailings Blind Study Area	112	n/a	143	n/a	n/a
Totals	**291**	**258**	**267**	**12**	**9**

Table 10. Assessment of blind study area manual feature extraction results

Test Area ID	True Positives	Missed Target Features	False Positives	Intersection by Area (m^2)	Binary Result Intersection
Lornex Blind Study Area	265	194	14	60%	86%
North Tailings Blind Study Area	112	0	26	42%	82%
Totals	**378**	**194**	**40**	**56%**[1]	**85%**[2]

1 = percent of combined data set area (m^2) overlap; 2 = percent of binary results for combined data set

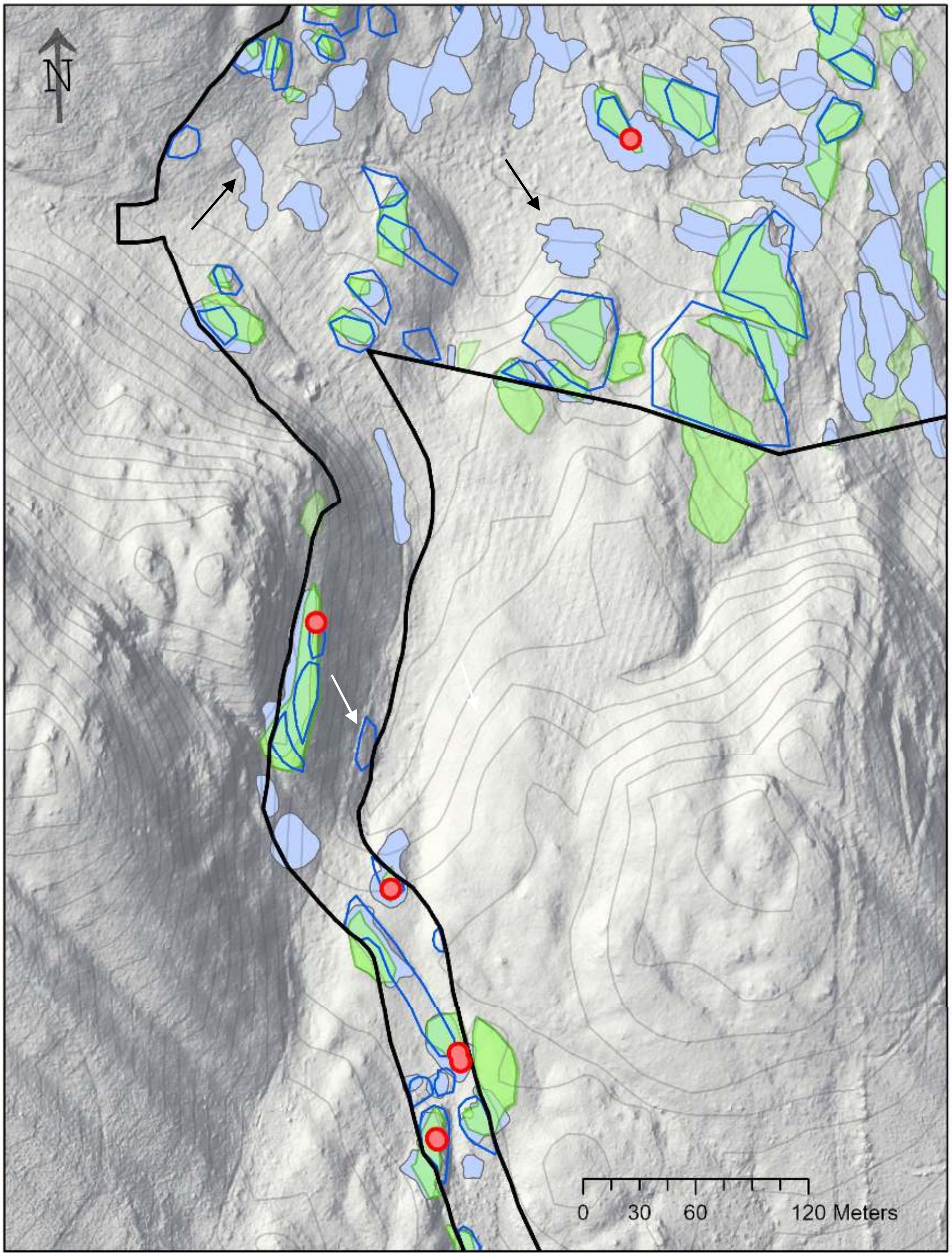

Figure 22. **Lornex blind study area results, showing NNTC areas of interest (green), NNTC subsurface test areas (light blue), MFE areas of interest (dark blue outline), recorded archaeological sites (red), example of false positive (white arrow) and examples of missed target features (black arrow)**

Data Source: 2014 LiDAR DEM property of Teck Resources; Standard Hillshade (Azimuth=270; Angle=45; z-factor=2); Arc GIS Pro produced 2.5 m contour lines

A total of 15% of the reviewer AOIs in the blind study areas were false positives, which is significantly higher than the test area results. This is likely the result of over sampling by the reviewer in the North Tailings blind study area, where far fewer AOIs were recorded during traditional survey. A more conservative approach during manual feature extraction would likely have resulted in a lower overall feature detection success but would have increased the binary intersection result while reducing the number of false positives (Grammar et al. 2017:321).

Differences in terrain, landform type and sampling strategy likely contributed to the variances in results between the blind study areas and the test areas. The higher ‘missed target features’ in the Lornex blind study area is assessed as being a result of an extensive low-profile microtopographic landform testing strategy in the original survey that could not be duplicated with the manual feature extraction method. It may be possible to correct for this using the DEM with relative slope and elevation kernel analysis.

4.4. Manual Feature Extraction AOI and Target Feature Intersection by Area (m^2)

Using the ‘intersect’ geoprocessing tool in ArcGIS each set of LiDAR-derived AOIs was compared with the target features to see how closely they aligned in total area (m^2). The intersectionality or the percentage of overlap between the traditional survey data and the manual feature extraction process results was then calculated (Table 11). The percentage of area (m^2) of target features captured by the manual feature extraction method is a measure of the method’s accuracy. As a complete dataset the test area AOIs overlapped 61% and the STAs overlapped 63% with the manual feature extraction results. The blind study area results identified a 39% overlap between the NNTC AOIs and manual feature extraction features (Table 12). Within the Lornex blind study area 70% of the STA feature area was captured by the manual feature extraction review.

Table 11. **Test area manual feature extraction intersectionality results by area**

Test Area ID	Total Area[1] of NNTC AOIs	Total Area of NNTC STAs	Total Area of MFE AOIs	Overlap of NNTC and MFE AOIs	Overlap of NNTC and MFE STAs	Percentage of overlap[2]	
						AOIs	STAs
Lornex Test Area 1	18,734	18,649	30,036	16,030	14,120	86%	76%
Lornex Test Area 2	2,807	n/a	4,051	933	n/a	33%	n/a
Lornex Test Area 3	12,432	n/a	14,053	7,982	n/a	64%	n/a
South Tailings Test Area 3	n/a	27,852	28,826	n/a	12,928	n/a	46%
South Tailings Test Area 4	n/a	17,341	11,582	n/a	6,434	n/a	37%
North Tailings Test Area 1	17,504	74,349	76,163	7,075	46,290	40%	62%
North Tailings Test Area 2	17,463	70,888	95,080	8,880	49,339	51%	70%
North Tailings Test Area 3	2,785	17,460	18,872	2,785	13,384	100%	77%
Totals	**71,725**	**226,539**	**278,663**	**43,685**	**142,495**	**61%**	**63%**

1) all measurements in metres squared
2) percentage of NNTC target feature area captured by manual feature extraction method

Table 12. **Blind study area manual feature extraction intersectionality results by area**

Blind Study Area ID	Total Area[1] of NNTC AOIs	Total Area of NNTC STAs	Total Area of MFE AOIs	Overlap of NNTC and MFE AOIs	Overlap of NNTC and MFE STAs	Percentage of overlap[2]	
						AOI	STA
Lornex Blind Study Area	65,865	150,385	69,076	24,060	104,190	37%	70%
North Tailings Blind Study Area	56,955	n/a	74,780	24,095	n/a	44%	n/a
Totals	**122,820**	**150,385**	**155,097**	**48,155**	**104,190**	**39%**	**70%**

1) all measurements in metres squared
2) percentage of NNTC target feature area captured by manual feature extraction method

4.5. Missed Target Features

Manual feature extraction and interpolation using LiDAR-derived DEM visualizations can only be implemented as a tool for archaeological prospection if both the error rate and success rate of target feature detection are understood. To accomplish this task each missed target feature (i.e., AOIs and recorded archaeological sites) were reviewed. The number of missed archaeological sites was quite small, so all the locations were re-evaluated in an error matrix. However, as a sample, only the location with the highest number of missed AOIs (Lornex Blind Study Area) was reviewed to understand more about the landscape attributes of the missed target features.

During the field visit missed target features within NTTA1 were visited to observe landscape attributes indicative of archaeological potential missed during the manual feature extraction process. After evaluating the missed archaeological site target features, four primary factors are identified which contributed to these features being missed. These factors include:

1) the landform on which the site is located was partially identified during manual feature extraction but the area selected failed to capture the archaeological site;

2) the microtopography with which the archaeological site is associated was obscured by adjacent landscape alteration;

3) the site itself is in a disturbed context and therefore, not associated with a typical landscape feature; and,

4) the site is located on a low-profile microtopographic feature that is difficult to observe using the LiDAR DEM visualizations. It is noted that Sky-view factor was the only visualization technique that, when re-examined, displayed contrast at one of the missed low-profile archaeological site locations.

Six recorded archaeological sites out of a data set of 49 were missed during the manual feature extraction process within the test areas and blind study areas. All missed sites represent limited subsurface lithic scatters measuring 25 to 150 m^2. The manual feature extraction method employed during this study captured 34 of 37 recorded archaeological sites (92% accuracy) within the test areas and 9 of 12 archaeological sites (75% accuracy) within the blind study areas. To examine this variance, the nature of each missed target feature was analyzed and compared with the baseline zonal statistical analysis results (Table 13). Additionally, a follow-up visual inspection of the LiDAR, field photographs and orthophotographic imagery was conducted (Figures 23 - 26).

One site location, EdRg-23 within STTA4, was visited in the field to examine the nature of the terrain and microtopography of the area. EdRg-23 was recorded in a disturbed context, its' original microtopographic landform destroyed during adjacent road construction. These types of disturbed or redeposited target features are unlikely to be identifiable during the manual feature extraction process. They require in-field surface survey of development infrastructure where surface artifacts may be present. Including EdRg-23, the re-evaluation of missed-archaeological site locations is summarized in Table 13.

