BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

BC OIL AND GAS RESEARCH AND INNOVATION SOCIETY

NORTHEAST BRITISH COLUMBIA LANDSLIDE SUSCEPTIBILITY MAP

PROJECT NO.: 2178001 DATE: December 17, 2020

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December 17, 2020
Project No.: 2178001

Brian Thomson, Program Manager
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PO Box 9331 Stn Prov Govt
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Dear Mr. Thomson,

Re: Northeast British Columbia Landslide Susceptibility Map

Please find enclosed our final report documenting the development of a landslide susceptibility map for part of northeast British Columbia.

Yours sincerely,

BGC ENGINEERING INC.
per:

Michael Porter, M.Eng., P.Eng., LEG (WA)
Principal Geological Engineer

EXECUTIVE SUMMARY

The British Columbia Oil and Gas Research and Innovation Society (BC OGRIS) requested that BGC Engineering Inc. (BGC) develop a landslide susceptibility map for part of northeast British Columbia (NE BC). The objective for the work was to identify areas with relatively higher or lower potential for slope movement. The outcome of this work is expected to be used by regulators to support authorization reviews and compliance planning and by industry to support the development of landslide hazard management programs. The scope of work was described in BGC's letter of intent, dated December 12, 2019. The work was authorized by BC OGRIS Recipient Agreement ES-Pipe-2021-01 dated June 12, 2020.

The scope of work comprised the development of a landslide susceptibility map for the western extent of the Western Canada Sedimentary Basin (WCSB) in NE BC. Specific work items included:

- Subdivision of the study area into an analytical study area and prediction area. The analytical study area (see Figure 2) consists of several strips of terrain within which lidar topography was used to develop a landslide inventory. The prediction area is the remainder of the study area outside the analytical study area.
- Selection, curation and preparation of various geospatial thematic data for consideration for potential inclusion in the landslide susceptibility map.
- Evaluation of the correlation of various geospatial data to the presence and absence of landslides mapped in an analytical study area.
- Combination of thematic geospatial data to create a map representing the spatial probability of landslide presence within the analytical study area.
- Optimization of the map to produce the best predictive power within the analytical study area, followed by application of the optimized susceptibility map to the prediction area in NE BC outside the analytical study area.
- Validation of the map by comparing expected and actual landslide presence in selected areas of known landslide presence within NE BC. The validation study area consists of 50 randomly selected circular plots across the study area, each 5 km in diameter.
- Reclassification of the susceptibility map from its raw numeric output to support decision making.

A modified approach to the weights of evidence method (Bonham-Carter et al., 1989) was used as the main framework to develop the landslide susceptibility map. A total of 57 candidate geospatial datasets were considered for inclusion in the landslide susceptibility model. This was reduced to 10 geospatial themes in the final model through testing and optimization. The resulting raw output was reclassified into two map forms: a qualitative map with five classes ranging from Very Low to Very High; and, a continuous raster map representing spatial probability of landslide presence, with values ranging from 0.0 to 0.9.

The map was validated by comparison with an inventory of landslides identified outside the analytical study area, and showed very good correspondence, suggesting very good predictive power across the whole map area.

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LIMITATIONS

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1.0 INTRODUCTION

The British Columbia Oil and Gas Research and Innovation Society (BC OGRIS) requested that BGC Engineering Inc. (BGC) develop a landslide susceptibility map for part of northeast British Columbia (NE BC). The objective for the work was to identify areas with relatively higher or lower potential for slope movement. The outcome of this work is expected to be used by regulators to support authorization reviews and compliance planning and by industry to support the development of landslide hazard management programs.

The scope of work was described in BGC's letter of intent, dated December 12, 2019. The work was authorized by BC OGRIS Recipient Agreement ES-Pipe-2021-01 dated June 12, 2020.

2.0 BACKGROUND

Landslides are widespread across the Western Canada Sedimentary Basin (WCSB), primarily occurring along valley slopes (Porter et al., 2019) and often occurring as rock slides in weak sedimentary rock or as earth slides in Holocene sediments. Porter et al. (2019) estimate the economic impact of these landslides in the WCSB as approximately $281 to $450 million per year.

The WCSB extends into NE BC, and BC OGRIS members are interested in understanding the distribution of landslide hazards in the region. BGC prepared a work plan for development of a landslide susceptibility map for the area of NE BC lying within the WCSB, and the approach was approved by BC OGRIS.

BGC has employed a similar approach for development of a landslide susceptibility map in the WCSB in Saskatchewan for a private client. A similar map has been developed by others using machine learning techniques for the WCSB in Alberta (Pawley et al., 2016a, 2016b). The study area for the work discussed in this report is illustrated in Figure 1.

This report documents the methodology used to produce the landslide susceptibility map including a review of the thematic geospatial data used, a discussion of the analytical methods, and an overview of the process used to validate the map. The report also discusses the intended use of the map and associated limitations. The report includes the following primary sections:

- Section 3.0 Methodology – an outline of the methods used in the work
- Section 4.0 Data – a description of the data used in the work and their sources
- Section 5.0 Results – a presentation of the results of each stage of the work
- Section 6.0 Use and Limitations – a discussion of the intended use of the work products and attendant limitations.

3.0 METHODOLOGY

3.1. General

The scope of work comprised the development of a landslide susceptibility map for the western extent of the WCSB in NE BC. Specific work items included:

- Subdivision of the study area into an analytical study area and prediction area. The analytical study area (see Figure 2) consists of several strips of terrain within which lidar topography was used to develop a landslide inventory. The prediction area is the remainder of the study area outside the analytical study area.
- Selection, curation and preparation of various geospatial thematic data for consideration for potential inclusion in the landslide susceptibility map.
- Evaluation of the correlation of various geospatial data to the presence and absence of landslides mapped in an analytical study area.
- Combination of thematic geospatial data to create a map representing the spatial probability of landslide presence within the analytical study area.
- Optimization of the map to produce the best predictive power within the analytical study area, followed by application of the optimized susceptibility map to the prediction area in NE BC outside the analytical study area.
- Validation of the map by comparing expected and actual landslide presence in selected areas of known landslide presence within NE BC. The validation study area consists of 50 randomly selected circular plots across the study area, each 5 km in diameter.
- Reclassification of the susceptibility map from its raw numeric output to support decision making.

These general steps are described in greater detail in the following sub-sections, which begin with an overview of the analytical approach used in the work. For the NE BC landslide susceptibility map, a modified version of the weights of evidence method (Bonham-Carter et al., 1989) was used to evaluate the correlation of specific themes[1] to the presence or absence of existing (mapped) landslides, and thus develop the susceptibility map.

3.2. Weights of Evidence Method

A modified approach to the weights of evidence method (Bonham-Carter et al., 1989) was used as the main framework to develop the landslide susceptibility map. The weights of evidence method is a bivariate statistical approach; this means landslides are compared statistically with each thematic map, one at a time, and individual relationships are subsequently combined. The method combines features of various thematic maps expected to have some relationship to the presence or absence of landslides. Weights are calculated for each thematic map based on the conditional probability (P) of the presence or absence of a landslide given the presence of the theme, and these individual weights are combined to develop an overall weight map.

The process of interrelating thematic data and the landslide inventory is illustrated in Figure 3. The individual thematic positive weights (W_i) are calculated by taking the logarithm of the ratio of

[1] A theme in this context refers to any geospatial dataset which could hypothetically be related to landslide occurrence. Examples could include slope angle, soil type, bedrock geology, or physiographic region, to name a few.

spatial probabilities, shown in Equation 1, below. The weights are combined through simple addition, which is mathematically equivalent to multiplication of the ratios of probabilities.

$$W_i = \log\left[\frac{P\{F_i \mid L\}}{P\{F_i \mid \bar{L}\}}\right] \quad [1]$$

Where:

W_i = The positive weight for the i^{th} thematic factor
F_i = The presence of the i^{th} thematic factor
L = The presence of a landslide
$\bar{L}$ = The absence of a landslide
and $P\{F_i \mid L\}$ is the probability of F_i given L.

In the GIS environment, the spatial probabilities in Equation 1 are calculated by summing the number of raster pixels where landslides are present or absent and where a specific factor is also present. Equation 1, using GIS raster algebra, hence becomes Equation 2, below.

$$W_i = \log\left[\frac{A_1/A_2}{A_3/A_4}\right] \quad [2]$$

Where:

A_1 = The area within the specific factor containing landslides
A_2 = The total area within the analytical study area containing landslides
A_3 = The area within the specific factor not containing landslides
A_4 = The total area within the analytical study area not containing landslides
and the analytical study is the area within which landslides have been completely mapped. Figure 2 shows the outline of the analytical study area.

The weight values are calculated within a specific point, or map pixel, where the i^{th} theme (say, soil type) has a specific value. The A_i values and calculated weight are the same at any other point on the map with the same thematic value, and therefore the number of different weight values for W_i depends on the number of different thematic values (e.g., number of different soil types).

Landslide susceptibility is obtained by combining the thematic weights, W_i, at each map pixel to obtain an overall combined weight, as shown in Equation 3 and Figure 4.

$$W_{Total} = W_{Soil} + W_{Bedrock} + W_{Slope} + \ldots \quad [3]$$

The combined map will have numeric values ranging between low (highly negative) and high (highly positive) values, where higher values represent a higher spatial probability of landslide presence. The numeric range in this combined map can be reclassified or subdivided into smaller ranges representing, for example, high, medium and low susceptibility. The selection of these categories is discussed in Section 4.0.

Two variations were made from strict application of the weights of evidence method:

1. W_i described in Equation 1 above is the "positive weight" and the formal weights of evidence method also includes consideration of negative weights. Positive weights, W_i, indicate a positive relationship between the presence of a factor and landslide presence, while negative weights indicate a negative relationship between factor and landslide presence. In the author's experience, inclusion of the negative weights adds little or no information or predictive value to the model, and so they were omitted from the work.
2. In the standard weights of evidence approach, thematic weight maps are combined through direct addition to produce the overall susceptibility map. This approach presumes that the various thematic maps considered for inclusion are independent of each other. In practice, the various themes are usually correlated to some degree, and better predictive power can be obtained by adjusting the value of included weight maps in the model. For example, slope angle may be more informative than land use class, and better predictive power may be obtained by giving the slope weight map more importance in the final map.

3.3. Landslide Inventory

A landslide inventory is a critical foundation of the weights of evidence method and any statistical landslide susceptibility mapping method. For optimum utility, we find that the inventory should:

- Consider a single type of landslide, or narrow range of related landslide types
- Be complete within a defined area, within which all terrain is known with confidence to be either landslide landforms or not
- Be completed at a consistent scale.

The analytical study area, shown in Figure 2, is the area within which landslides have been mapped. The analytical study area comprised several areas within which lidar hillshade images were available and was selected to represent the typical range of physiographic and geological characteristics within the overall study area within the WCSB in NE BC. Mapping was conducted at a nominal scale of 1:50,000 and focused on large landslides having a minimum dimension of about 100 m or greater.

Examples of landslide mapping are included at two different scales in different parts of the study area in Figure 5 and Figure 6.

3.4. Selection of Thematic Data

The weights of evidence method considers a selection of geospatial themes that may have a correlation to landslide presence. Various geospatial themes were chosen for initial consideration based on experience and judgement. A recent state-of-the-art report on statistical methods for landslide susceptibility mapping (Reichenbach et al., 2018) shows that the following types of thematic data are commonly used in practice:

- Morphological:
    - Slope
    - Aspect
    - Curvature
    - Elevation

  - Other morphometric
  - Geomorphological.
- Geological:
  - Geo-lithological
  - Geo-structural
  - Distance to fault.
- Land cover:
  - Land use/cover
  - Soil type
  - Distance to road
  - Tree cover
  - Other anthropogenic factors.
- Hydrological:
  - River/catchment
  - Distance to river.
- Other:
  - Precipitation
  - Geotechnical
  - Earth observation
  - Seismic
  - Other climactic
  - Landslide related
  - Other.

Thematic data covering this range of topics were gathered and tested for inclusion in the model.

3.5. Map Optimization

A first map was created by combining the calculated weight maps for each considered thematic map.

A first round of map optimization was completed through step-wise removal of individual weight maps to determine whether they add or subtract from model predictive power. When model power improved through deletion of a weight map, it was tentatively removed, and subsequently re-checked several more times as the number of included weight maps diminished. If in later checks its inclusion in the modified model improved model performance, it was again retained in the model, subject to further checks. Several rounds of checking were conducted for the complete set of weight maps, resulting in the reduction from 57 potential weight maps to a final list of 10 themes included in the model.

A second round of map optimization was completed through step-wise modification of importance of each individual weight map in the model. Model predictive power was compared by varying the contribution of each weight map by a factor ranging from 0.5 to 2. For example, slope angle weights might be multiplied by 2 for inclusion in the model, with bedrock weights multiplied by 0.5

and land use weights multiplied by 1.5. The full set of 10 candidate weight maps was adjusted several times in sequence until no further improvements in model performance were observed.

A third and final round of map optimization was completed after adjusting importance of the final 10 weight maps by checking the previously discarded weight maps once more to see if their inclusion might again yield further model improvements. This final optimization step did not yield meaningful differences in map performance.

3.6. Map Validation

The landslide susceptibility map was developed through statistical analysis of landslide presence and absence within a small proportion of the overall map area. Its predictive power is known with confidence within the analytical study area where landslides were completely mapped, but is initially unknown outside the analytical study area. It is necessary to check model performance outside the analytical study area to determine the overall predictive power. This was done by generating a second landslide inventory in a map validation study area independent of the analytical study area.