Figure 23. View southwest of recorded archaeological site EcRg-36 located in the Lornex blind study area, missed during manual feature extraction

Photo credit: A.E.W.LP field program July 25, 2018

Table 13. Archaeological sites missed by LiDAR-derived DEM manual feature extraction evaluation

Site ID	Area/ BSA[1] ID	Mean Slope	Slope Range	Evaluation
EdRg-23	STTA4	23°	38°	This site is located only 3 m outside of the manual feature extraction AOI. The location is a disturbed bank at the edge of a mine access road and is likely the remnant deposit from a high potential microtopographic landform destroyed by the road construction. It is unlikely that a site of this nature would be identifiable using the MFE[2] method, however, while in the field ground-truthing the adjacent AOI this disturbed surface find would likely be encountered.
L48701-DM17-T001	NTTA1	7°	10°	An LiDAR-derived AOI is located 12 m east of the site boundary on the same landform. However, the majority of the NNTC test area is located outside of the nearest manual feature extraction AOI, which only captured the easternmost portion of this low-profile landform (Figure 23).
EcRg-36	Lornex BSA	4	17	The closest LiDAR-derived AOI is located 36 m northeast. There are also several missed AOI features in the vicinity of this site suggesting that the landscape attributes of these target features are not easily observable during the MFE process (Figures 24 and 25). Upon review of the different visualization techniques, the site location appears minimally elevated above surrounding terrain but is adjacent to level, elevated and well-defined features which may have led to this area not being selected during MFE review.
EcRg-40	Lornex BSA	10	17	This site is located 24 m southwest of the nearest LiDAR-derived AOI. The landform is not distinguishable from surrounding terrain in any of the visualizations, apart from Sky-view Factor. It is likely that the difference in elevation between this landform and surrounding terrain is too low-profile to observe using most LiDAR visualization techniques
EcRg-43	Lornex BSA	10	17	The closest LiDAR-derived AOI is located 36 m southwest. There are also several missed AOI features in the vicinity of this site suggesting that the landscape attributes of these target features are not easily observable during the MFE process. Upon review of the different visualization techniques, the site location appears minimally elevated above surrounding terrain but is adjacent to a mine access road and the area appeared disturbed and featureless during MFE.A photograph (Figure 26) of the site shows a heavily impacted, low-relief microtopographic landform, bisected by a road. The linear road feature may have dissuaded this area being selected as an AOI during the MFE review.

1) BSA = Blind Study Area; 2) MFE = manual feature extraction

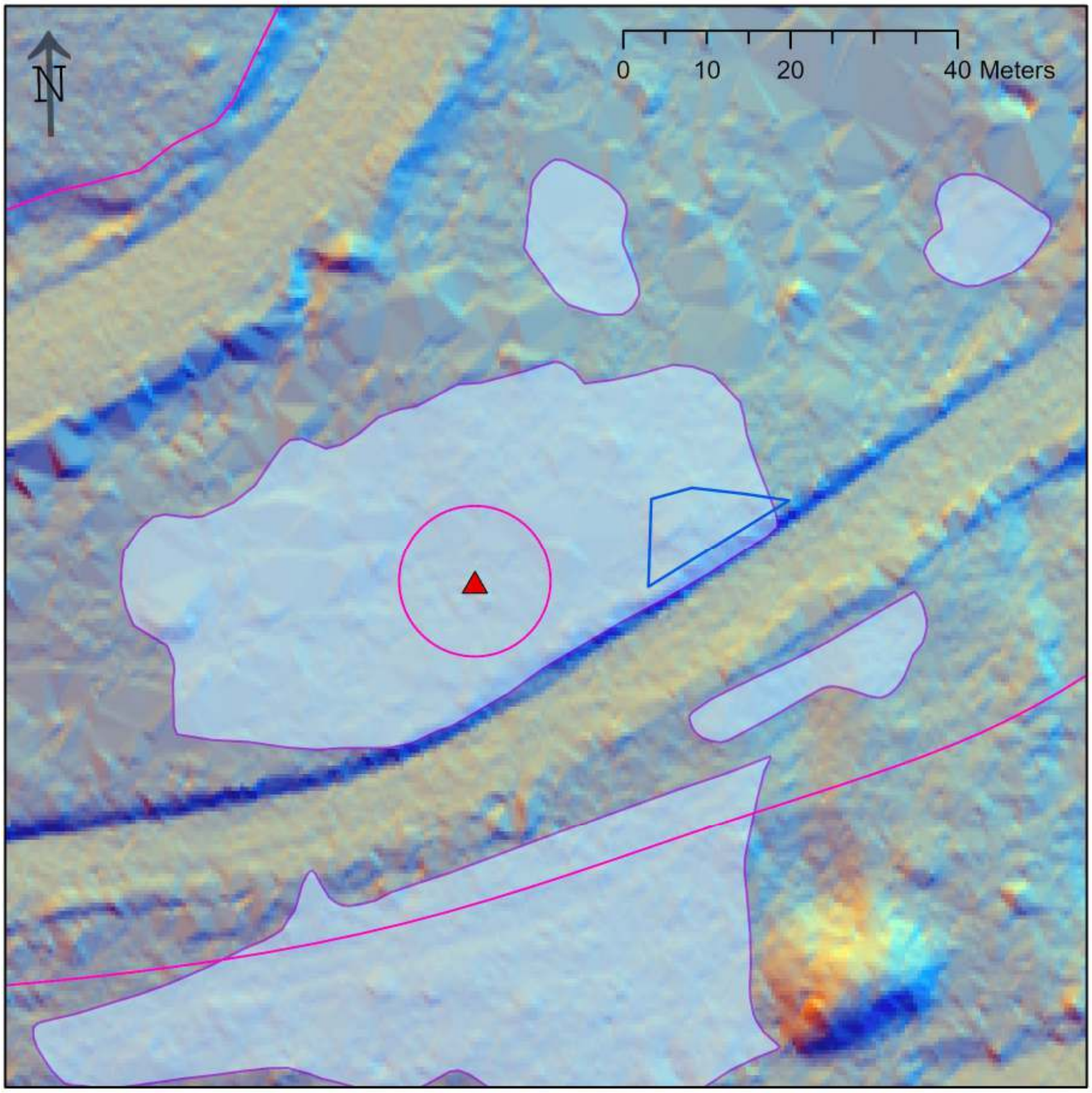

Figure 24. **North tailings test area 1, showing NNTC STA polygons (light blue) and manual feature extraction AOIs (dark blue), recorded archaeological site L48701-DM17-T001 (red triangle 10 m buffered with pink circle)**

Data Source: 2014 LiDAR DEM property of Teck Resources; Multi-Direction Hillshade (Directions=16; Angle=35)

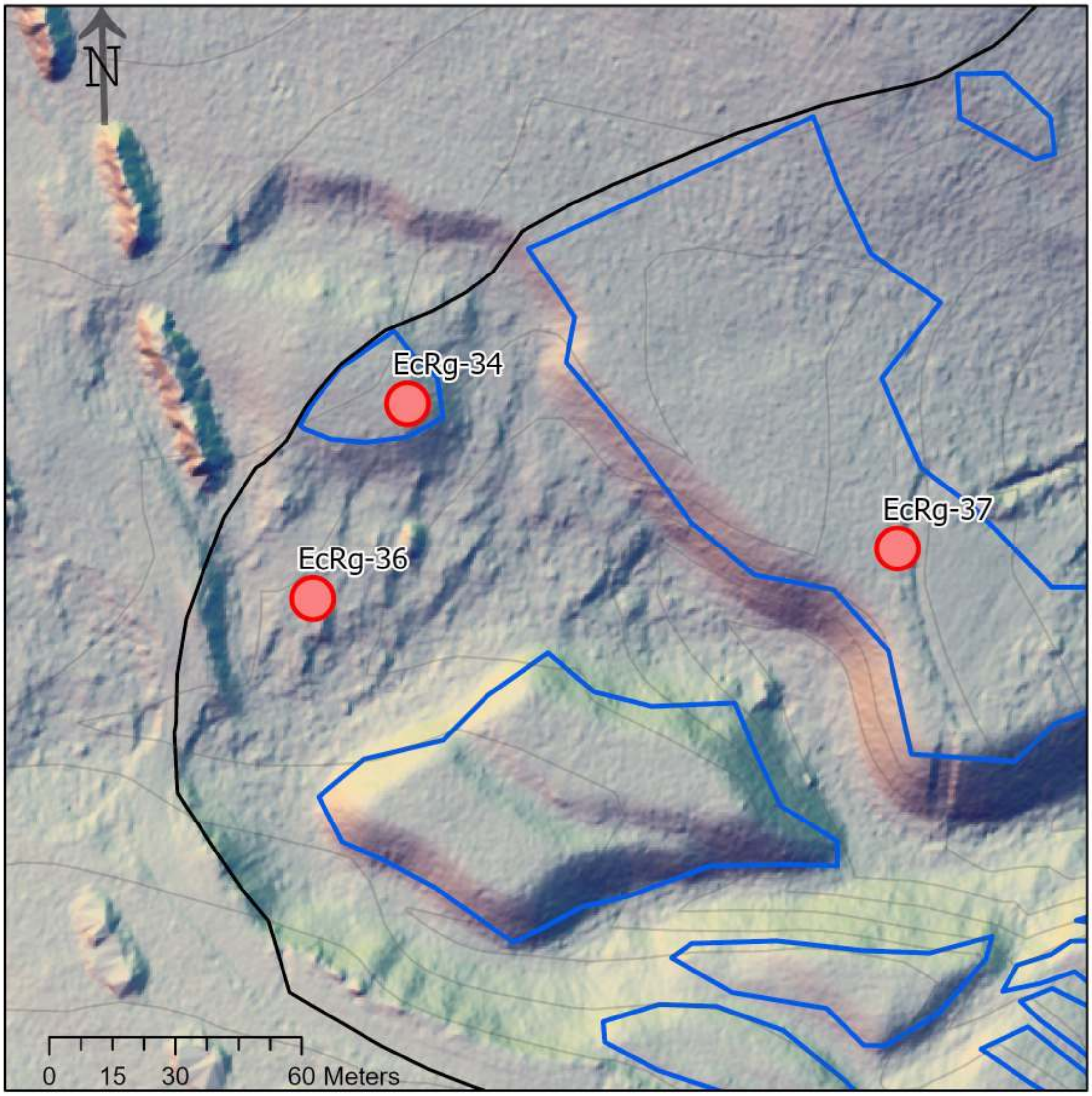

Figure 25. **Lornex blind study area showing manual feature extraction AOIs (dark blue) and missed archaeologcal site EcRg-36**

Data Source: 2014 LiDAR DEM property of Teck Resources; blended image with Slope Gradient (50% transparency); Standard Hillshade (50% transparency); and Multi-Direction Hillshade (Directions=16; Angle=35)

Figure 26. **View north-northwest toward recorded archaeological site EcRg-43 located in the Lornex blind study area, missed during manual feature extraction**

Photo credit: A.E.W.LP field program August 21, 2018

4.5.1. Areas of Interest and Subsurface Test Areas

The test areas cumulatively had fairly low occurrences of missed AOI and STA target features (2% STAs and 29% of AOIs missed). The Lornex blind study area had the highest occurrence of AOIs (50%; n=90) and STAs (100; 39%) missed during the manual feature extraction process. Upon review of the missed target feature locations within the Lornex blind study area, several factors contributed to the oversight. The Lornex blind study area, in general, has fairly level, high elevation terrain with s-shaped microtopographic ridges and eskers present from past glacial run-off erosion. Many of these features are small and low-relief, while other are deeply incised and show-up as high-contrast in several of the visualization techniques.

Further, this is the largest study area selected and, at the time the orthophotography was taken in 2014, it had been logged for mine pit expansion. There are other land-altering impacts to the area from logging and road construction as well as sediment removal and piling associated with mine activities (Figure 27). These landscape disturbances impede the visibility of microtopographic features during manual feature extraction as they obscure the natural landscape attributes with artificial relief.

Figure 27. **View north within northern portion of the Lornex blind study area showing land altertaion from logging and road construction**
Photo credit: A.E.W.LP field program August 21, 2018

4.5.2. Ground Observations

Ground-truthing of remotely sensed archaeological areas of interest is essential in assessing the efficacy of methods. Since the test areas and blind study areas have all been subject to Phase 2 and/or Phase 3 survey, the majority of the manual feature extraction results regarding intersection and detection success can be assessed without further field survey. However, the landscape attributes and nature of missed AOIs as well as results from the ground-truthing of false positives requires in field survey. Due to scheduling and other issues[6], a review of missed AOI locations was limited to a single, brief field visit as it has been noted. The false positive polygons and centroid points have

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[6] Fieldwork was further restricted as a consequence of the 2020 coronavirus pandemic in relation to government, university and facility operator guidelines.

been provided to NNTC and, perhaps, future inspection of these areas can be undertaken.

The methods and techniques employed by a crew excavating shovel tests on an AOI in the north tailings area was observed, and locations of missed target features were visited to identify landscape attributes that could account for an absence of visual evidence in the LiDAR-derived imagery. Figure A.1 shows an area where at least 20 target features were not captured by the manual feature extraction review (Appendix A). These locations were observed during the field visit, and although the general terrain in this area is gently sloping and featureless, small glacial erratic boulders were identified as AOIs as these areas have higher cultural significance and often have been found in association with lithic scatters in NNTC territory (Kim Christensen, personal communication 2020; Figure 28). This in an example where traditional knowledge is integrated into heritage resource management programming but where the identification of these feature in MFE review is extremely difficult. This consideration subsequently would be incorporated in the phase 2 field survey.

In the north tailings area, one location was visited where sedimentation from the tailings pond has buried the original surface topography. This type of land alteration has significant impacts on the archaeological potential and testing strategy employed in an area but cannot be observed in the LiDAR visualization.

Figure 28. North tailings test area 1, view southeast of missed NNTC AOI with large boulder in gently sloping, undifferentiated terrain (15-Sept-2020)

Piro and Campana (2008:325) suggest that target features can be identified by different methods to varying degrees but that “the inherently different characteristics of the various techniques produces a quantitative enrichment in the representation of the buried evidence.” Redundancy in data acquisition and interpolation can be smoothed in the data using intersection and in the comparison of remotely sensed information and ground-truthed results.

As previously described, STTA4 was also visited to observe the location of a recorded archaeological site and STAs not captured during the manual feature extraction process. The terrain is a gentle, featureless slope (10°) with minimal breaks or changes. The sites identified at the edges of the test area are near the defined edges of the terrain and, while the manual feature extraction captured the archaeological site locations, many of the AOIs on the gently sloping terrain showed no characteristics indicative of archaeological potential during the LiDAR-analysis. The professional judgement and personal preference of the recorder in the field as well as assessments of potential relative to the results of surrounding STAs likely contributed to the discrepancy between the manual feature extraction and traditional survey AOI results in STTA4. Additionally, this test location, while generally featureless and gently sloping has a very clear view of the valley below from the northern extent. While the landform located directly adjacent to a mine access road does not appear high potential when reviewing the LiDAR visualizations, in person the viewshed quality of the location is impressive and denotes archaeological potential as a strategic camping and hunting location.

Digital viewshed analysis in the form of isolation models have been created using LiDAR-derived elevation data (Challis et al. 2011). This type of intangible landscape aspect is difficult to assess without being present on the ground. Further, Martinez-del-Pozo and others (2013:241) remind us that while viewshed analysis and other geoprocessing tools for ascribing inherent archaeological value to terrain are valuable, they run the danger of evaluating past landuse based on modern topography.

4.6. Accuracy Validation

The accuracy of the manual feature extraction method was assessed using the Kvamme's gain analysis to review the test area and blind study area results. This analysis first required the percentage of area identified as having archaeological potential within each test area to be calculated. Next the percentage of the total sites that were captured within each test area was calculated and these totals input into the Kvamme gain equation. The Lornex test area 3 and the North Tailings blind study area have no recorded archaeological sites and both were therefore not included in this accuracy validation analysis.

The Kvamme's gain statistical analysis of the test area results is 0.82 and 0.79 for the blind study areas (Tables 14 and 15). These results show that the manual feature extraction process could meet the Provincial accuracy requirements to be considered a moderately effective model with further refinement and reviewer experience. Further, the manual feature extraction analysis method would be a valid modelling technique for archaeological site prospection at the Highland Valley Copper Mine.

Table 14. Test area results Kvamme's gain calculation

Test Area ID	Total Area (m^2)	Total Area AOIs (m^2)	Percentage of Area Covered by Model	Percentage of Total Sites within Model Area	Kvamme Gain[1]
Lornex Test Area 1	217,594	30,036	0.14	1.00	0.86
Lornex Test Area 2	45,669	4,051	0.09	1.00	0.91
South Tailings Test Area 3	88,753	28,826	0.35	0.67	0.48
South Tailings Test Area 4	75,599	11,582	0.15	1.00	0.85
North Tailings Test Area 1	538,734	76,163	0.14	0.95	0.85
North Tailings Test Area 2	512,558	95,080	0.19	1.00	0.81
North Tailings Test Area 3	70,075	18,872	0.27	1.00	0.73
Totals	**1,548,982**	**264,610**	**0.17**	**0.95**	**0.82**

1) equation used: [1 – (percentage of total area covered by the predictive model/percentage of total sites within the model area)]

Table 15. Blind study area results Kvamme's gain calculation

Test Area ID	Total Area (m^2)	Total Area AOIs (m^2)	Percentage of Area Covered by Model	Percentage of Total Sites within Model Area	Kvamme Gain[1]
Lornex Blind Study Area	436,611	69,076	0.16	0.75	**0.79**

1) equation used: [1 – (percentage of total area covered by the predictive model/percentage of total sites within the model area)]

The results of the test area and blind study area LiDAR-derived MFE analysis presented in Tables 7 and 8 were used to calculate the F_1-score for each group. First the factors required for the calculation (True Positive, Missed Target Feature and False Positive) were used to calculate the Sensitivity and Precision for each group. Finally, the F_1-Score was calculated using the Precision and Sensitivity for each group. The test area manual feature extraction review had an F_1-score of 0.87 and the blind study area results had an F_1-score of 0.72 (Table 16). While the test area results had good classification accuracy, the blind study area results had only a fairly good overall accuracy.

Table 16. Manual feature extraction results F_1-score accuracy calculation

Calculation Equation[1]	Test Area	Blind Study Area
Precision (P) $\mathbf{TP}/(\mathbf{TP}+\mathbf{FP})$	$\frac{512}{512+18}=0.97$	$\frac{266}{266+14}=0.95$
Sensitivity (R) $\mathbf{TP}/(\mathbf{TP}+\mathbf{MTF})$	$\frac{512}{512+135}=\ 0.79$	$\frac{266}{266+193}=0.58$
F_1 score $\mathbf{2PR}/\ (\mathbf{P}+\mathbf{R})$	$\frac{2(0.97)(0.79)}{0.97\ x\ 0.79}=0.87$	$\frac{2(0.95)(0.58)}{0.95+0.58}=0.72$

1) Calculation uses data presented in Tables 8 and 9.

4.7. False Positive Review

It is important to understand the nature of the AOIs selected during LiDAR-assisted manual feature extraction which do not correspond to any microtopography assessed as having archaeological potential by NNTC. To this end, all 'false positive' AOIs identified during manual feature extraction analysis were saved in ArcGIS as a separate georeferenced layer and subject to in-office visual review and zonal statistics. The purpose of this re-evaluation was to identify landscape characteristics (e.g., disturbance, steep slopes) that may explain the absence of NNTC-assessed archaeological potential. Slope analysis was conducted for each false positive and compared with the mean slope for recorded archaeological sites in the study area, 10° mean slope/10° slope range, and the STA slope analysis results which indicate a mean slope of 9° with a 21° range in slope. The results of this review are presented in tabular format in Appendix B.

There were 18 false positives identified within the test areas and 40 identified within the blind study areas. Five false positive locations from the test areas have a mean slope within two degrees of the objective parameters and of those only four have a slope range within two degrees of the objective. Within the blind study areas 23 false positives have a mean slope within 2 degrees of the objective criteria and of those 9 have a range that also meets the objective criteria. This suggests that conducting zonal statistical analysis on MFE results may refine the areas of identified false positives to ensure that landscape attributes meet the objective criteria for the study area.

Seven of the test area false positives and 14 of the blind study area false positives were reassessed as having low archaeological potential. This re-evaluation was based on: 1) a comparison of the zonal statistics with the objective criteria parameters; 2) a review of orthophotography to better understand previous land alteration; and, 3) a review of all the LiDAR-derived image visualizations. This represents a 36% decrease in false positives. A multi-reviewer workflow with an experienced second opinion of all AOIs potentially could lead to similar reductions. It also is possible that these locations do in fact have archaeological potential not identified during a phase 2 survey. Potential reasons for this include low-relief or limited definition of microtopography, recorder training or preference, dense vegetation cover or past land alteration. Future in-field examination of false positives, thus, will be an important consideration for use of LiDAR based data in survey design to understand the error and success rate of the method.

4.8. Cost-Benefit Analysis

To complete the cost-benefit analysis a hypothetical heritage management program was devised to assess the costs associated with incorporating LiDAR-analysis into the workflow. Program financial data and estimates of effort were acquired from NNTC to provide a hypothetical baseline level-of-effort for program execution per hectare. Cost estimates for the hypothetical 3-phased assessment program and the assumptions they are based on are presented in Appendix C.

The current heritage management program at HVC is a three-phased approach. To assess the cost-benefit of incorporating LiDAR into the archaeological prospection toolkit I theoretically proposed replacing Phase 2 traditional survey with in-office LiDAR analysis. A hypothetical budget based on the assumptions provided and standard industry labor rates and fees, was created for manual feature extraction LiDAR-analysis and traditional survey (Appendix C). A sample project area measuring 30 ha was proposed, assuming that 15% of the total area would be assessed as having high archaeological potential and require phase 3 systematic ground-truthing. The high potential area percentage is based on the total area within the two blind study areas assessed as having high archaeological potential during traditional survey, which was 14%. Associated labour costs include project management and GIS technician post-field data processing. Expenses include accommodation and per diem for all out-of-town field personnel, and regional travel. LiDAR analysis involves project management and senior scope review and planning, pre-processing of data visualizations and geospatial map production. No expenses are anticipated for this project as the LiDAR imagery is already available for the entire development area.

The total hypothetical budget to complete a three-phased traditional survey and assessment is $246,675. Phase 2 represents 14% of the total budget at $34,875. The cost estimate for completing LiDAR-analysis of the test area is $6,750. With phase 2 survey replaced or modified by incorporating LiDAR-analysis into the workflow an 82% budget reduction could be achieved in phase 2. In this scenario there would be an overall program cost saving of 13%. Interestingly, no time would be saved by using the LiDAR-analysis method in place of phase 2 survey as the review and the survey are estimated to each take 5 days. Although a standardized estimate of one hour of LiDAR-review for each hectare of development area was used for this analysis, this method would likely become more efficient and refined as the experience and development size increase.

As there is high-resolution LiDAR data available for the study area there are no costs included for acquiring this data. However, for other heritage resource management studies, acquisition of project-specific LiDAR data usually costs approximately $125 to $635 CAD/square mile (2.59 km^2) (Gallagher and Josephs 2016:203). Alternatively, there are ever increasing opensource sets of LiDAR imagery and developers, industrial clients as well as local and federal government agencies often have their own proprietary LiDAR data sets collected for a variety of non-archaeological purposes. For example, the Canadian LiDAR data opensource network focuses on sharing existing LIDAR data for research (Opitz 2013:30). As with most technological innovation, the main cost is in the development of the new process and training of personnel or subcontracting specialists to complete the analysis. These costs can be identified as a relative saving based on efficiencies created in the traditional survey and archaeological prospecting program. The availability of opensource software to complete this type of analysis democratizes archaeological site prospection and makes remote sensing a potentially viable tool for any archaeological study. Access to LiDAR data is often the biggest hurdle for prospective researchers but the advent of low-pass drone-captured LiDAR (Risbøl and Gustavsen 2018) will potentially provide more opportunities for data acquisition.