For this work, the map validation study area was defined by 50 randomly located circular areas (see Figure 7), each 5 km in diameter, within which lidar data were available. This validation study area represents the typical range of physiographic and geological characteristics within the overall study area in NE BC. Landslides were mapped in these areas using the same approach as that used to generate the landslide inventory in the analytical study area; an example is shown in Figure 8. These landslides formed the statistical basis for model validation outside the analytical study area.

The model was also validated qualitatively through visual comparison of the model with other available landslide data that had been generated at various scales for other clients and projects in the study area.

3.7. Reclassification to Support Decision Making

The optimum landslide susceptibility map is a continuous-value raster over the entire range of calculated weight values. While informative, this data alone is not particularly useful or directly informative since the weight values are not associated with a meaningful reference scale. The susceptibility map may be more directly useful if the weight values are reclassified into a set of discrete values that provide some indication of the potential likelihood of landslides being present within a particular area. The map has been reclassified from its raw (full-scale) form in two ways:

- Qualitative (classified) model: BGC has developed a landslide susceptibility map for parts of Saskatchewan using a similar approach, and has previously reclassified that map into five classes. That map has been approximately aligned to the AER map for Alberta (Pawley et al., 2016a and 2016b) using a similar set of five classes, and the current (raw) model for NE BC has also been reclassified to approximately match the Alberta and Saskatchewan maps. This alignment is only approximate since the methods used to generate each of the three maps differ.

- Spatial probability model: the raw model has been reclassified to give integer pixel values representing the approximate spatial probability of landslide presence, with values ranging from 0.0 to 0.9 (i.e., ranging from approximately 0% to 90% probability of landslide presence).

4.0 DATA

A total of 57 geospatial themes were considered for potential inclusion in the model. The geospatial themes and the data sources considered for the model are provided in Table 4-1, below.

Table 4-1. Thematic data selected for initial consideration for the NE BC Landslide Susceptibility Map.

Geospatial Theme	Data Source	Rationale for Initial Selection
Morphological themes:		
Elevation	Canadian Digital Elevation Model; Scale 1:50,000 (Natural Resources Canada, 2015); and Shuttle Radar Topography Mission Elevation Dataset (USGS 2002)	May correlate with weak geologic units more prone to landslides or areas with higher precipitation due to orographic effects.
Slope Angle	Canadian Digital Elevation Model; Scale 1:50,000 (Natural Resources Canada, 2015); and Shuttle Radar Topography Mission Elevation Dataset (USGS, 2002)	Certain ranges of slope angles are known to be landslide prone for common geological units in NE BC. The steeper the slope, the greater the driving force for movement.
Slope Aspect	Canadian Digital Elevation Model; Scale 1:50,000 (Natural Resources Canada, 2015)	Influences soil moisture, which can contribute to instability.
Local Relief – range of elevation within a defined area surrounding a point	Canadian Digital Elevation Model; Scale 1:50,000 (Natural Resources Canada, 2015); and Shuttle Radar Topography Mission Elevation Dataset (USGS 2002)	Local elevation changes are indicative of the scale of terrain features, and the likelihood that driving forces may exist for the development or propagation of landslides. This interpretation reveals long slopes or steep slopes, either of which can be affected by instability.
Topographic Curvature	Canadian Digital Elevation Model; Scale 1:50,000 (Natural Resources Canada, 2015)	Can indicate sharp breaks in terrain and the shape of the slope breaks (convex vs. concave), and therefore be indicative of landslide morphology. Can influence drainage and/or stresses in the ground, both of which affect slope stability.

Geospatial Theme	Data Source	Rationale for Initial Selection
Valley bottom flatness	Hectares BC (2019)	Valley form may influence type and frequency of landslide process(es).
Topographic complexity – local variability of slope angle and curvature	Canadian Digital Elevation Model; Scale 1:50,000 (Natural Resources Canada, 2015)	Non-uniform topography is often associated with landslide landforms and may be emphasized by local variability in slope angle or curvature.
Geological themes:		
Bedrock Type	Cui et al. (2019)	Certain bedrock types are more prone to landslides. The dataset was limited to sedimentary bedrock in the WCSB in NE BC.
Distance to faults	Cui et al. (2019)	Landslide occurrence may be more common near tectonic faults, either as a result of natural or anthropogenic seismic activity or due to the natural evolution of the faulted landscape.
Surficial landforms/ expression	Hectares BC (2019)	Landslides tend to be associated with certain types of surface expression (e.g., steeper slopes, hummocky topography).
Soil parent materials	Hectares BC (2019)	Certain soil materials are more prone to landslides.
Physiographic region	Hectares BC (2019)	General landscape-forming processes, and associated landslide types and activity, may vary between physiographic regions.
Land cover themes:		
Land use	Hectares BC (2019)	Plant cover and land use can be a proxy for surficial geology and may reveal smaller features than observable in available soil mapping.
Vegetation age	Hectares BC (2019)	Past occurrence of landslides may be related to vegetation type, age and height.
Vegetation height	Hectares BC (2019)	
Vegetative cover	Hectares BC (2019)	
Hydrological themes:		
Watersheds	Hectares BC (2019)	Landslide incidence may vary between drainage units or with position on a slope.
Hydrologic slope position	Hectares BC (2019)	
Ecological drainage unit	Hectares BC (2019)	
Soil drainage	Hectares BC (2019)	Rate of soil drainage can influence tendency for infiltration and seepage.

Geospatial Theme	Data Source	Rationale for Initial Selection
Distance to streams	Internal BGC data hosted in River Network Tools™, based primarily on watercourse and waterbody data from the Canadian National Hydro Network (Natural Resources Canada, 2016).	Landslides are often associated with river processes, and landslides in the WCSB are often associated with river valleys.
Other (miscellaneous) themes:		
Precipitation falling as snow	Hectares BC (2019)	Landslide occurrence may vary with changes in various climactic parameters.
Frost free days	Hectares BC (2019)	
Days below freezing	Hectares BC (2019)	
Mean annual precipitation	Hectares BC (2019)	
Mean annual temperature	Hectares BC (2019)	
Ecological province	Hectares BC (2019)	Landslide occurrence may vary across regions.
Distance to roads	Hectares BC (2019)	Human influence on the landscape can cause landslides, or human development can reflect avoidance of or affinity to specific landform types and processes.

Many of the geospatial themes considered for the model are not fully independent; for example, slope angle and relief are generally related and both likely correlated to soil type, surface expression and land cover. The importance of thematic inter-dependence is tested through model optimization as discussed in Section 3.5.

Geologic judgement was used to evaluate how to group and subdivide thematic data. For discrete-valued data (i.e., typically polygon vector data like soils and bedrock, and also rasters with a limited set of discrete values), judgement was used to assess which types can be reasonably combined to create factors with statistical significance while maintaining an adequate range of factors to produce meaningful variation in the calculated weights. In the case of bedrock, several dozen different bedrock formations were grouped into four classes by dominant bedrock lithology, including: fine-grained sediments; marine / carbonate sediments; coarse-grained sediments, intrusive volcanics and other strong crystalline rocks; and, unclassified / undivided sediments and volcanics. This classification reflects the relatively limited variability in rock lithology across the study area. Further detail regarding methods employed to curate the various data sets for optimum value in the model is given by Quinn (2014).

Judgement was also used to define some weight values that could not be calculated based on limitations of the analytical study area. For example, when a factor was not present within any landslide within the analytical study area, the calculated weight (i.e., the logarithm of the spatial probability) is negative infinity, which is not usable within the context of the susceptibility map. For these factors, the weight value was typically set to 0 to reflect absence of knowledge about the factor, rather than certain knowledge of absence.

Some raster thematic data have continuous values, and in such cases, bins were created, assigning discrete values representing ranges of values, to support their inclusion in the analysis. For continuous-valued raster data, bin selection was done to produce a reasonably small number of statistically significant categories with distinct weight values.

5.0 RESULTS

The optimized landslide susceptibility map was created using weight values from the following themes, where the relative importance assigned to each theme, ranging between 0.5 and 2, was obtained through step-wise scenario testing as described earlier:

- Hydrologic slope position x 2 (here “x 2” means the weight values were multiplied by 2 prior to inclusion in the combined model)
- Distance to 7th order streams x 1.5
- Distance to streams 6th order or higher x 1.5
- Local relief (over 5 x 5 pixels, or 110 m x 110 m) x 1
- Distance to 9th order streams x 1
- Topographic aspect x 1
- Local relief (over 3 x 3 pixels, or 66 m x 66 m) x 0.5
- Slope angle x 0.5
- Soil parent materials x 0.5
- Standard deviation of slope angle (over 1 x 10 pixels, or 220 m x 220 m) x 0.5.

The thematic maps and their associated weight maps are illustrated in Figures 9 to 18. Note that the weight values were multiplied by 1000, for convenience, to allow the weight maps to be manipulated as integer-value rasters. The map that results from combination of the individual thematic weight maps is a continuous-valued raster with combined weights ranging in value from -10,423 to 6,993, with a 22 x 22 m raster grid, which is based on the highest resolution input data. The high and low values are associated with the highest and lowest landslide densities while values around zero represent a landslide density approximately equal to that of the overall study area.

Figure 19 shows the susceptibility map’s predictive power within the analytical study area, with model predictive power shown as standard curves known as receiver operating characteristic curves. These curves are plots of true positive rate, or sensitivity (i.e., ratio of true positives to the sum of true positives and false negatives) versus true negative rate, or [1 – specificity] (i.e., the ratio of true negatives to the sum of true negatives and false positives). A curve that reaches higher values of true positives for lower values of true negatives has better predictive power, more accurately constraining a higher proportion of real landslide terrain to a smaller area on the map.

The blue line representing the 3rd trial in Figure 19 represents the final map, developed from a combination of 10 thematic weight maps with varying importance as described previously. As can be seen, the optimized susceptibility model is expected to constrain 90% of mapped landslides within approximately 15% of the analytical study area, and nearly 95% of landslides within 20% of the study area. Performance of the initial map, developed from linear combination of all 57 candidate weights, along with that of an interim trial map, are shown for comparison. Two earlier trials described earlier in the report are also plotted in Figure 19 for comparison.

The raw map output is illustrated in Figure 20. The distribution of map area and landslide area, as represented by number of pixels, as a function of raw susceptibility value, is illustrated in Figure 21. The Figure shows that landslides cluster mainly in higher susceptibility values, ranging mainly between about -2000 to 7000. By contrast, there is a broader range of susceptibility values across the whole map. By inspection, one can see that landslides comprise nearly all of the map area for susceptibility values greater than about 4000, and they represent a very small proportion of the map for values less than about -2000.

The raw continuous value raster has been subdivided into weight ranges that represent landslide density thresholds that may be useful for decision support; these are subject to review and can be easily modified. The selected weight ranges and their associated landslide density are shown in Table 5-1. Within Table 5-1, Weight Limits represent the relative likelihood of an existing landslide of unknown activity being present at a given location. Negative weights suggest that landslides are less common than the overall study area average; positive weights suggest they are more common than average. These five qualitative susceptibility categories, ranging from Very Low (VL) to Very High (VH), are superimposed on the distribution of map area and landslide area in Figure 22 for visual reference.

The expected landslide density at a given point inferred from the landslide susceptibility model (Table 5-1) is the spatial density of landslides in the associated weight range and is equivalent to the spatial probability of the presence of an existing landslide (of unknown age or activity). For example, in the Very High (VH) susceptibility map class where landslide density is mapped as approximately 0.9, there is a roughly 90% chance (P ~ 0.9) that a given map pixel is within an existing landslide (of unknown age and activity). This value is about an order of magnitude higher than that of the overall background value across the analytical study area (overall average landslide density was approximately 0.07). The Very Low (VL) susceptibility map class represents a spatial probability of landslide presence (~ 0.001) that is more than an order of magnitude lower than that of the overall background value across the study area. The High (H), Moderate (M) and Low (L) classes represent intermediate probabilities of landslide presence, between those of the Very High and Very Low classes.

A continuous function describing spatial probability of landslide presence can be obtained by dividing landslide area (the orange curve in Figure 22) by area of the whole map (black curve in Figure 22). The grey curve is Figure 22 shows a monotonically increasing function representing spatial probability of landslide presence as a function of susceptibility value.

Table 5-1. Landslide susceptibility classification proposed for use.

Susceptibility Class	Weight limits	Spatial probability of landslide presence	Proportion of the study area (%)
Very High (VH)	> 4059	~ 0.9	0.5
High (H)	902 to 4059	~ 0.4	13.5
Moderate (M)	- 891 to 902	~ 0.1	13.0
Low (L)	-4297 to -891	~ 0.01	30.6
Very Low (VL)	< -4297	~ 0.001	42.5

Figure 20 shows the raw continuous raster susceptibility map. Figure 23 shows the map reclassified with five different susceptibility values, also showing some project-mapped landslides for qualitative comparison. Figure 24 shows the other reclassified version of the map, in this case with pixel values representing the approximate spatial probability of landslide presence. Project-mapped landslides are again shown for qualitative comparison.

An alternate way of representing the meaning of the map is through confusion matrices, which show the distribution of true and false positives and negatives for a given value of the map. Figure 25 illustrates the concept, showing that, for example, true positives are correct predictions of landslides, whereas false negatives are incorrect predictions of landslide absence at an actual landslide location. In this case, we consider a total of 160,459 map pixels, of which 11,389 (~ 7%) are in landslides.

Every susceptibility value can be associated with a distribution of true and false positives and negatives, and Figure 25 includes confusion matrices for the lower thresholds of the Low, Moderate, High and Very High susceptibility classes. One can obtain a very low proportion of false negatives (57 of 69,088, or 0.08%) by looking at all areas of the map of Low or higher class. This low number of false negatives comes at a cost of high rate of false positives (80,038 of 91,371, or 87.6%).