4.9. Analysis Results Summary

The total area (m^2) selected by R1 and R2 intersected by 50%, and the recorded archaeological site capture success rate was 10% higher in the R2 results, with three additional sites captured in three test areas. This shows both differences in the reviewer interpretation as a result of gaining experience as well as general differences in visual interpretation over time. It is important to regularly check the interpretation bias of reviewers during LiDAR-analysis using control areas. This iterative process allows the reviewer to gain experience and become aware of the ways in which their interpretations of DEMs affect target feature detection success rates.

Traditional survey and LiDAR-derived AOI data were compared for eight test areas and two blind study areas based on five factors (Tables 7-10). The comparisons were examined as a combined data set before delving into the specific results for each location. Although results varied between each test area for some review factors, there were also consistencies between many of the results.

The test area results indicate:

- Overall intersection (m^2)[7]: 62%
- True positives: 71% AOIs, 81% STAs and 92% of archaeological sites
- False positives: 6% (n=18)
- Missed target features: 29% AOIs and 19% STAs and 8% of archaeological sites
- Binary intersection results[8]: 94%

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[7] Total overlap of area in metre squared identified during LiDAR analysis and traditional survey

[8] Percentage of manual feature extraction AOIs that at least partially intersected with target features

The blind study area results indicate:

- Overall intersection (m^2): 56%
- True positives: 72% AOIs, 61% STAs and 75% of archaeological sites
- False positives: 14% (n=40)
- Missed target features: 31% AOIs, 39% STAs and
- of archaeological sites
- Binary intersection results: 85%

Although the rate of false positives and missed target features in the blind study areas are higher than the test areas, the archaeological site detection rate is still quite high. This indicates that the manual feature extraction method would be effective as a tool for archaeological prospection with additional fine-tuning through iterative ground-truthing and in-office reviewer training.

The manual feature extraction method meets Provincial standards for a moderately effective archaeological potential model based on a Kvamme's gain calculation between 0.79 and 0.82. These results indicate that the manual feature extraction LiDAR-analysis method would meet Provincial standards for a moderately effective predictive model with some refinement. The LiDAR-derived imagery analysis process also captured over 70% of recorded archaeological sites in between 10 and 20% of the land base, meeting secondary criteria for a moderately efficient potential model. The F_1-score for the test area results was 0.87 and 0.72 for the blind study areas. While the test area F_1-score indicates a good classification accuracy, the blind study area results had only a fairly good overall accuracy. This accuracy could be improved by including a multi-reviewer workflow with an experienced second opinion as well as using an interactive approach and a confidence scale assignment to allow the methods to be informed by previous results.

Chapter 5. Discussion & Conclusion

5.1. Discussion

The LiDAR-based approach to archaeological survey for heritage resource management concerns at the Teck Highland Valley Copper Mine had archaeological site and AOI detection rates equivalent to those identified in similar LiDAR studies (Bennett et al. 2012), including the use of LiDAR-framed potential models in BC (Millennia 2006). Most target features missed by the manual feature extraction process were low-relief landforms that did not display contrast during LiDAR imagery review. Other studies have identified that features elevated more than 1 m above surrounding terrain are more likely to be detected (Risbøl et al. 2013:267; Krasinski et al 2016). If very low-profile landforms are commonly missed during manual feature extraction, the LiDAR point cloud data can be post-processed using a specific technique (i.e., Gaussian low-pass filter), which smooths the DEM and reduces the noise created by macrotopography, amplifying the contrast of low-profile target features (Kokalj and Hesse 2017).

As with all remote sensing archaeological prospection techniques, analysis of LiDAR-derived DEMs should be used in conjunction with other sources of data, including geological reports, historic aerial photography, orthophotography, topographic survey data, traditional knowledge, ethnographic descriptions and previous archaeological work in the surrounding region (Krasinski et al. 2016; Henry et al. 2019). LiDAR-derived archaeological survey data subsequently should be validated through ground-truthing to provide a greater understanding of remote sensing interpolation (Daukantas 2014). A multi-scale approach to archaeological prospection yields the best results for feature detection and provides a greater degree of confidence in the process to address regulatory and Indigenous stewardship requirements.

LiDAR-derived ground surface modelling is a powerful tool for archaeological prospection. The possibilities for using LiDAR-derived raster data to answer research questions regarding past landscape use and site distribution are considerable. Understanding how past peoples interacted with the landscape by analysing regional site attributes, relationships with resources and landscape features, and distribution through geoprocessing and elevation data manipulation is the next stage in remote sensing research in HVC and Southern Interior of BC. These fields of study include viewshed analysis, catchment analysis, analysis of paleoenvironmental changes and their impact of site erosion, preservation, and distribution.

Having access to archaeological data in a geodatabase allows for meaningful investigation and analysis long after development-related impacts have altered the landscape and removed heritage resources. The Lornex area was surveyed and ground-truthed in 2016 and following the completion of the archaeological study the area was expanded into the valley mine pit. Figure 21 shows the archaeological data collected by NNTC as well as the manual feature extraction interpolation from this study, overlaid with 2019 orthophotography. The more recent imagery shows how land alteration has removed the physical remains of heritage on the landscape, while the spatial evidence has been preserved for future study. Instead of being untethered from reality, this data has spatial significance when incorporated with the point cloud data collected during LiDAR survey. The spatially-referenced data effectively preserves a vast amount of site distribution and ground-truthing data for future research.

5.2. Addressing Research Questions

This research answered each of the four research questions posited at the beginning of the study.

Question 1: How effective is LiDAR data as a tool for planning field inventories and for the prospection of archaeological sites within the HVC study area?

Sub-question: In a blind study, would AOI polygons identified by reviewing LiDAR data sets correlate with target features (AOI, STA and recorded archaeological sites) identified during a traditional field assessment of the same area?

Answer: LiDAR is assessed as being an effective tool for planning archaeological prospection. The manual feature extraction method captured 75% to 92% of recorded archaeological sites. However, this method missed 31% of the AOIs identified during traditional survey. This indicates that the AOIs identified by LiDAR-analysis do provide a high level of confidence that the majority of archaeological sites would be captured during subsequent ground-truthing. It also suggests that the original phase 2 survey may have been overly conservative in its definition of areas of archaeological interest. Further comparative study could provide insight into how these discrepancies occurred, and how LiDAR and/or traditional survey methods can be fine-tuned.

From an operational planning perspective, LiDAR-analysis is assessed as a moderately effective tool in the HVC environment. Between 72% and 100% of the LiDAR-derived AOIs intersected with NNTC-recorded target features. This indicates that LiDAR-analysis would be effective as a general planning tool, which could then be judgementally modified during ground-truthing. This should be an iterative process in which the feedback from LiDAR-selected AOIs is provided to the reviewer so that the methods used for in-office landform interpolation can be adjusted accordingly.

Question 2: Does LiDAR analysis allow for more refined landform selection than traditional methods?

LiDAR is a slightly coarser tool than anticipated. The manual feature extraction method identified 3% more area (m^2) than was subject to subsurface testing during phase 3 survey in the blind study areas and 23% more area in the test areas. This is attributed to the difficulty in delineating only the highest potential portion of microtopographic features during LiDAR-imagery interpolation.

Question 3: What criteria and guidelines would be most effective for the interpretation of LiDAR data for site inventory work within the study area?

The review and identification of the best methods and criteria for LiDAR-derived manual feature extraction conducted during this study addresses question three. The best practices, workflow and data visualization techniques used were identified as the most appropriate for the study area based on a review of contemporary studies in LiDAR data analysis for archaeological prospection. These include Boardman and Bryan (2018); Bennett and others (2012); Challis and others (2001); Devereaux and others (2008); Doneus (2013); Doneus and Kühteiber (2013); Johnson and Ouimet 2014; and, Kokalj and Somrak (2019). Different LiDAR-analysis methods consider the study area topography (Kokalj and Hesse 2017), the vegetation density (Crow et al. 2007), the parameters of the target features (Freeland et al 2016), and the LiDAR acquisition methods and post-processing techniques (Hesse 2010; Golden et al. 2016; Opitz 2013). As this study prospects for microtopographic features rather than anthropogenic features, visualization techniques and analysis methods employed during geomorphological survey proved effective and relevant (Smith and Clark 2005; Hiller and Smith 2008).

The interpretation bias analysis identified how different the assessment of landscape potential during manual feature extraction changes over time based on experience and visual interpretation. This could likely be resolved if the LiDAR analyst was more familiar with the landscape and NNTC guidelines for landform identification and testing. Experience of the reviewer is likely one of the strongest factors in successful LiDAR feature detection. Using multi-layered, blended visualization techniques that were processed with the specific project area terrain attributes in mind proved to be very beneficial. Although some visualizations like LRM and sky-view factor are not as visually intuitive as artificial illumination techniques, the data reflects slope relevance and exposure. This is incredibly useful when assessing landscape attributes suitable for past land use activities such as elevation and slope gradient.

Several researchers (Quintus et al. 2017, Grammer et al. 2017, Mayoral et al. 2017) have identified contrast as the most significant factor for increasing the effectiveness of in-office feature detection. However, the low-profile of many of the AOI landforms, as well as the high level of previous disturbance, contributed to high archaeological site detection rates but comparatively lower feature or AOI detection rates and overall intersectionality. The LiDAR-derived DEM visualizations were not effective in displaying low-relief microtopographic features that are elevated less than 1 m above surrounding terrain. The resolution of the LiDAR imagery could be adjusted during collection, processing and/or filtering to account for the attributes of these specific target features or using kernel analysis to characterize data points based on specific parameters.

The LiDAR data acquisition method was not controlled for as part of this study and therefore was not necessarily processed in the most optimal way for target feature detection. It is worth mentioning that factors such as point density and the use of full-waveform laser scanning can contribute to higher feature detection rates in areas with dense vegetation cover, or where very low-profile target features are present (Krasinski et al. 2016; Schindling and Gibbes 2014; Doneus et al. 2008). This would require government or development stakeholders to commission a LiDAR data set in support of, or sensitive to the needs of the heritage resource management industry.

Question 4: If any, what is the cost-benefit associated with utilizing LiDAR to plan and execute field inventories at HVC?

The target feature detection success rate and percentage of archaeological sites captured by the manual feature method are equivalent to other studies testing the efficacy of LiDAR data for archaeological prospection (Bennett et al. 2012, Millennia 2006). This method could, therefore, increase efficiency without sacrificing the quality of the results. It is feasible to assume that analyzing a proposed development area using the manual feature extraction method or developing a LiDAR-derived potential model would increase the efficiency of a heritage management program at HVC or in similar types of project areas. These data effectively could be used to refine and target survey methodology during phase 2 assessment. Resource savings, thus, could be diverted to Phase 3 investigations, the most-costly and time-consuming stage of fieldwork. This would include prioritizing systematic data recovery in recorded archaeological sites in imminent danger of destruction from mine development activities and inundation from the tailings pond. The cost benefit analysis concluded that an 82% savings could be achieved by replacing phase 2 survey with LiDAR-analysis. This would result in a 13% cost savings for the overall heritage management program. As the LiDAR data has been acquired for other operational planning activities at the mine there is no additional cost associated with data acquisition.

Of course, the cost-benefit analysis is based on hypothetical and simplified cost structures and level of effort estimates. It is only intended as an exercise to examine how LiDAR-analysis could provide financial benefits during a typical heritage management program. I propose the LiDAR analysis-modelling be completed at the preliminary in-office potential analysis stage, which then informs the phase 1 heritage field reconnaissance. This would allow the entire archaeological impact assessment to be completed within a shorter schedule and at a lower cost to the proponent. This analysis is theoretical as the implementation of manual feature extraction methods into the heritage program in an iterative workflow process was not possible during this field season. The inclusion of LiDAR-analysis into the traditional HRM archaeological field prospection workflow is assessed as adding value to the customer (Teck) by increasing productivity in relation to cost, while maintaining financial equilibrium for HRM providers.

5.3. Confounding Factors

Based on the results of this study I have identified a number of factors that, potentially if not probably, affect or create variable results between the traditional survey and LiDAR-analysis site prospection methods. These include:

- Personal preference, techniques, and experience of in-field recorder
- Limited experience of the manual feature extraction reviewer in the area
- NNTC-specific feature recording techniques using traditional knowledge
- LiDAR data not collected, processed, or filtered for archaeological prospection
- LiDAR-derived DEM not effective in displaying low-relief features
- Recorded archaeological site in a disturbed context

Millennia (2006:37) noted in their study that the potential model tended to miss identifying archaeological sites that were in a disturbed setting where the landform associated with the original site context has been destroyed by modern land use, in this instance road construction. Henry and others found that "LiDAR-derived imagery can be misleading but can still be beneficial when used in conjunction with a multi-scaler, multi-method, research strategy that seeks to rediscover the remains of monumental earthen architecture constructed by precontact societies" (2019:1514). This is also true of LiDAR imagery review at HVC due to the level of previous land alteration and can be remedied using a multi-reviewer process and comparison of manual feature extraction results with recent topographic maps and orthophotographs. In the end a combination of field survey and ground-truthing of manual feature extraction results would likely lead to a refined workflow and increased feature detection success.

5.4. Benefits and Implications for NNTC and Teck

This research has the potential to contribute to improving heritage stewardship by applying new techniques and technologies to enhance the effectiveness of site identification, recording, assessment and preservation. A primary objective was to identify whether LiDAR imagery analysis can be used to plan archaeological field inventories. In-field ground truthing of LiDAR-analysis based on manual feature extraction could not be undertaken within the scope of current research. However, previous surveys and field work provide a systematic and comprehensive data set for comparative analysis. Based on this comparison, I believe LiDAR could reduce the required coverage of traditional survey and facilitate more streamlined design planning and budget forecasting. This study also illustrates that LiDAR-analysis can meet the level of confidence for archaeological site prospection and preservation required by NNTC, proponent and regulatory standards.

Budgetary and schedule constraints may be alleviated using LiDAR analysis, allowing for more resources to be focused on site protection, identification and mitigation. Since LiDAR-analysis has the potential to increase efficiency and save a significant portion of the budget from phase 2 survey, resources could be reallocated to the backlog of phase 3 assessment work, focusing on high priority areas requiring systematic data recovery and mitigation in response to anticipated impacts from mining operations. Additionally, as a planning tool, LiDAR analysis is low impact and requires minimal cost so the proponent may want to review additional landscapes and areas to inform the most versatile and mutually beneficial project component placement, potentially reducing the level of impact to high potential archaeological terrain.

The available LiDAR data would be useful for the creation of a 5 m-pixel potential model based on the AOI and archaeological site landform criteria assembled for this study. Additional parameters for potential such as distance to waterways and traditional use information could be incorporated into the model. These potentially will increase AOI detection success to the level of the pedestrian survey. Modelled terrain could be ‘ground-truthed’ against the existing high volume of data acquired during impact assessments to fine-tune the assigned landscape characteristics. When using any new method for archaeological prospection, including automated algorithms and potential modelling, the results must be continually reviewed, and adjustments made to investigation and interpretation methods. This iterative process is a type of fine-tuning that has been shown to increase rates of target feature identification and a higher confidence in results (Freeland et al. 2016; Quintus et al. 2017). The examination of ground-truthing results, including false positives and missed AOIs, would also improve the LiDAR-analysis process and likely lead to the identification of more archaeological sites.

It is likely that a combination of potential modelling and manual feature extraction would refine the AOIs prior to ground-truthing. However, the efficiency and efficacy of these combined methods would need to be ascertained through several seasons of the heritage field program at HVC. Geodatabases of remote sensed heritage site data combined with varied data sources "serve many purposes, informing research, management, strategic planning, community outreach and so on" (Crowley et al. 2020:110).

LiDAR-analysis is considered a coarse research method although it has been identified as being most effective at the analysis of vast study areas where traditional survey methods are not feasible. Manual feature extraction techniques may not be refined enough to capture subtle landscape attributes that denote archaeological potential in the study area, and therefore, should be viewed as a tool in the archaeological prospection program, rather than an isolated prospection method. Traditional survey assessment that focuses on validating LiDAR selected areas of potential, and adjusting or increasing AOIs, based on experience and visual assessments of landscape attributes, will likely be necessary to validate results if manual feature extraction is incorporated into the heritage program toolkit. It is unlikely that LiDAR will completely replace the need for traditional survey as it would be difficult in the rugged terrain of HVC to have high enough confidence in the results of LiDAR analysis alone. However, the data analysis techniques would likely benefit the heritage management program as a pre-field survey planning tool that could save time and budget that could be reallocated to other activities such as systematic data recovery or ethnographic research.

5.5. Benefits and Implications for the HRM Industry

A broad objective of this research was to provide best practices associated with LiDAR-analysis for archaeological prospection within BC. The costs associated with this type of analysis and the recommended methods and criteria for analysis will provide opportunities for its implementation in other HRM project areas. Technological innovation can have an immense impact on the way in which heritage resource management is conducted. However, to implement this type of process we must understand the potential benefits and risks as well as best practices and measurable review milestones.

From a regulatory perspective, it can be difficult to manage provincial or national-scale heritage programs in an up-to-date and current manner without the use of geodatabases and LiDAR-derived large-scale heritage site mapping programs. The rapid pace of development as well as natural erosional impacts to heritage resources calls for innovative ways to record and manage areas with archaeological potential and known resources. Cowley et al (2020) identify best practices for the large-scale applications of remote sensing for heritage management programs and identify key factors which contribute to successful implementation of these programs. As with any type of digital data workflow, provincial-scale registration of remotely-sensed data, including potential-modelling and automated feature extraction, requires specific systems to be tested and a thorough analysis of data acquisition, processing and analysis requirements (Cowley et al 2020). The heritage regulator in BC stores the results of potential modelling and georeferenced site locations within the on-line RAAD application and has standards for potential model creation and reliance during research (Archaeology Branch 2009). At the same time, large-scale rapid remote sensing surveys in partnership with industry and developers, while being conducted in response to specific developments, have not proliferated in HRM practices in BC.

Beyond this study, LiDAR-analysis has the potential to contribute to our understanding of land-use patterns and site distribution in logistically challenging areas. Where LiDAR is available, it can fill-in critical knowledge gaps and provide a research framework for future archaeological work (Krasinski et al. 2016; Howey et al 2016). Large-scale LiDAR studies around the world clearly demonstrate the types of questions and insights that can be addressed relative to ancient societies, their spatial imprint on the landscape, and their relationship with landscape and other aspects of regional geography. LiDAR data analysis on a wide-spread scale in BC has the potential to offer similar insight when combined with the ethnographic information, recorded heritage resources and other types of data. In this, LiDAR can provide an expanded context for research conducted in the HRM industry. This study shows that using LiDAR-analysis to ascribe landscape potential and guide archaeological prospection can provide cost-saving opportunities for industry stakeholders through efficiency without sacrificing quality.

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Supplementary Material

For supplementary material accompanying this paper

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Appendix A.

Figures A.1 to A.6

Figure A.1. **North tailings test area 1 showing NNTC AOI polygons (green), NNTC STA polygons (purple), MFE Review 2 AOIs (blue), recorded archaeological sites (red), examples of false positives and missed target features**

Data Source: 2014 LiDAR DEM property of Teck Resources; Standard Hillshade (Azimuth=270; Angle=45; z-factor=2); ArcGIS Pro produced 2.5 m contour lines

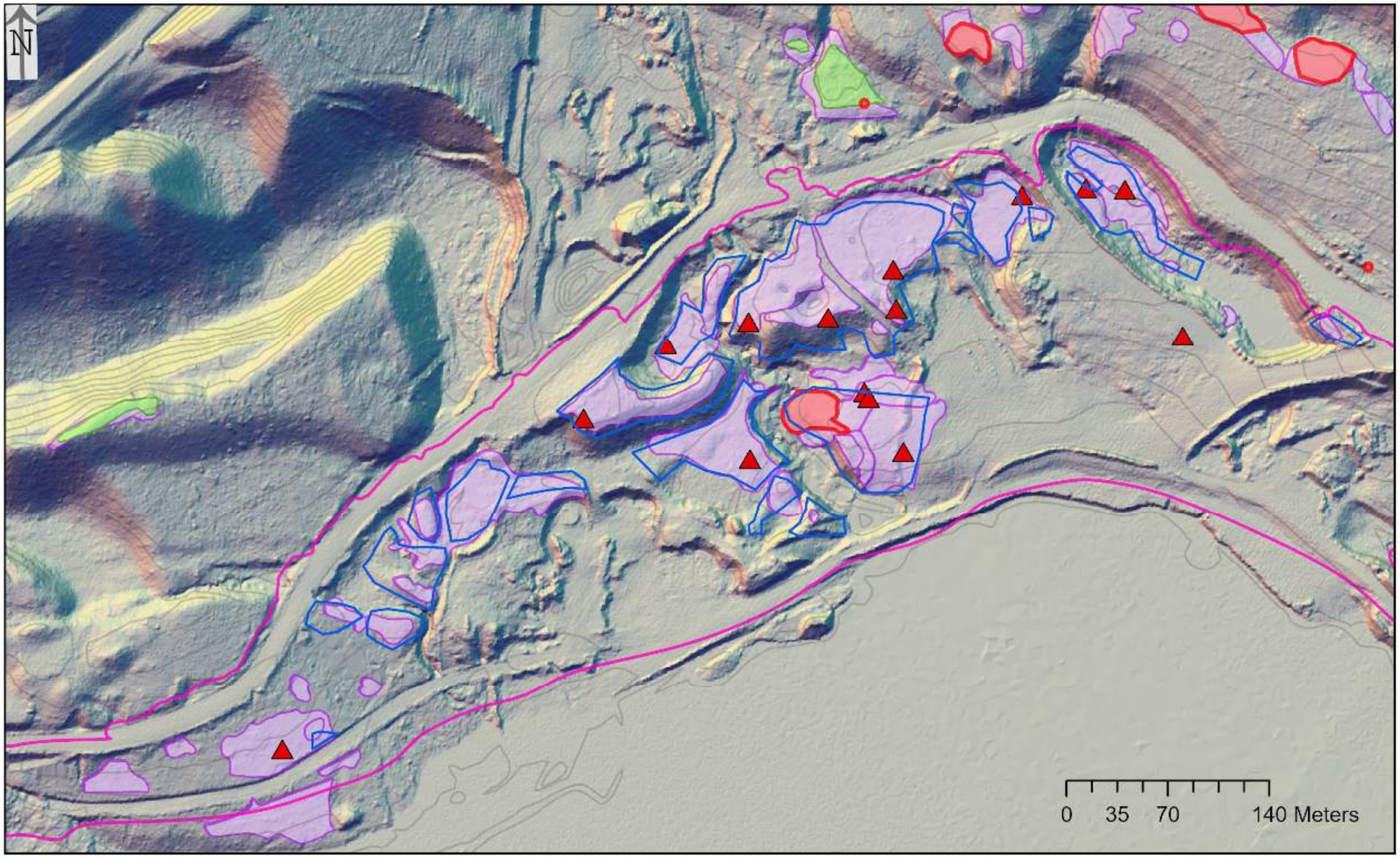

Figure A.2. **North tailings test area 1 showing NNTC STAs (purple), NNTC AOIs (green), manual feature extraction AOIs (blue), recorded archaeological sites (red)**