Selection of a meaningful threshold for use of the map may involve a trade-off between the value of true positives and negatives versus the cost of false positives and negatives, which may vary according to the application under consideration. The accuracy, or proportion of true results (i.e., true positives and negatives divided by all cases), is approximately 50%, 80%, 91% and 93% for these same four thresholds. For example, consider the Low threshold which has 80,364 true results (69,031 plus 11,333) of 160,459, which is 50.0%.

Meaning of the model outside the analytical study area was unknown prior to formal validation. Model validation results are shown in Table 5-2 below. One can obtain a sense of model validity by comparing conditions within the analytical study area (the area of landslide inventory forming the basis for the model) with those in the validation study area. Both the analytical and validation study areas are expected to be reasonably representative of average physiographic and geological conditions across the whole study area, with the latter representing a smaller area (i.e., approximately 1/8 the size of the analytical study area). One can see that the outcomes in the two study areas are broadly similar, with the following differences:

- The validation study area has a marginally higher landslide density than expected from the model based on the analytical study area in the Low, Moderate and High categories (i.e., 1.6%, 11.1% and 42.8% versus 1.0%, 10.9% and 36.9%). This result errs slightly on the unconservative side, but the classes remain separated by the same order of magnitude and retain essentially the same meaning.
- The validation study area has lower landslide density than expected in the Very Low and Very High categories (i.e., ~ 0% and 12.7% versus 0.1% and 87.8%). The very low result in the Very High category errs on the conservative side and can be explained by the very small area sampled in the validation study area (i.e., only 0.3% of the area is classified as Very High.

Overall, the validation results suggest excellent general meaning of the landslide susceptibility map across the study area, while at the same time highlighting the presence of variability across the map and associated uncertainty.

Table 5-2. Validation results.

Landslide Susceptibility Class		Proportion of Study Area (%)		Landslide density (%)	
Numeric	Descriptive	Analytical study area	Validation study area	Analytical study area	Validation study area
1	Very Low	42.5%	44.8%	0.1%	0.0%
2	Low	30.6%	34.6%	1.0%	1.6%
3	Moderate	13.0%	10.4%	10.9%	11.1%
4	High	13.5%	9.8%	36.9%	42.8%
5	Very High	0.4%	0.3%	87.8%	12.7%

6.0 USE AND LIMITATIONS

There are a few key considerations that affect the accuracy and/or confidence of this work, as outlined below:

- The landslide susceptibility map presents the expected presence of existing landslides of unknown age and activity. These features can sometimes be identified with reasonable confidence in readily available satellite imagery, are often identified with confidence in low-resolution lidar imagery, and in this work have typical minimum dimensions in the order of 100 m. Smaller features such as those immediately adjacent to river banks, roads, or other construction activity (e.g., local slumping or other shallow instability) were not considered in the analysis, and thus the resulting model should not be assumed to have predictive power for small landslides.
- The geospatial data used in the analysis were available at various scales, and the accuracy of the resulting model is limited by those themes' spatial accuracy. The landslide susceptibility map is judged meaningful at a nominal scale of about 1:50,000, and has little

or no statistical validity when zoomed in to show greater detail. The map should therefore not be used as a decision support on its own, in the absence of other information about landslide potential.

- The map is a raster with 22 x 22 m grid, based on the highest resolution thematic data, namely the 1:50,000 CDED topography (Natural Resources Canada, 2015). Many of the input themes are lower resolution, with 100 x 100 m grid, and the landslide inventory forming the basis for the analysis included features with minimum dimensions of 100 m or greater. Therefore, while the raster map can be visualized at 22 x 22 m, the actual resolution is no better than 100 x 100 m.
- The statistical meaning of the map is accurate, to the extent described in this report, inside the analytical study area. Model accuracy outside the analytical study area is expected to be similar but is not known precisely.
- Interpretation of landslide morphology is subjective and relies on expert judgement. Some landforms derived from unrelated geomorphic processes can resemble landslides, and the presence of heavy vegetation or human development can obscure existing landslide features. The mapping therefore errs to some unknown degree in both over-interpretation (i.e., identification of landslides where none exist) and under-interpretation (i.e., failure to identify existing landslides).
- The result of this work is a landslide susceptibility model, and this label implies the potential for future landslide occurrence. In fact, the landslide susceptibility values at raster pixel locations represent the spatial probability that an existing landslide of unknown activity is present at that pixel, and not, strictly speaking, the probability of future landslide development. The map should therefore be read as indicating only the spatial probability of the presence of existing landslides of unknown activity.
- The landslide susceptibility model does not provide guidance on landslide activity (i.e., whether a landslide, if present, is active, dormant or relict) as this information is not possible to interpret from desktop imagery alone. Determination of whether a landslide is actively moving would require a site-specific field assessment and/or monitoring by means of repeat survey, geotechnical instrumentation such as slope inclinometers, or remote sensing techniques such as InSAR or repeated lidar scans. Assessment of landslide activity has not been carried out as part of the current study.
- The landslide susceptibility map is intended as a screening tool and should not be relied on in the absence of other information. Indications of relatively lower or higher susceptibility should be used as one piece of information to help support a judgement as to the level of effort needed in further work, and not as the sole basis for a decision about activities or land use.
- Effects of sectoral activities (e.g., oil & gas, forestry, water reservoir operation) or other landscape-altering land use activities on landslide susceptibility have not been considered in developing these maps. The effects of such activities on landslide susceptibility would require further site-specific analysis.
- Precipitation events, forest fires, human activity, and long-term climate change may increase the potential for landslides. This suggests that the spatial probability of

encountering a landslide may increase over time, such that future review and revision of the map may be warranted.

7.0 ACKNOWLEDGEMENTS

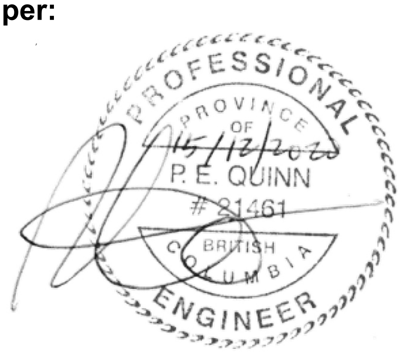
The work described in this report benefited from constructive feedback from Brain Thomson of BC OGRIS and Dung Nguyen and Dr. Gouri Bhuyan of the BC Oil and Gas Commission. Additional technical suggestions were provided by Dr. Andrée Blais-Stevens of the Geological Survey of Canada, and by Dr. Marten Geertsema of BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development.

8.0 CLOSURE

We trust this meets your current needs. If there are any questions about the work, please do not hesitate to contact the undersigned.

Yours sincerely,

BGC ENGINEERING INC.
per:



Pete Quinn, Ph.D., ing., P.Eng. (ON, BC, AB, SK)
Principal Geotechnical Engineer

Reviewed by:

Corey Froese, M.Sc., P.Eng., P.Geo. (BC, AB, SK)
Principal Geological Engineer

MP/CF/md/mm

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FIGURES

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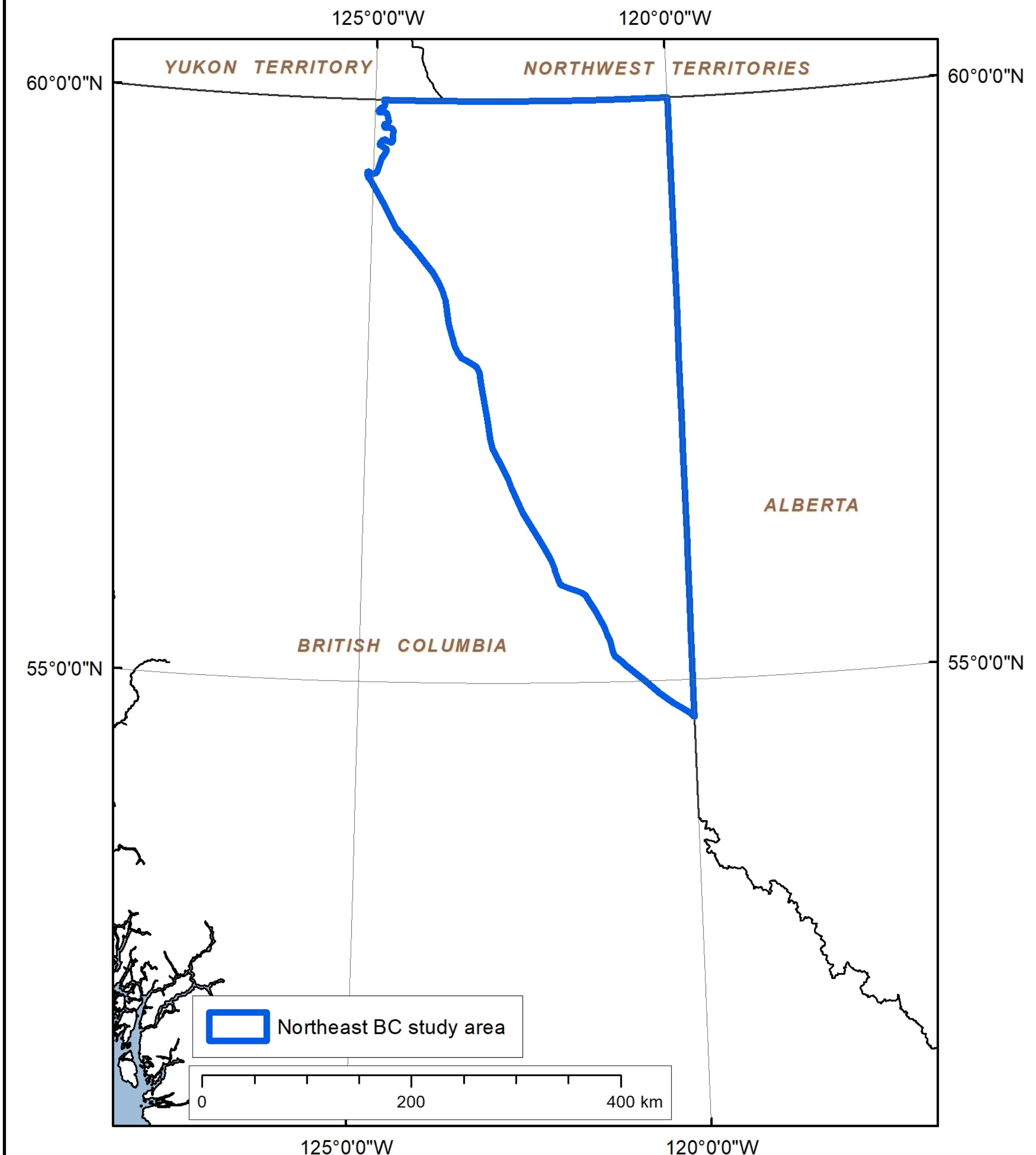

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Northeast BC study area is delimited by the extent of the Alberta Plateau, which represents the northwest extent of the Western Canada Sedimentary Basin in northeast BC. Mapping obtained from BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development at www.catalogue.data.gov.bc.

PREPARED BY: PQ	FIGURE TITLE: Study Area			
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society			
APPROVED BY: PQ	SCALE: As shown	PROJECT NO: 2178-001	FIGURE NO: 1	

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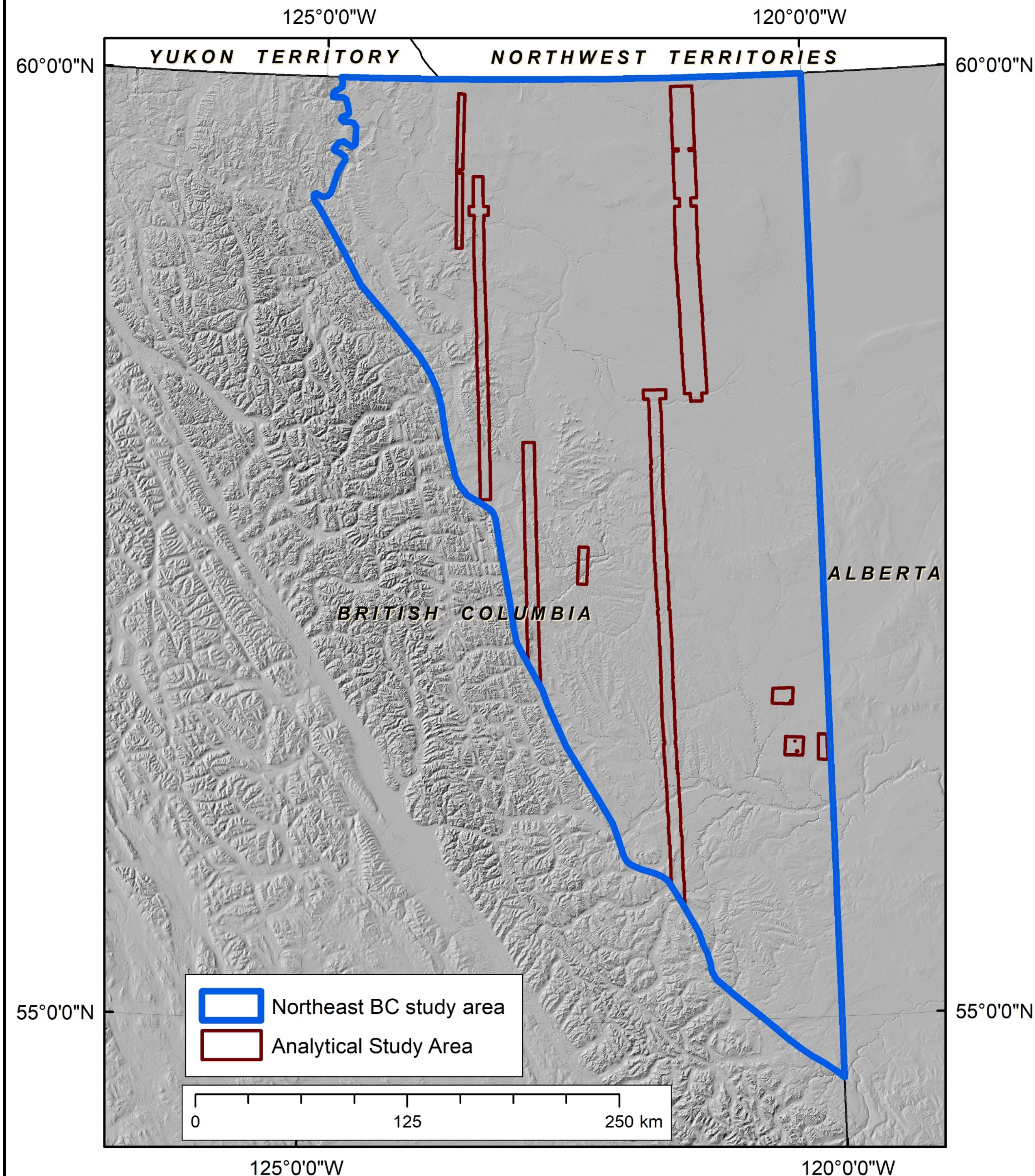

NOTES:	PREPARED BY: PQ	FIGURE TITLE: Analytical Study Area		
1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020. 2. Hillshade topographic relief map derived from Canadian Digital Elevation Data (CDED).	CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
	APPROVED BY: PQ	SCALE: As shown	PROJECT NO: 2178-001	FIGURE NO: 2

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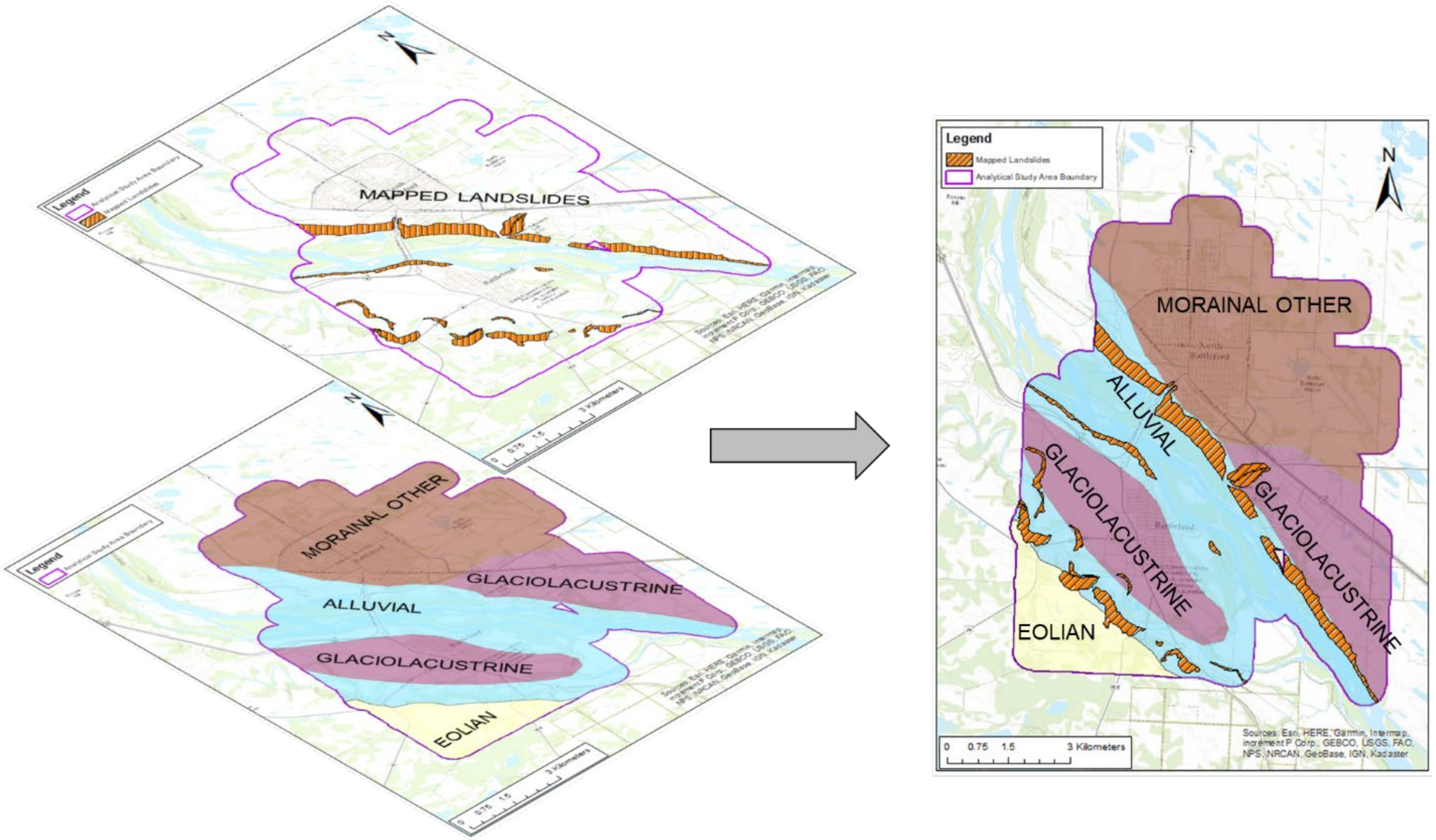

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. In this example, a surficial geology map (below) is compared spatially with mapped landslides (above) to produce a comparison (right) which serves as the basis for statistical analysis and calculation of weight factors, as described in the report.

PREPARED BY: PQ	FIGURE TITLE: Relating landslides with geospatial thematic data		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 3

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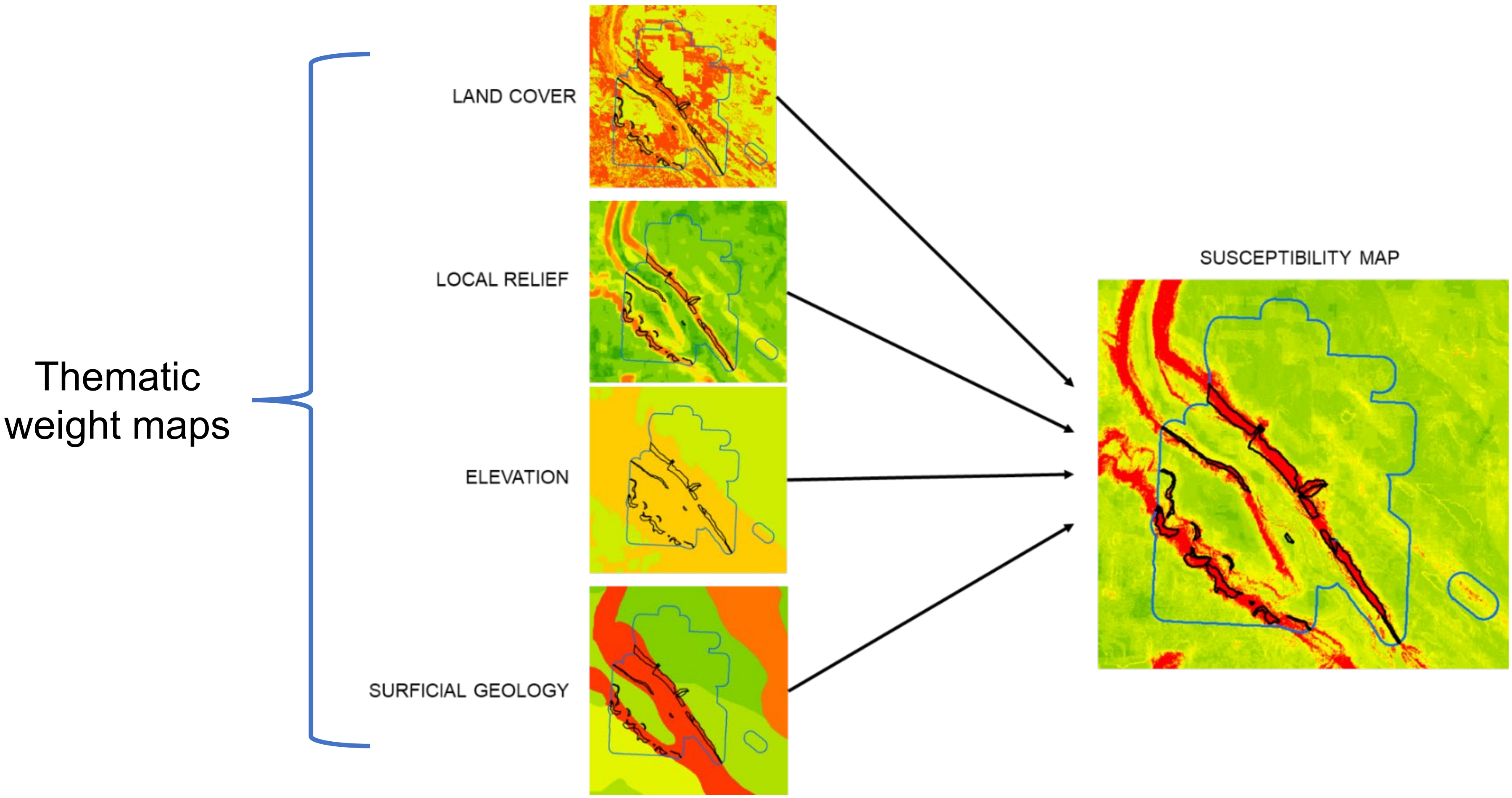

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Calculation of weights to produce the thematic weight maps is described in the report; these thematic weight maps are combined through raster addition to produce the susceptibility map.

PREPARED BY: PQ	FIGURE TITLE: Example combination of weight maps to produce the overall map		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 4

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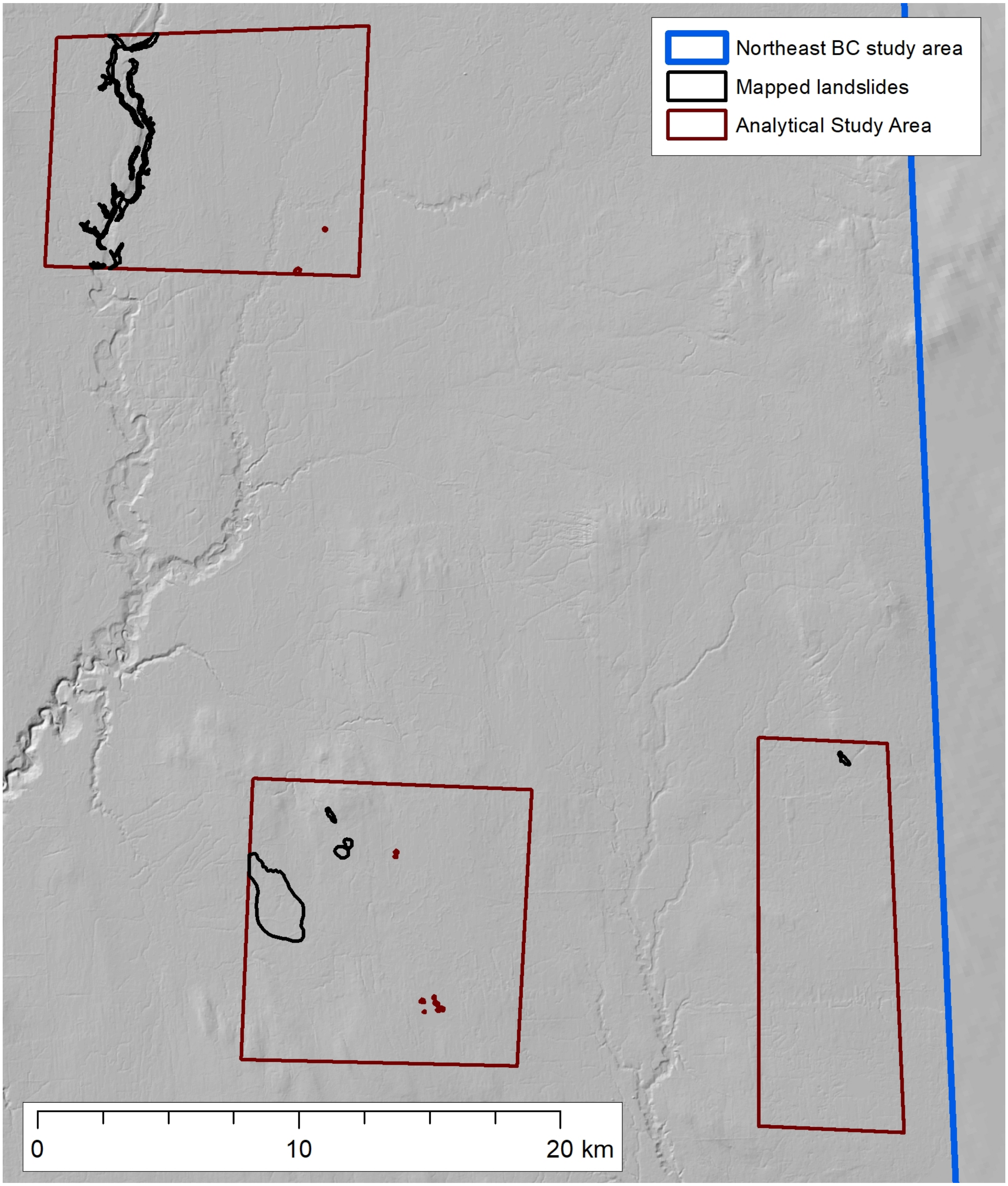

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Hillshade topographic relief map derived from Canadian Digital Elevation Data (CDED).