Data Source: 2014 LiDAR DEM property of Teck Resources; Multi-Hillshade RGB (Directions = 16, Angle = 35°);ArcGIS Pro produced 2.5 m contour lines

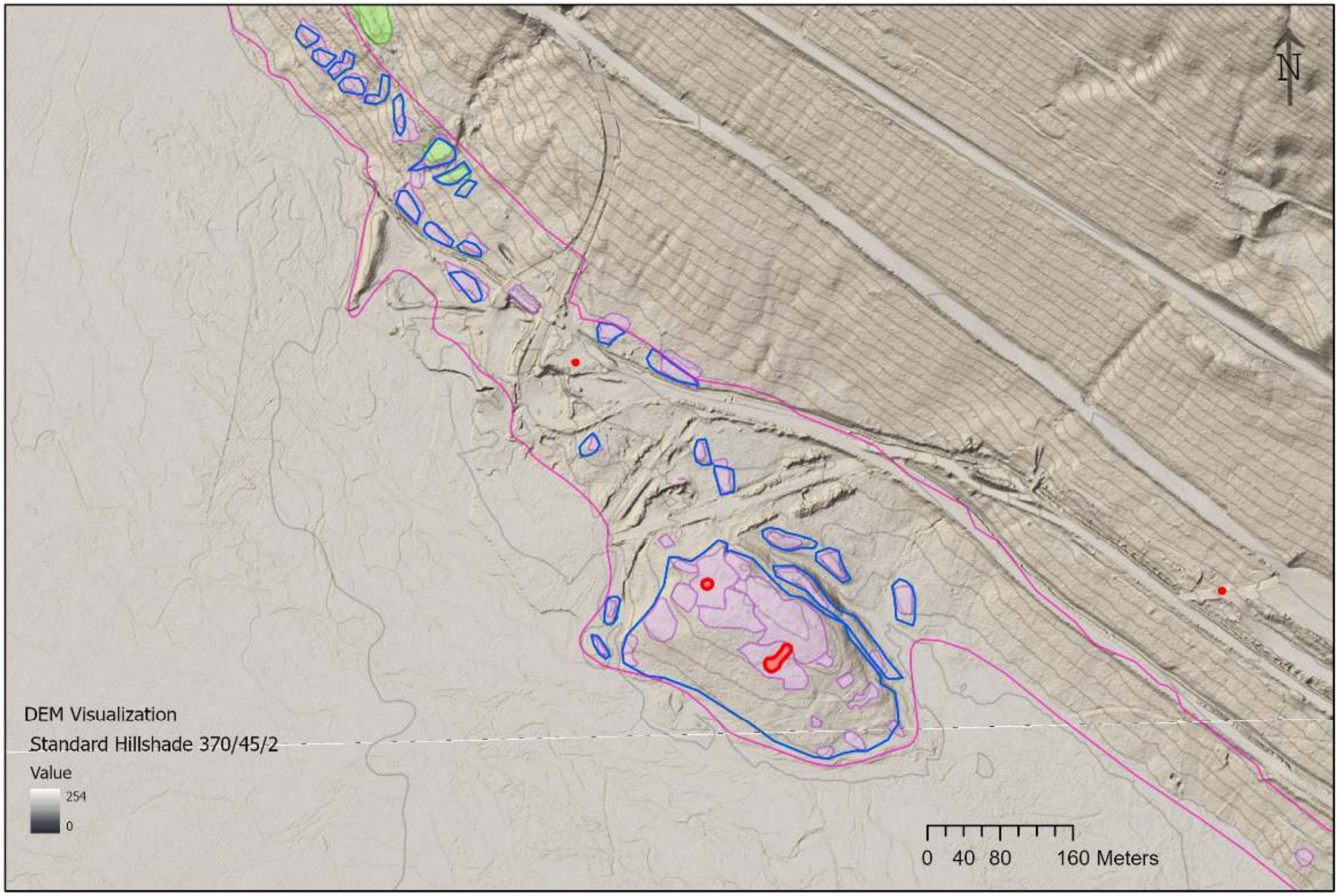

Figure A.3. **North tailings test area 2 showing NNTC AOI polygons (green), NNTC STA polygons (purple), MFE Review 2 AOIs (blue), recorded archaeological sites (red), examples of missed target features**

Data Source: 2014 LiDAR DEM property of Teck Resources; Standard Hillshade (Azimuth=270; Angle=45; z-factor=2); ArcGIS Pro produced 2.5 m contour lines

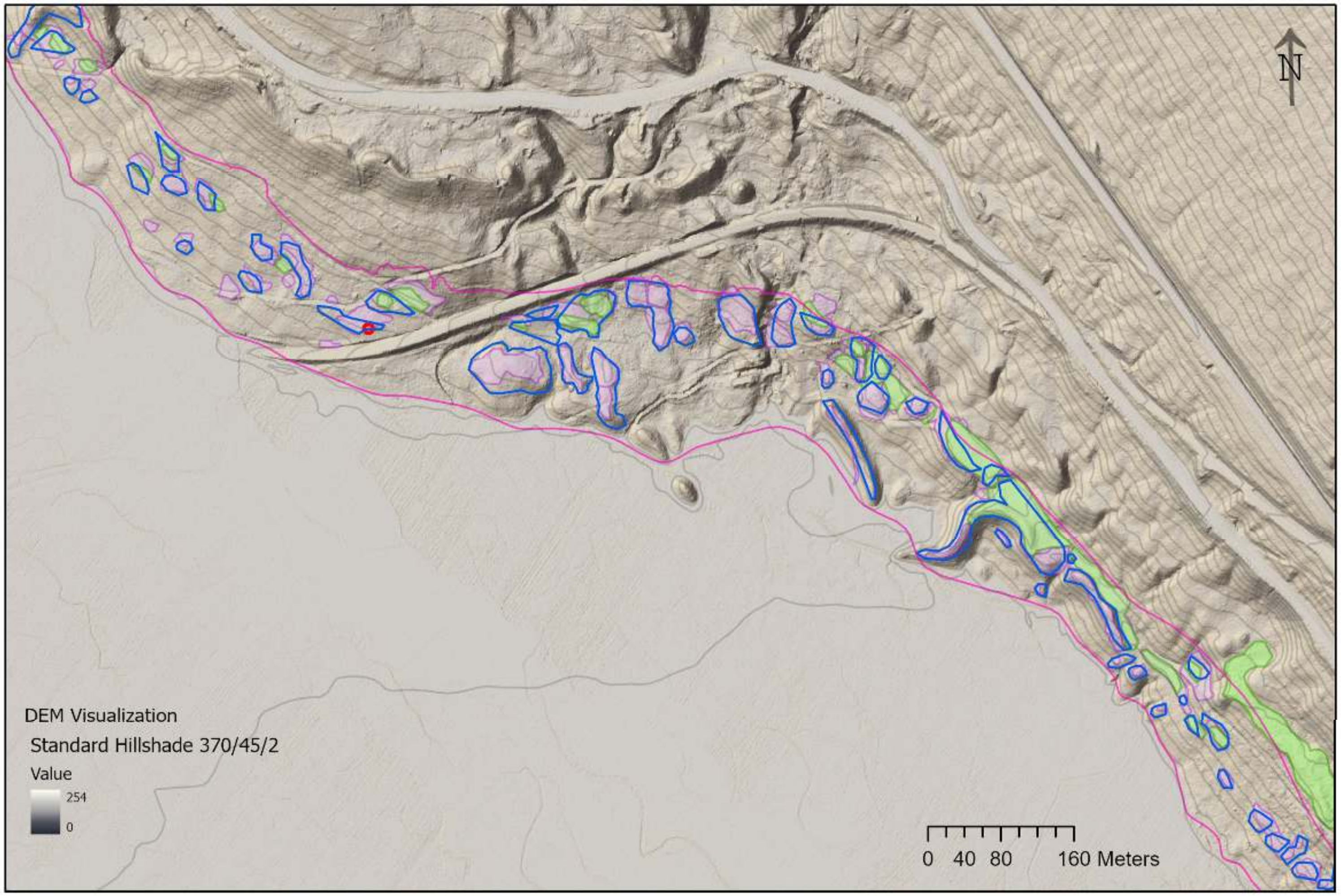

Figure A.4. **North tailings test area 2 showing NNTC AOI polygons (green), NNTC STA polygons (purple), MFE Review 2 AOIs (blue), recorded archaeological sites (red), examples of missed target features**

Data Source: 2014 LiDAR DEM property of Teck Resources; Standard Hillshade (Azimuth=270; Angle=45; z-factor=2); ArcGIS Pro produced 2.5 m contour lines

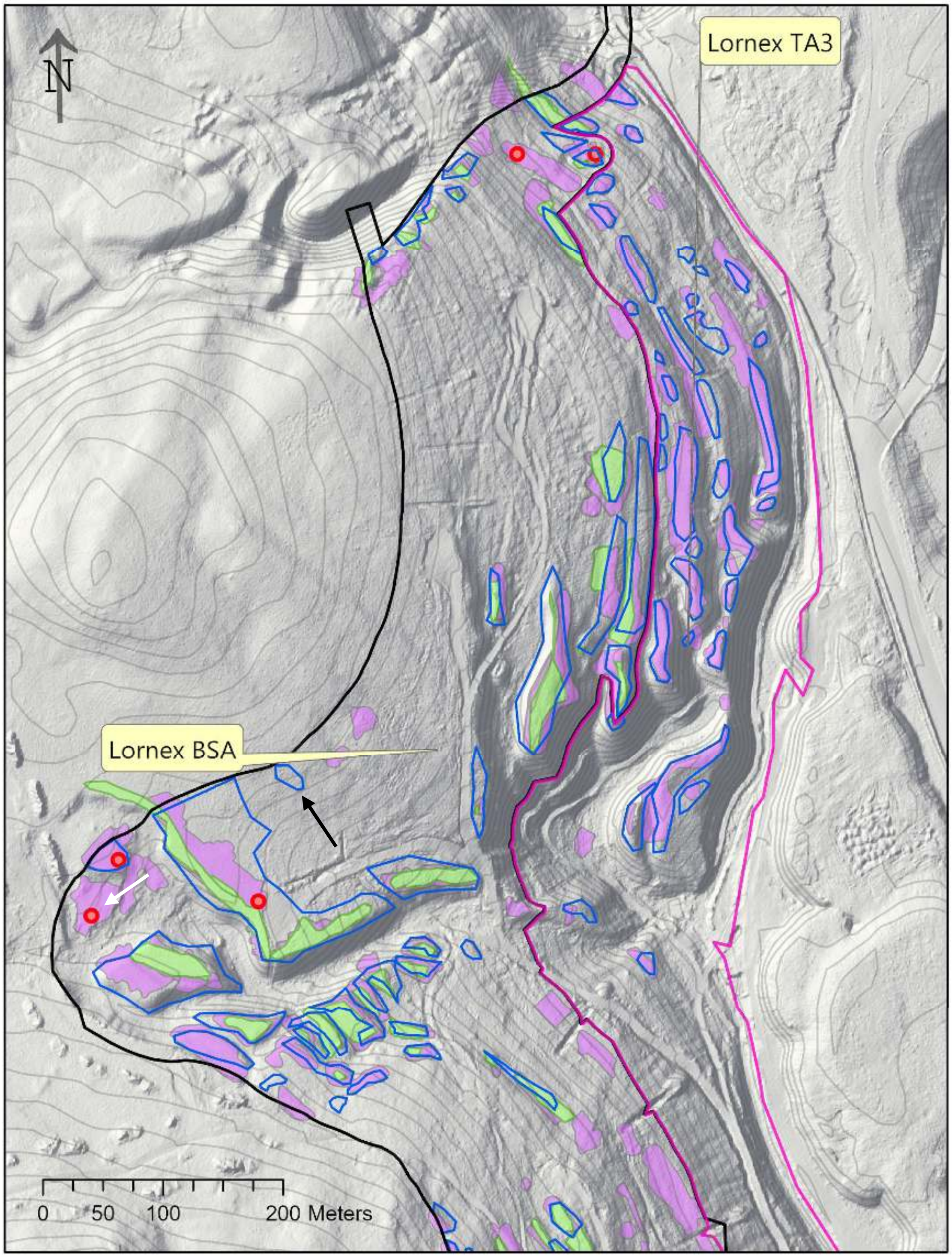

Figure A.5. **Lornex blind study area and Lornex test area 3 showing NNTC AOI polygons (green), NNTC STA polygons (purple), manual feature extraction AOIs (blue), recorded archaeological sites (red), example of false positives (black arrow) and missed target features (white arrow)**