PREPARED BY: PQ	FIGURE TITLE: Example #1 of mapped landslides	
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society	
APPROVED BY: PQ	SCALE: As shown	PROJECT NO: 2178-001	FIGURE NO: 5

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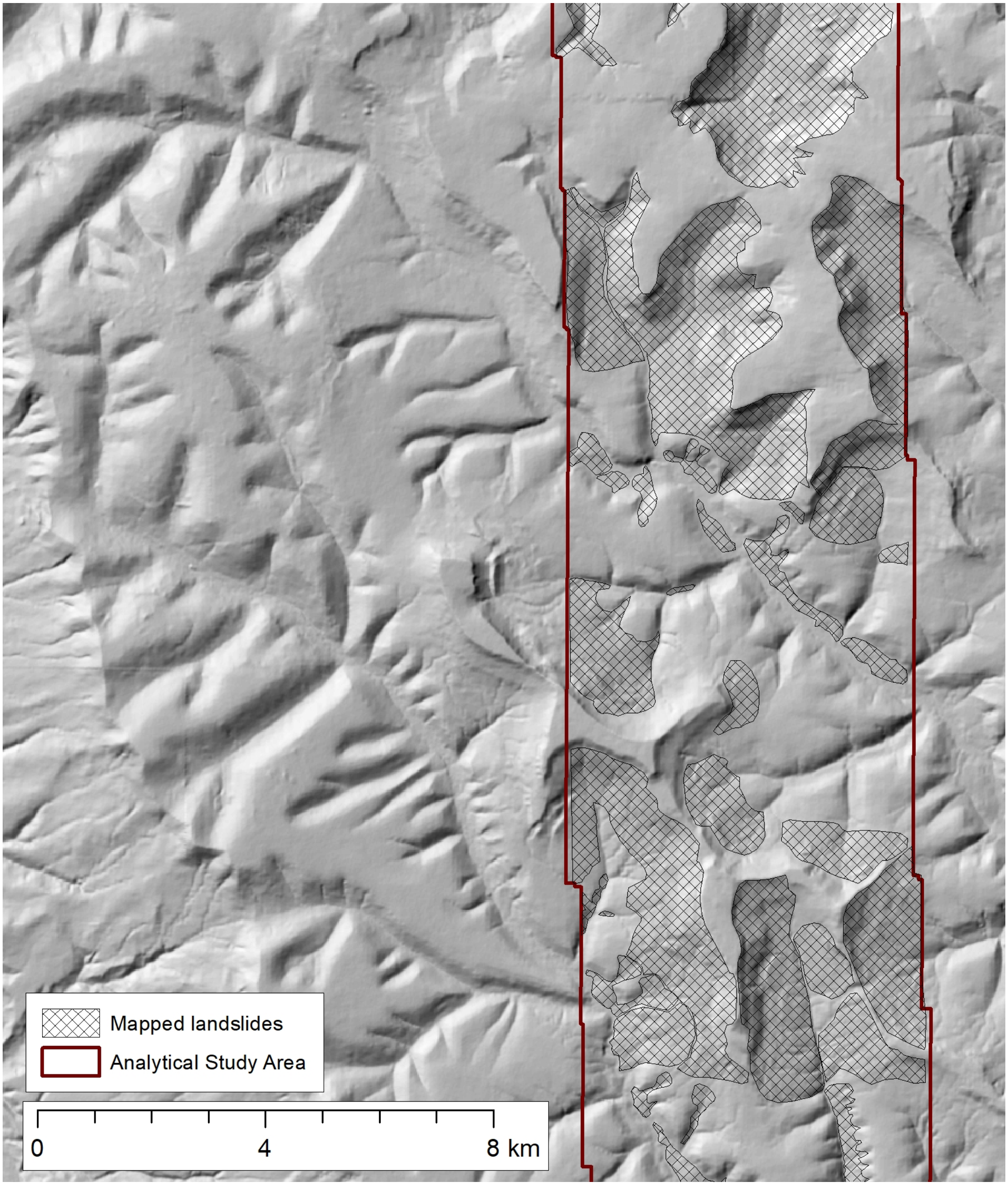

NOTES:
1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Hillshade topographic relief map derived from Canadian Digital Elevation Data (CDED).

PREPARED BY: PQ	FIGURE TITLE: Example #2 of mapped landslides		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: As shown	PROJECT NO: 2178-001	FIGURE NO: 6

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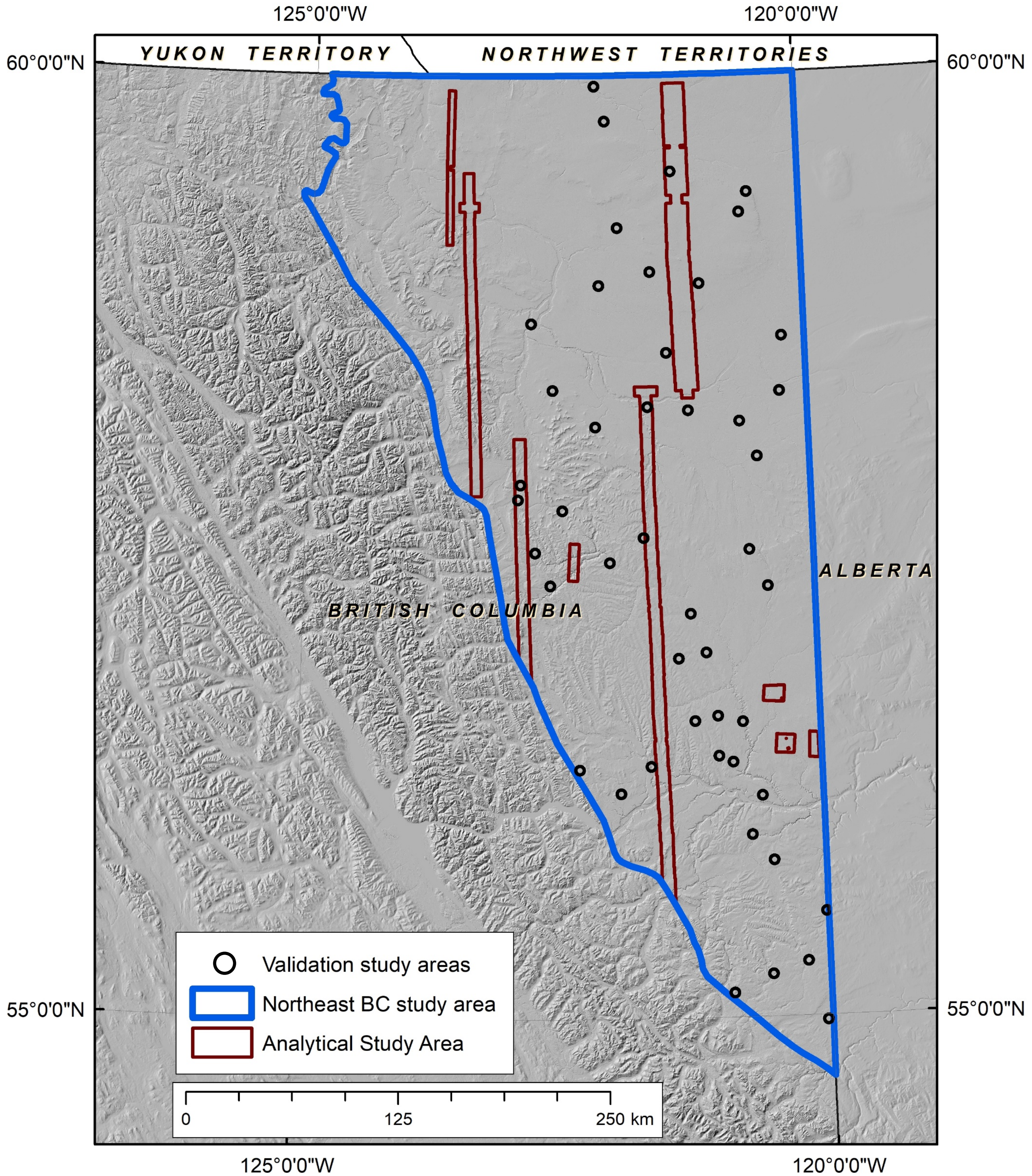

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Hillshade topographic relief map derived from Canadian Digital Elevation Data (CDED).
3. The landslide inventory used to build the model was mapped within the analytical study. Landslides were mapped within the validation study areas to test the model's predictive power, as described in the report.

PREPARED BY:	FIGURE TITLE		
PQ	Validation Study Areas		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: As shown	PROJECT NO: 2178-001	FIGURE NO: 7

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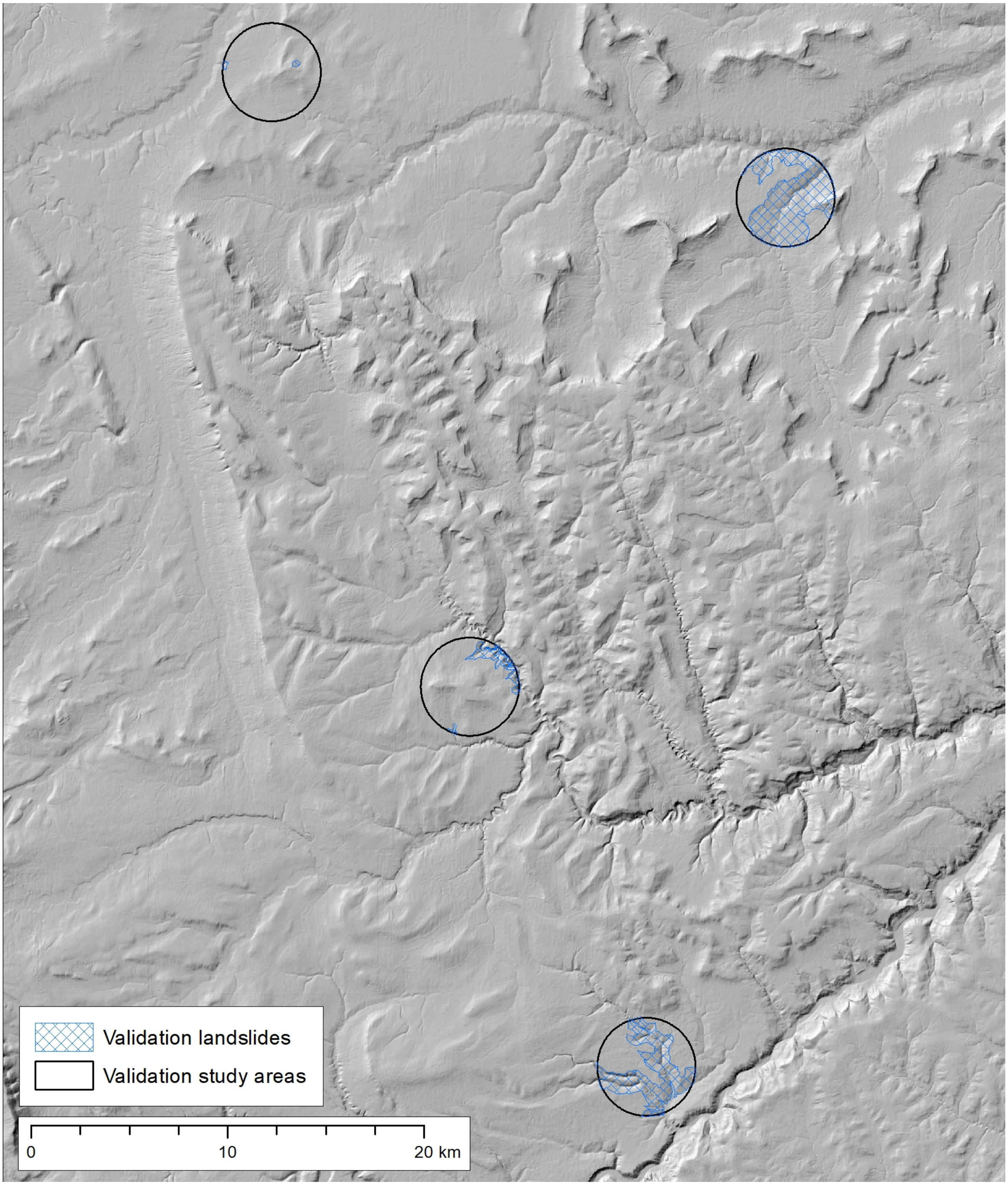

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Hillshade topographic relief map derived from Canadian Digital Elevation Data (CDED).

PREPARED BY: PQ	FIGURE TITLE: Mapped landslides in validation study areas			
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society			
APPROVED BY: PQ	SCALE: As shown	PROJECT NO: 2178-001	FIGURE NO: 8	

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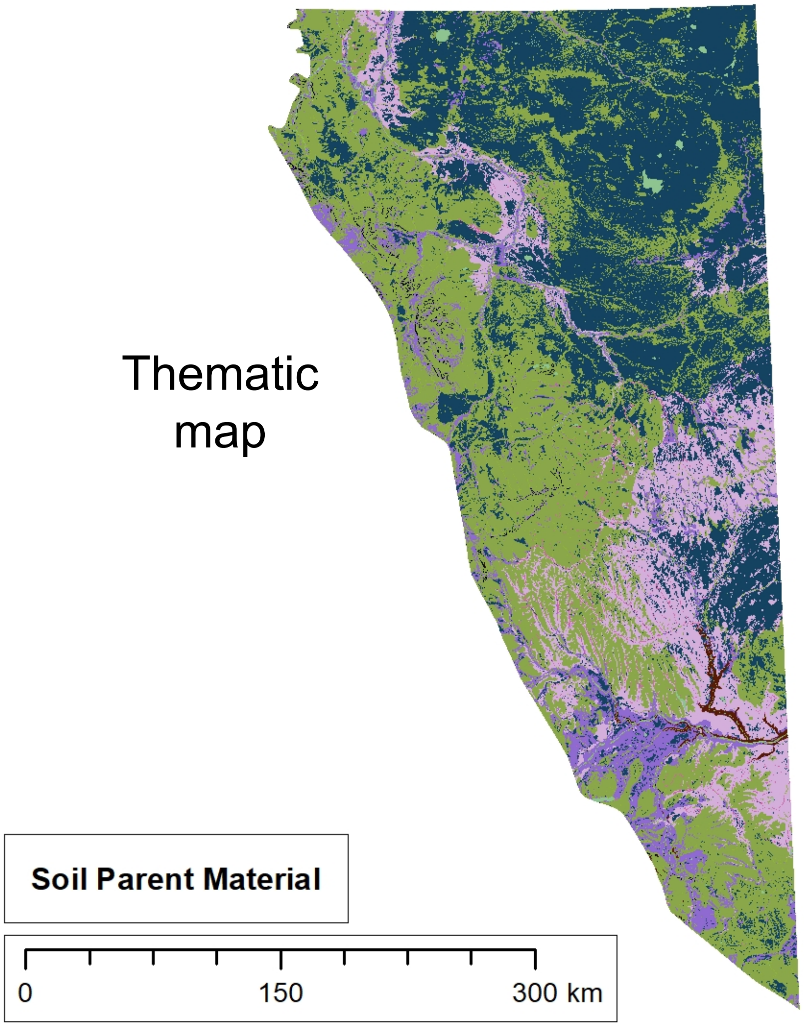

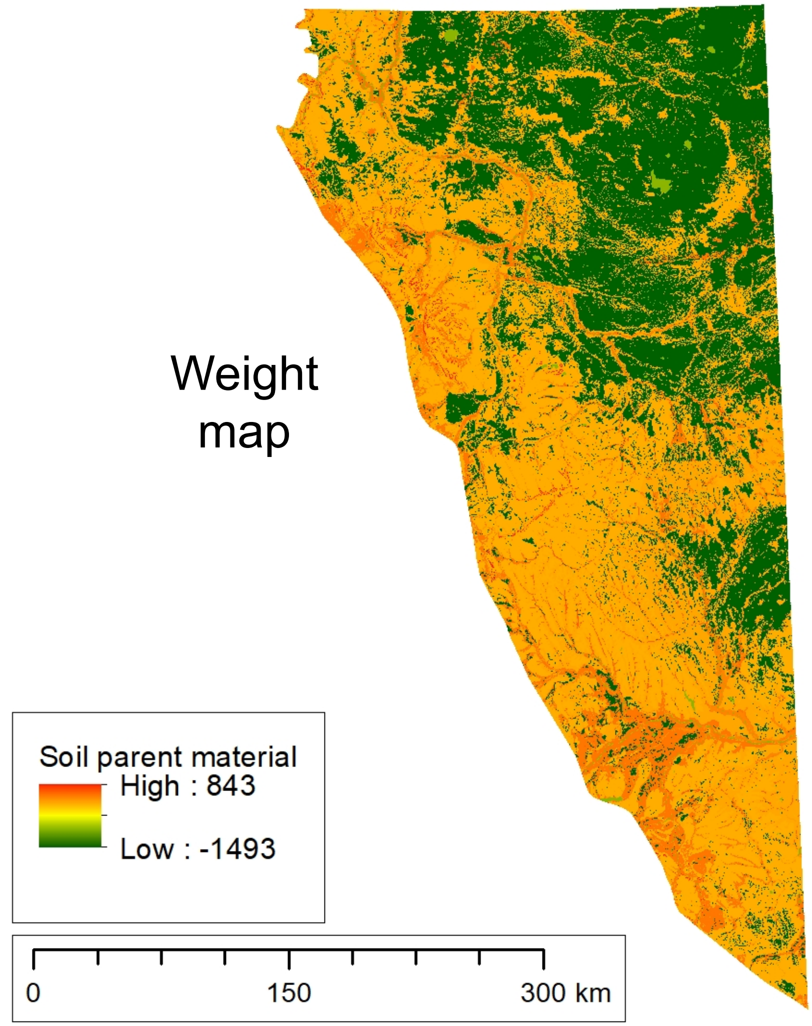

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Thematic data obtained from Hectares BC at www.hectaresbc.org.
3. The process used to develop the soil parent material map was described in a paper presented to the DSM 2014 workshop in Nanjing China. CE Bulmer et al. 2014 "Improved soil mapping in British Columbia, Canada with legacy soil data and Random Forest."
4. No legend is provided for the thematic map since there are too many distinct material types for effective presentation. The dominant material types are till, organics, lacustrine, glaciolacustrine and fluvial, with lesser amounts of glaciofluvial, colluvium and bedrock.

PREPARED BY:	FIGURE TITLE		
PQ	Soil Parent Material		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 9

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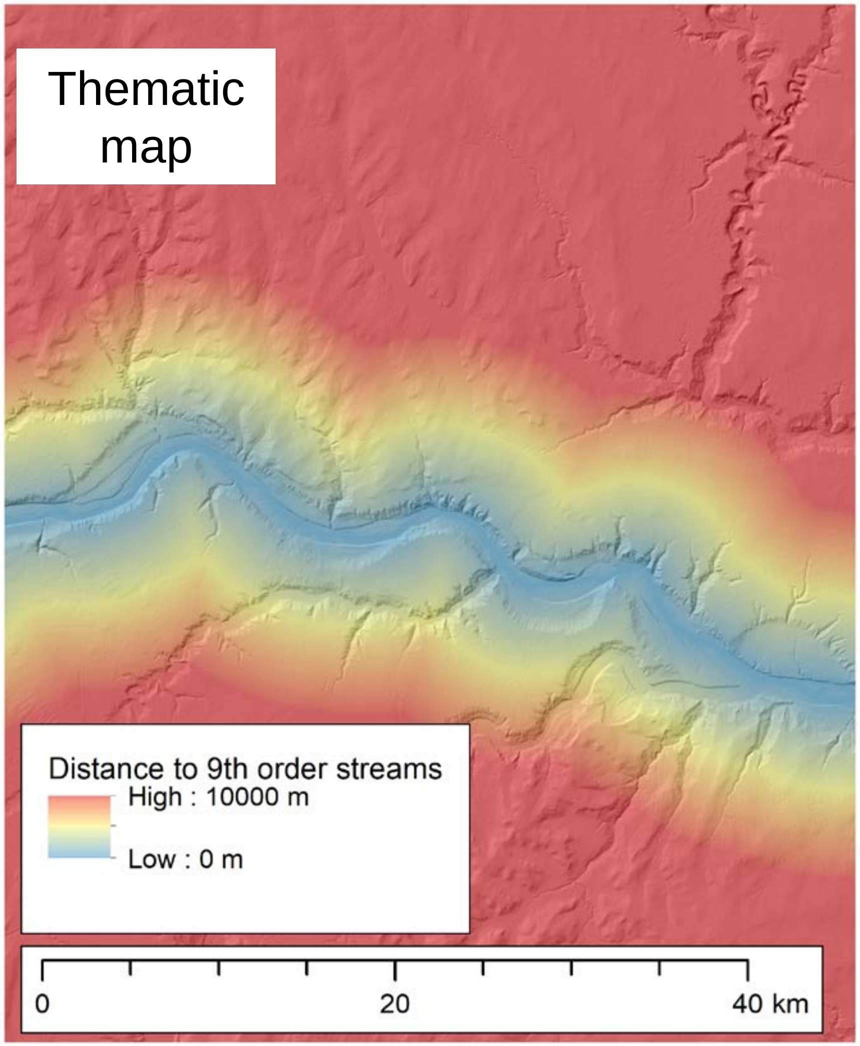

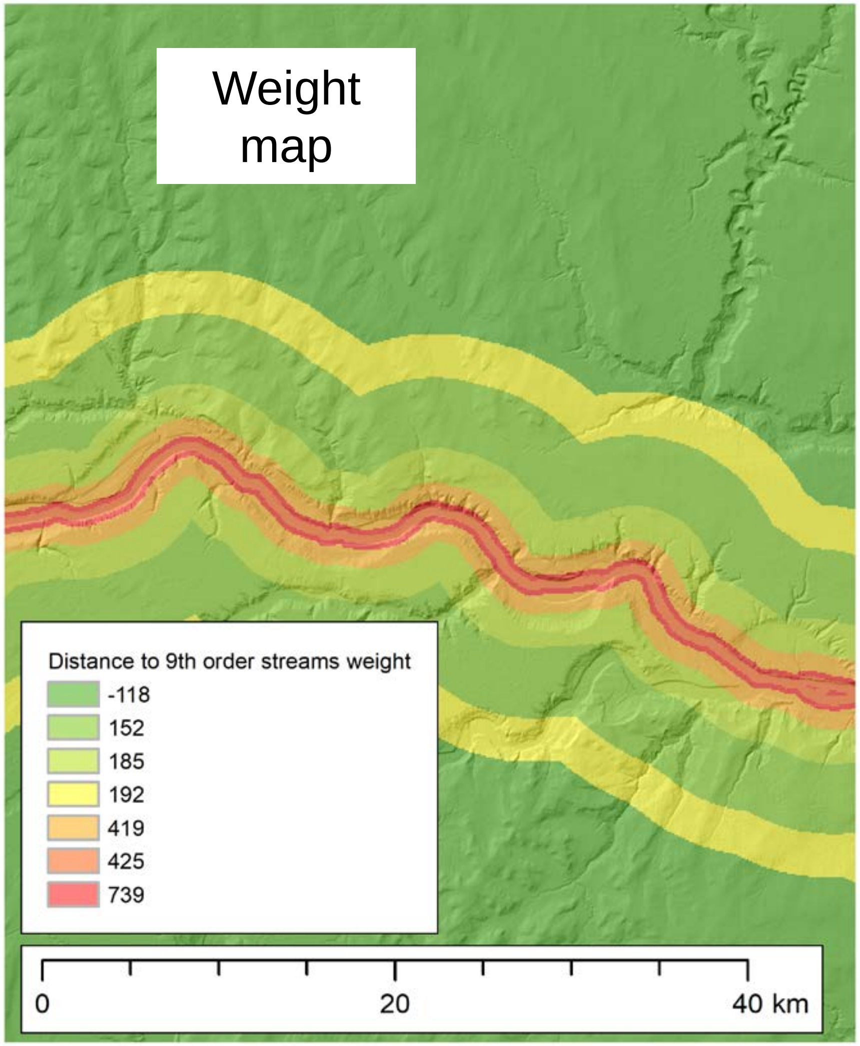

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Stream data obtained from BGC's River Network Tools™. See report for further details.

PREPARED BY: PQ	FIGURE TITLE: Distance to 9th order streams		
CHECKED BY:	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 10

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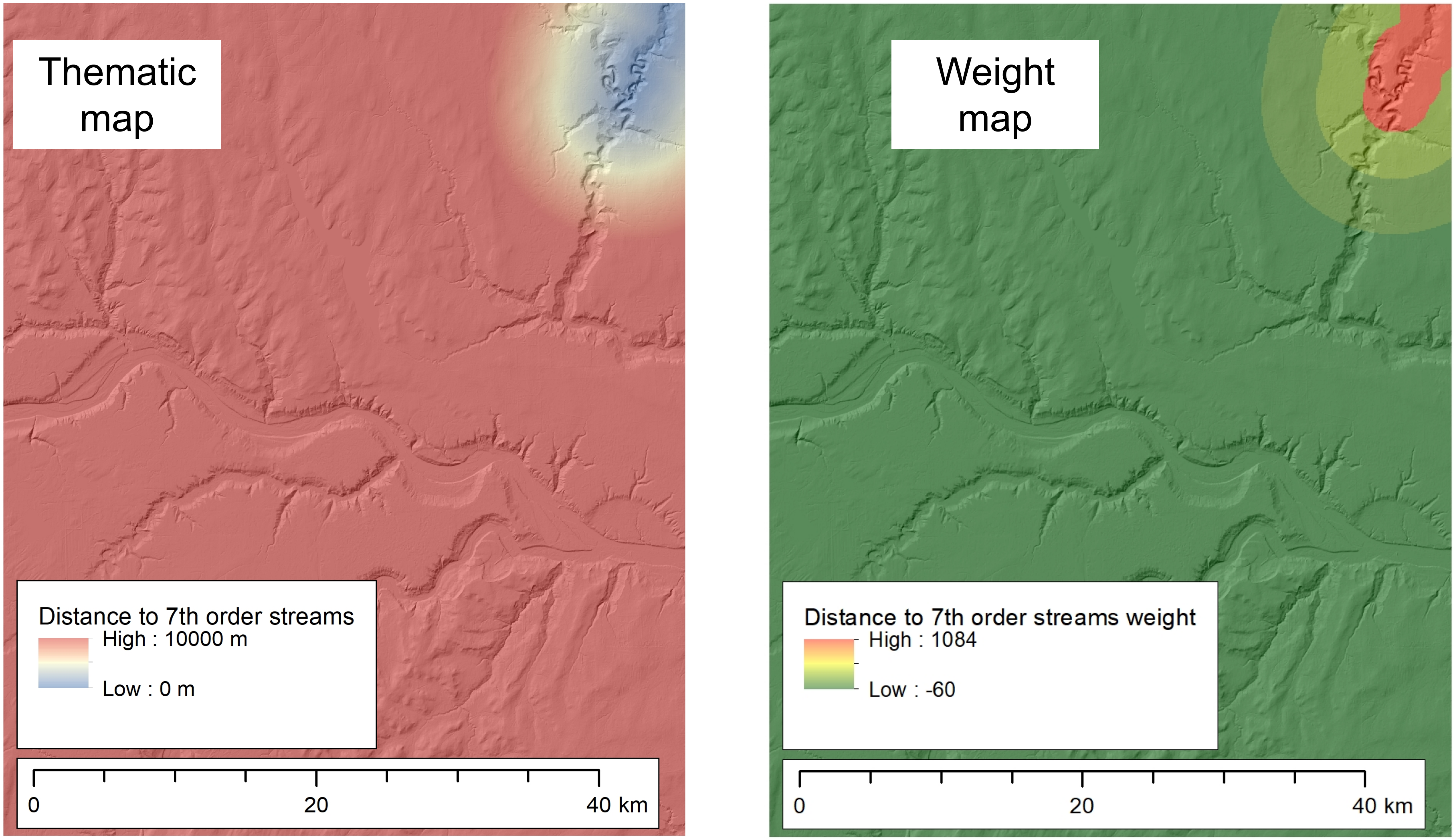

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Stream data obtained from BGC's River Network Tools™. See report for further details.