Data Source: 2014 LiDAR DEM property of Teck Resources; Standard Hillshade (Azimuth=270; Angle=45; z-factor=2) ArcGIS Pro produced 2.5 m contour lines

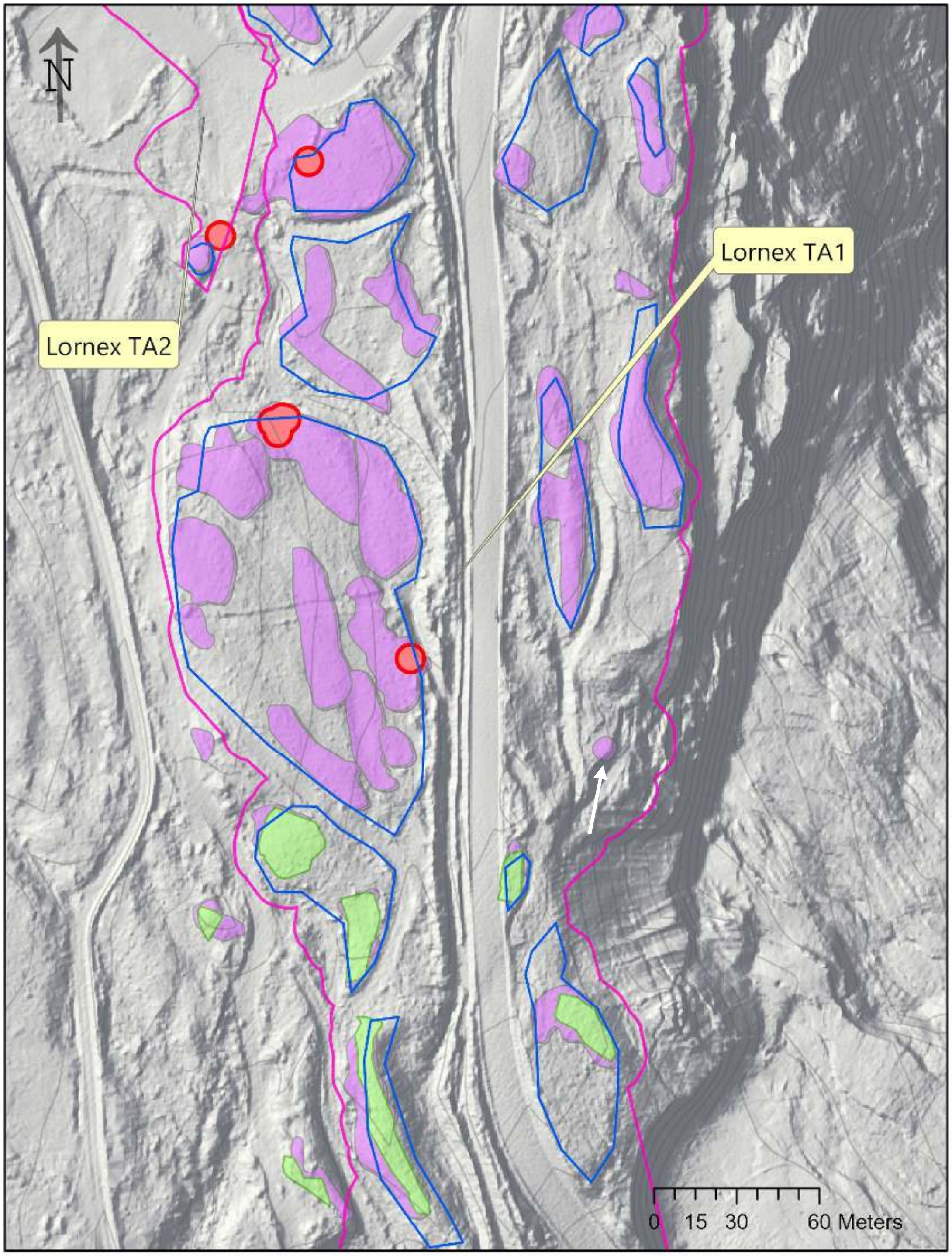

Figure A.6. **Lornex blind study area and Lornex test area 3 showing NNTC AOI polygons (green), NNTC STA polygons (purple), manual feature extraction AOIs (blue), recorded archaeological sites (red), example of missed target feature (white arrow)**

Data Source: 2014 LiDAR DEM property of Teck Resources; Standard Hillshade (Azimuth=270; Angle=45; z-factor=2); ArcGIS Pro produced 2.5 m contour lines

Appendix B.

False Positive Error Matrix Review Results

Test Area False Positive AOI Analysis Results

False Positive ID	Mean Aspect	Mean Elevation	Mean Slope	Slope Range	Analysis and Review of Interpolation	Archaeological Potential
FP1-LTA1	90	1579	12°	42	No obvious land alteration other than vegetation clearing Slope median and range meet objective criteria.	Reassert MFE[1] assessment as AOI[2]
FP2-LTA2	85	1563	9°	29	Appears to be greater relief due to modern road cut through low-relief landscape. Slope median and range meet objective criteria. No obvious land alteration other than vegetation clearing	Reassert MFE assessment as AOI
FP3-LTA2	97	1563	13°	34	Appears to be greater relief due to modern road cut through low-relief landscape. Slope median and range not far-off objective criteria. No obvious land alteration other than vegetation clearing	Reassert MFE assessment as AOI
FP4-LTA2	210	1567	18°	41	Appears to be greater relief due to modern road cut through low-relief landscape. Slope median and range higher than objective criteria No obvious land alteration other than vegetation clearing	Reassess as low potential
FP5-LTA2	167	1603	15°	36	Adjacent major access road, portion of AOI appears to be artificially levelled and piled land associated with road pull-out Slope median and range higher than objective criteria	Reassess as low potential
FP6-LTA3	63	1555	14°	28	Appears to be greater relief due to modern road cut through low-relief landscape. Slope median and range not far-off objective criteria. No obvious land alteration other than vegetation clearing	Reassert MFE assessment as AOI
FP7-LTA3	68	1555	12°	23	Appears to be greater relief due to modern road cut through low-relief landscape. Slope and range not far-off objective criteria. No obvious land alteration other than vegetation clearing	Reassert MFE assessment as AOI
FP8-STTA4	296	1298	12°	21	Appears to be greater relief due to modern road cut through low-relief landscape. Slope median and range meet objective criteria.	Reassert MFE assessment as AOI

False Positive ID	Mean Aspect	Mean Elevation	Mean Slope	Slope Range	Analysis and Review of Interpolation	Archaeological Potential
FP9-STTA4	307	1295	17°	32	Appears to be greater relief due to modern road cut through low-relief landscape. Slope median and range higher than objective criteria. Land alteration from clearing and levelling associated with adjacent road.	Reassess as low potential
FP10-STTA4	218	1305	21°	38	Area impacted by adjacent road construction and land clearing. Slope median and range higher that objective criteria	Reassess as low potential
FP11-STTA4	284	1306	15°	35	Area impacted by adjacent road construction and land clearing. Slope median and range higher that objective criteria	Reassess as low potential
FP12-STTA3	255	1280	16°	32	Slope median and range higher than objective criteria. No obvious land alteration	Reassert MFE assessment as AOI
FP13-STTA3	223	1270	6°	17	Slope median and range lower than objective criteria. No obvious land alteration. LiDAR imagery shows contrast and definition of landform	Reassert MFE assessment as AOI
FP14-NTTA1	155	1259	13°	29	Area impacted by mining land clearing and tailings pond-associated sediment build-up	Reassess as low potential
FP15-NTTA1	193	1255	9°	22	Appears to be greater relief due to modern road cut through low-relief landscape. Slope and range meet objective criteria. No obvious land alteration other than vegetation clearing	Reassert MFE assessment as AOI
FP16-NTTA1	171	1247	8°	19	Appears to be quite low-relief Slope and range meet objective criteria. No obvious land alteration other than vegetation clearing	Reassert MFE assessment as AOI
FP17-NTTA1	188	1256	14°	23	Slope median and range meet objective criteria. No obvious land alteration other than vegetation clearing	Reassert MFE assessment as AOI
FP18-NTTA3	223	1271	17°	43	Adjacent to major access road, level-relief likely the result of land clearing for a pull-out Slope median and range higher than objective criteria.	Reassess as low potential

1) MFE = manual feature extraction; 2) AOI = area of interest

Blind Study Area False Positive AOI Analysis Results

False Positive ID	Mean Aspect	Mean Elevation	Mean Slope	Slope Range	Analysis and Review of Interpolation	Archaeological Potential
FP1_NTBSA	207	1280	10	37	Appears to be greater relief due to modern road cut through low-relief landscape. Slope mean meets objective criteria, but the range is much higher. Land clearing associated with vegetation removal	Reassess as low potential
FP2_NTBSA	189	1279	11	30	Appears to be greater relief due to modern road cut through low-relief landscape. Slope mean meets objective criteria, but the range is much higher. Land clearing associated with vegetation removal	Reassess as low potential
FP3_NTBSA	235	1276	10	22	Slope median and range meet objective criteria. However, upon reexamination of the LiDAR imagery the landform appears to be very low-relief	Reassess as low potential
FP4_NTBSA	217	1288	12	22	Slope median and range meet objective criteria. Landform appears well-defined and elevated in the LiDAR imagery No obvious land alteration	Reassert MFE assessment as AOI
FP5_NTBSA	217	1276	12	14	Slope median meets objective criteria Landform appears well-defined and elevated in the LiDAR imagery No obvious land alteration	Reassert MFE assessment as AOI
FP6_NTBSA	212	1268	11	15	Slope median meets objective criteria Landform appears well-defined and elevated in the LiDAR imagery No obvious land alteration	Reassert MFE assessment as AOI
FP7_NTBSA	214	1271	13	23	Appears to be greater relief due to modern road cut through low-relief landscape. Slope median and range meet objective criteria.	Reassert MFE assessment as AOI
FP8_NTBSA	225	1270	12	24	Slope median and range meet objective criteria.	Reassert MFE assessment as AOI

False Positive ID	Mean Aspect	Mean Elevation	Mean Slope	Slope Range	Analysis and Review of Interpolation	Archaeological Potential
					Landform appears well-defined and elevated in the LiDAR imagery No obvious land alteration	
FP9_NTBSA	243	1277	12	20	Slope median and range meet objective criteria. Landform appears well-defined and elevated in the LiDAR imagery No obvious land alteration	Reassert MFE assessment as AOI
FP10_NTBSA	220	1286	15	12	Slope median higher than objective criteria. Close to major access road	Reassess as low potential
FP11_NTBSA	238	1283	13	16	Slope median meet objective criteria, the range is lower Landform appears well-defined and elevated in the LiDAR imagery No obvious land alteration	Reassert MFE assessment as AOI
FP12_NTBSA	230	1282	15	17	Slope median higher than objective criteria. Close to major access road	Reassess as low potential
FP13_NTBSA	226	1264	16	16	Slope median is higher than objective criteria and the range is lower No obvious land alteration	Reassess as low potential
FP14_NTBSA	231	1278	13	18	Slope median and range meet objective criteria. Landform appears well-defined and elevated in the LiDAR imagery No obvious land alteration	Reassert MFE assessment as AOI
FP15_NTBSA	240	1265	17	21	Slope median is higher than objective criteria	Reassess as low potential
FP16_NTBSA	242	1274	14	20	Slope median and range are close to objective criteria. Landform appears well-defined and elevated in the LiDAR imagery No obvious land alteration	Reassert MFE assessment as AOI
FP17_NTBSA	191	1262	12	24	Appears to be greater relief due to modern road cut through low-relief landscape.	Reassert MFE assessment as AOI

False Positive ID	Mean Aspect	Mean Elevation	Mean Slope	Slope Range	Analysis and Review of Interpolation	Archaeological Potential
					Slope median and range are close to objective criteria.	
FP18_NTBSA	180	1267	8	33	Appears to be greater relief due to modern road cut through low-relief landscape Slope median meets objective criteria but range is higher Land clearing from vegetation removal	Reassert MFE assessment as AOI
FP19_NTBSA	174	1280	9	23	Landform appears well-defined and elevated in the LiDAR imagery Slope median and range meet objective criteria.	Reassert MFE assessment as AOI
FP20_NTBSA	184	1272	13	24	Landform appears well-defined and elevated in the LiDAR imagery Slope median and range meet objective criteria. Adjacent major access road	Reassert MFE assessment as AOI
FP21_NTBSA	187	1277	14	36	Appears to be greater relief due to modern road cut through low-relief landscape Slope median is close to objective criteria, range is higher	Reassert MFE assessment as AOI
FP22_NTBSA	193	1271	13	34	Appears to be greater relief due to modern road cut through low-relief landscape Slope median is close to objective criteria, range is higher	Reassert MFE assessment as AOI
FP23_NTBSA	179	1262	11	24	Appears to be greater relief due to modern road cut through low-relief landscape Slope median and range meet objective criteria.	Reassert MFE assessment as AOI
FP24_NTBSA	188	1267	11	22	Appears to be greater relief due to modern road cut through low-relief landscape Slope median and range meet objective criteria.	Reassert MFE assessment as AOI
FP25_NTBSA	131	1272	19	44	Appears to be greater relief due to modern road cut through low-relief landscape Slope and median higher than objective criteria	Reassess as low potential
FP26_NTBSA	203	1275	20	33	Slope and median higher than objective criteria.	Reassess as low potential
FP28_LBSA	152	1612	10	19	Slope median and range meet objective criteria.	Reassess as low potential

False Positive ID	Mean Aspect	Mean Elevation	Mean Slope	Slope Range	Analysis and Review of Interpolation	Archaeological Potential
					Upon closer inspection of LiDAR imagery, appears very low-relief and undefined.	
FP29_LBSA	64	1583	13	30	Appears to be greater relief due to modern road cut through low-relief landscape. Slope and range not far off objective criteria. No obvious land alteration other than vegetation clearing	Reassess as low potential
FP31_LBSA	63	1616	9	17	Slope median and range meet objective criteria. No obvious land alteration other than vegetation clearing.	Reassert MFE assessment as AOI
FP32_LBSA	90	1613	12	19	Slope median and range meet objective criteria. No obvious land alteration other than vegetation clearing.	Reassert MFE assessment as AOI
FP35_LBSA	96	1618	16	28	Slope median is higher than objective criteria while the range is closer. No obvious land alteration.	Reassert MFE assessment as AOI
FP36_LBSA	66	1616	20	19	Slope median is higher than objective criteria while the range is closer. No obvious land alteration.	Reassert MFE assessment as AOI
FP37_LBSA	109	1618	8	15	No obvious land alteration other than vegetation clearing Slope median and range meet objective criteria.	Reassert MFE assessment as AOI
FP38_LBSA	143	1583	8	21	No obvious land alteration other than vegetation clearing. Slope median and range meet objective criteria.	Reassert MFE assessment as AOI
FP39_LBSA	108	1608	14	19	No obvious land alteration. Slope median and range meet objective criteria.	Reassert MFE assessment as AOI
FP40_LBSA	89	1615	18	32	On closer inspection of the orthophotography, this location appears to be a debris and sediment pile at the edge of a cutblock	Reassess as low potential
FP41_LBSA	264	1625	13	17	No obvious land alteration. Slope median and range meet objective criteria.	Reassert MFE assessment as AOI
FP44_LBSA	128	1622	9	28	Appears to be greater relief due to modern road cut through low-relief landscape. Slope median meets objective criteria, but the range is too high. No obvious land alteration other than vegetation clearing	Reassess as low potential

False Positive ID	Mean Aspect	Mean Elevation	Mean Slope	Slope Range	Analysis and Review of Interpolation	Archaeological Potential
FP45_LBSA	111	1610	13	20	No obvious land alteration other than vegetation clearing Slope median and range close to objective criteria.	Reassert MFE assessment as AOI
FP46_LBSA	100	1610	12	27	While this area is on an elevated, defined landform, this AOI captures the centre of the area and the edges are where NNTC locations are located.	Reassess as low potential

Appendix C.

Cost-Benefit Analysis Budgets and Assumptions

Cost Benefit Analysis

A cost-benefit analysis was conducted to identify time and cost savings associated with incorporating LiDAR-analysis into Phase 2 survey. This was completed by developing a hypothetical project and associated budget and schedule for each method, the traditional 3-phased approach and an approach integrating LiDAR-analysis into phase 2. The cost-benefit analysis assumptions included:

- hypothetic project area measuring 30 ha (300,000 m^2)
- Phase 1 Heritage Field Reconnaissance - 15 ha/day (3-person crew)
    - 2 days to complete
- Phase 2 Survey - covers 7 ha/day (6-person crew)
    - 5 days to complete
- Phase 3 AIA - covers 8-days per ha (6-person crew)
    - 15% of project area (4.5 ha/45,000 m^2) assessed as high potential
    - a minimum of 5 tests per 100 m^2 (2,250 tests)
    - 60 tests/day
    - 38 field days

During phase 3 AIA a six-person crew can excavate an average of 60 tests per day. In a project component measuring 1 ha (10,000 m^2) an average of 15% of the terrain or 1,500 m^2 is assessed as having archaeological potential. The methodology requires a minimum of 5 tests per 100 m^2 to achieve the desired level of confidence so 500 tests per hectare. A Phase 3 crew would then require 8 days per ha to clear landforms plus an additional half day for site recording and mapping assuming positive finds for a total of 8 days per hectare. The 30 ha-sample used for this analysis would then take a minimum of 38 field days to complete Phase 3 assessment.

To make the budgets more realistic, regional travel, per diem and accommodation is included for the Field Director and three First Nation crew members for phase 2 and 3 assessments. Phase 1 reconnaissance includes no travel expenses assuming locally-provided workers. Project management is calculated as 5-10% of field and expense budget and reporting is calculated as 20%.

Phase 1 Heritage Field Reconnaissance Cost Estimate

Position	Fee/hour[1]	Estimated Hours	Total Budget
Project Manager	$100	6	$600
Senior Technician	$75	32	$2,400
Junior Technician (n=2)	$50	44	$2,200
GIS Technician	$100	14	$1,400
		Total Labour Fees	**$6,000**
Expenses			
Vehicle	$100/day	2 days	$200
		Total Expenses	**$200**
		Total Cost Labour and Expenses	**$6,200**

1 - Rates are hypothetical for the purpose of this cost-benefit analysis

Assumptions for Phase 1 Heritage Field Reconnaissance Cost Estimate:

- For this estimate a 2-day survey will be conducted covering 30 ha of proposed development area.
- 9-hour field-days
- One vehicle required at $100/day charge-out rate
- Project management per phase is estimated as 10% of fees and expenses.
- Local work with no hotel or per diem cost

Phase 2 Traditional Survey Cost Estimate

Position	Fee/hour[1]	Estimated Hours	Total Budget
Project Manager	$100	10	$1,000
Field Director	$75	108	$8,100
Senior Technician	$75	53	$3,975
Junior Technician	$50	49	$2,450
GIS Technician	$100	32	$3,200
First Nation Participants (n=3)	$450/day	21 days	$9,450
		Total Labour Fees	**$28,175**

Position	Fee/hour[1]	Estimated Hours	Total Budget
Expenses			
Vehicles (n=2)	$100/day	18 days	$1,800
Accommodation (n=4)	$125/day	28 days	$3,500
Per diem (n=4)	$50/day	28 days	$1,400
		Total Expenses	**$6,700**
		Total Cost Labour and Expenses	**$34,875**

1 - Rates are hypothetical for the purpose of this cost-benefit analysis

Assumptions for Traditional Phase 2 Cost Estimate:

- For this estimate a 5-day survey will be conducted covering 30 ha of proposed development area.
- 9-hour field-days
- Two vehicles required at $100/day charge-out rate
- $50/day per diem
- An additional two days of regional travel for the three First Nation participants and the field director archaeologist.
- Project management is estimated as 10% of labour and expenses
- Post-field data management and reporting is estimated as 20% of labour and expenses

Phase 2 Survey Using LiDAR-Derived Manual Feature Extraction Cost Estimate

Position	Fee/hour[1]	Estimated Hours	Total Budget
Project Manager/ Senior Review	$100	15	$1,500
Field Director	$75	30	$2,250
GIS Technician	$100	30	$3,000
		Total Cost Labour Fees	**$6,750**

1 - Rates are hypothetical for the purpose of this cost-benefit analysis

Assumptions for LiDAR-Analysis:

- 30-ha project area will be analyzed to identify areas of interest
- Pre-processed LiDAR data is available for entire area
- Time estimates are based on workflow developed for this study 1 hour/ha

- Project management and senior review is estimated as ½-hour/ha
- No external subcontractors are required for this proposed methodology.

Phase 3 Archaeological Impact Assessment Cost Estimate

Position	Fee/hour[1]	Estimated Hours	Total Budget
Project Manager	$100	80	$8,000
Field Director	$75	572	$42,900
Senior Technician	$75	350	$26,250
Junior Technician	$50	483	$24,150
GIS Technician	$100	112	$11,200
First Nation Participants (n=3)	$450/day	126 days	$56,700
		Total Labour Fees	$169,200
Expenses			
Vehicles (n=2)	$100/day	80 days	$8,000
Accommodation (n=4)	$125/day	160 days	$20,000
Per diem (n=4)	$50/day	160 days	$8,000
		Total Expenses	$36,000
		Total Cost Labour and Expenses	**$205,200**

1 - Rates are hypothetical for the purpose of this cost-benefit analysis

Assumptions for Phase 3 AIA Cost Estimate:

- For this estimate a 38-day assessment will be conducted covering 30 ha of proposed development area.
- 6-person crew
- 1 shift requiring 2 days regional travel for field director and 3 First Nations
- 9-hour field-days
- Two vehicles required at $100/day charge-out rate
- $50/day per diem (field director and First Nations)
- Project management is estimated as 5% of labour and expenses
- Post-field data management and reporting is estimated as 20% of labour and expenses