PREPARED BY: PQ	FIGURE TITLE: Distance to 7th order streams
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society
APPROVED BY: PQ	SCALE: NTS; PROJECT NO: 2178-001; FIGURE NO: 11

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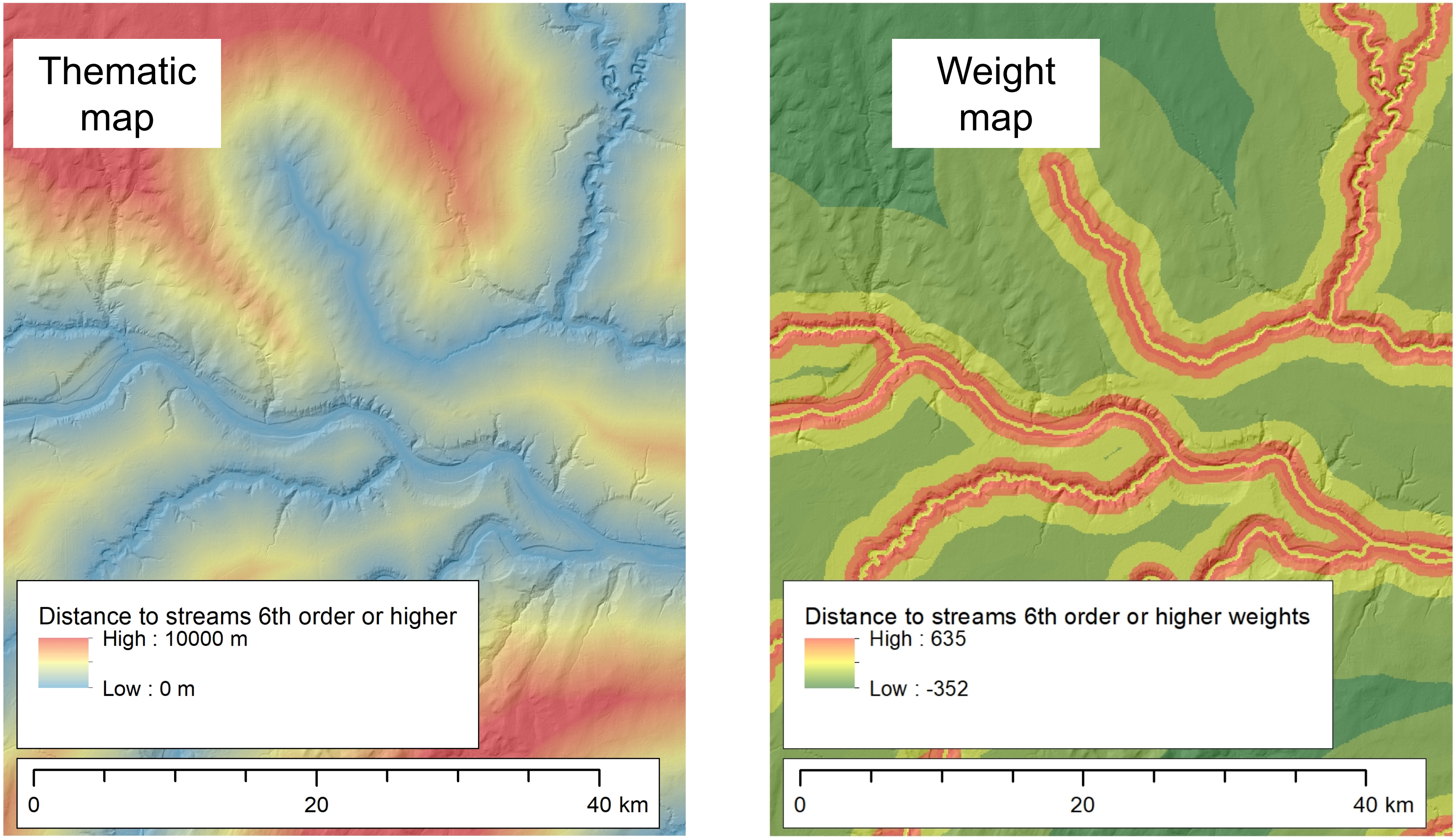

NOTES:
1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Stream data obtained from BGC's River Network Tools™. See report for further details.

PREPARED BY: PQ	FIGURE TITLE: Distance to 6th order and higher streams
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society
APPROVED BY: PQ	SCALE: NTS; PROJECT NO: 2178-001; FIGURE NO: 12

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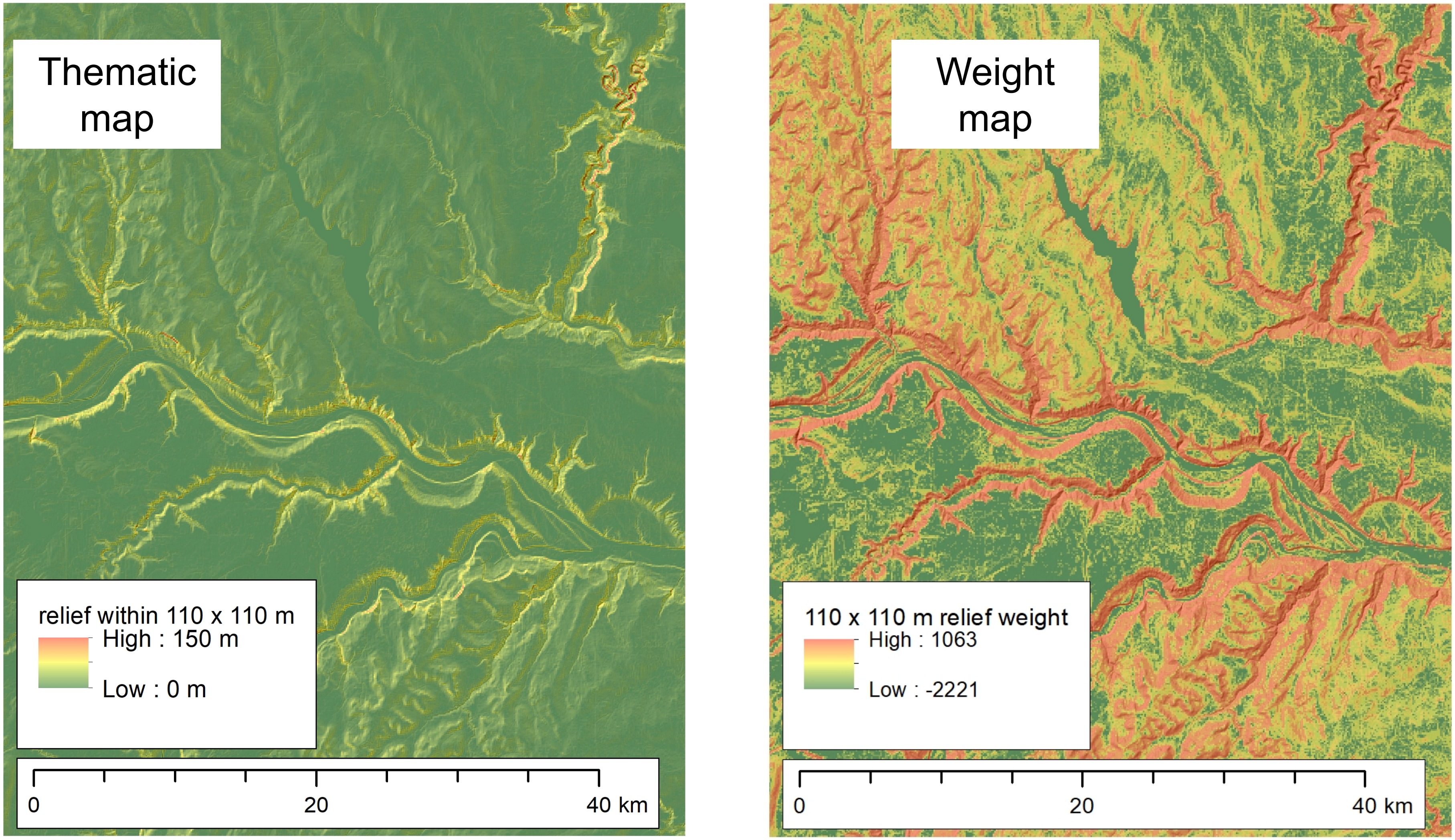

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Topographic interpretations generated from Canadian Digital Elevation Data: Natural Resources Canada. Laval, Quebec. [computer file]. National Topographic Database, 1:50 000, map code 31H/12, version 3.10. Ottawa: Natural Resources Canada, Geomatics Canada, 1995.

PREPARED BY:	FIGURE TITLE		
PQ	Topographic relief 110 x 110 m		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 13

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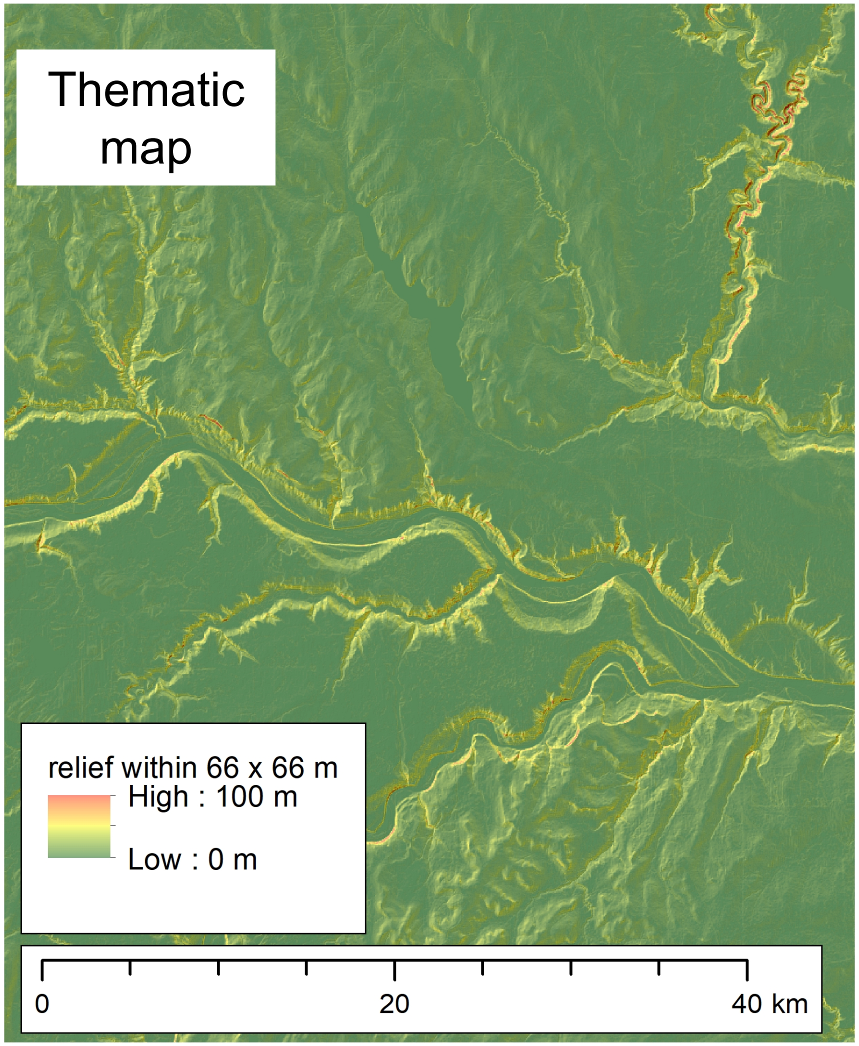

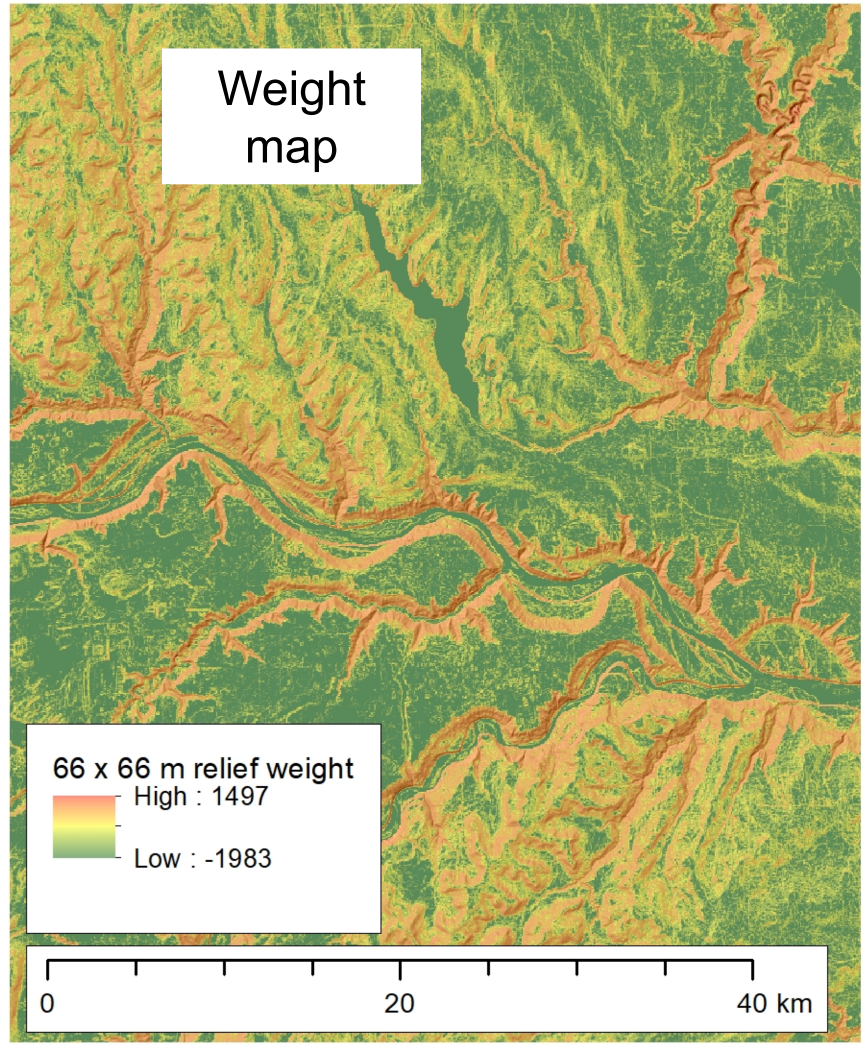

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Topographic interpretations generated from Canadian Digital Elevation Data: Natural Resources Canada. Laval, Quebec. [computer file]. National Topographic Database, 1:50 000, map code 31H/12, version 3.10. Ottawa: Natural Resources Canada, Geomatics Canada, 1995.

PREPARED BY: PQ	FIGURE TITLE: Topographic relief 66 x 66 m			
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society			
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 14	

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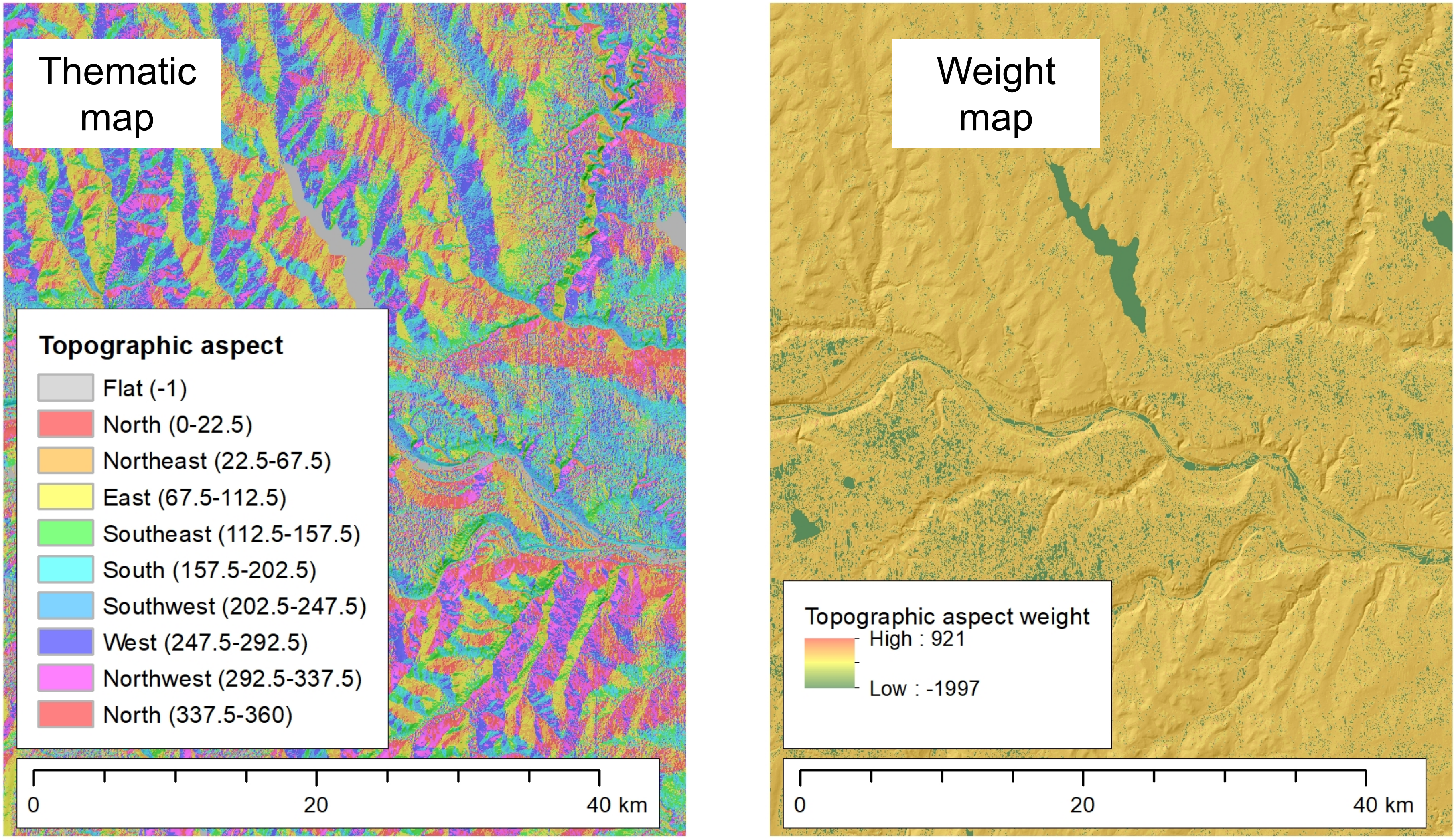

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Topographic interpretations generated from Canadian Digital Elevation Data: Natural Resources Canada. Laval, Quebec. [computer file]. National Topographic Database, 1:50 000, map code 31H/12, version 3.10. Ottawa: Natural Resources Canada, Geomatics Canada, 1995.

PREPARED BY: PQ	FIGURE TITLE: Topographic aspect			
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society			
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 15	

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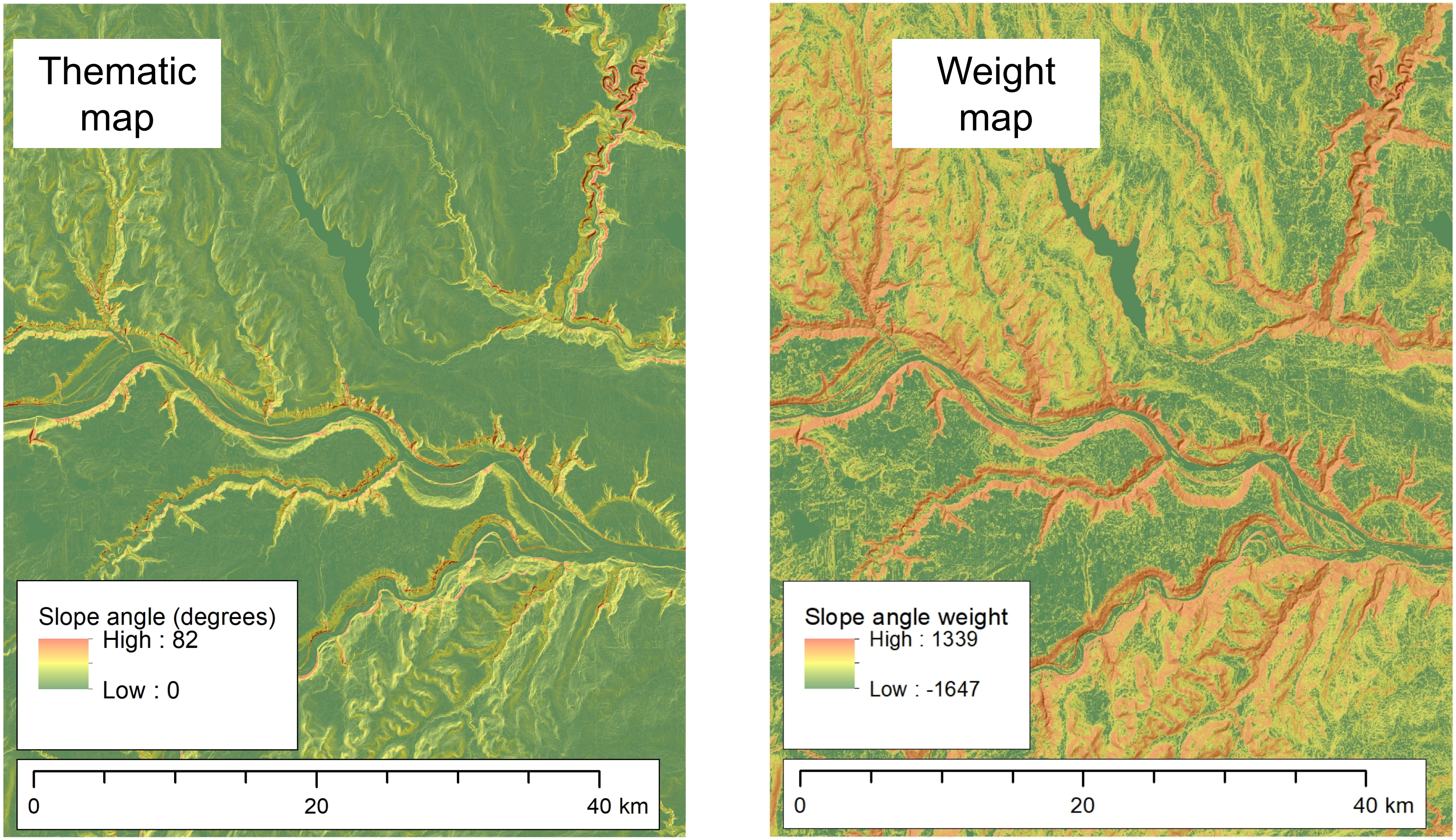

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Topographic interpretations generated from Canadian Digital Elevation Data: Natural Resources Canada. Laval, Quebec. [computer file]. National Topographic Database, 1:50 000, map code 31H/12, version 3.10. Ottawa: Natural Resources Canada, Geomatics Canada, 1995.

PREPARED BY: PQ	FIGURE TITLE: Topographic slope		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 16

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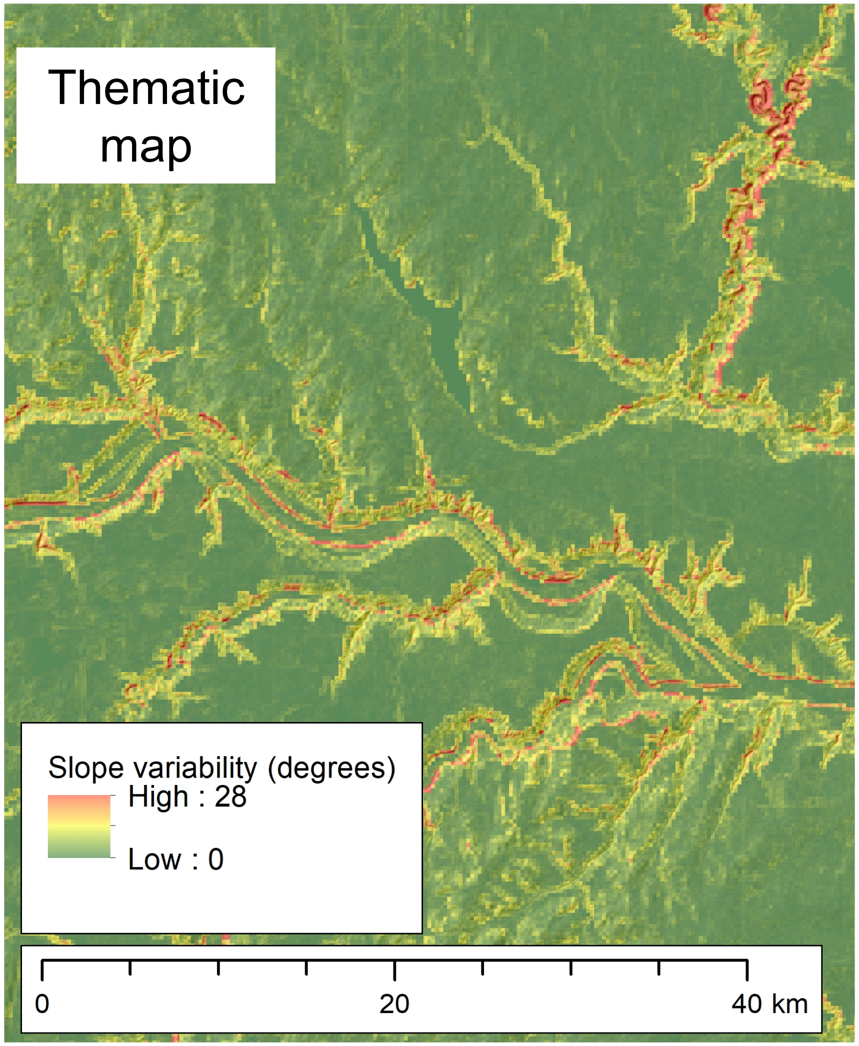

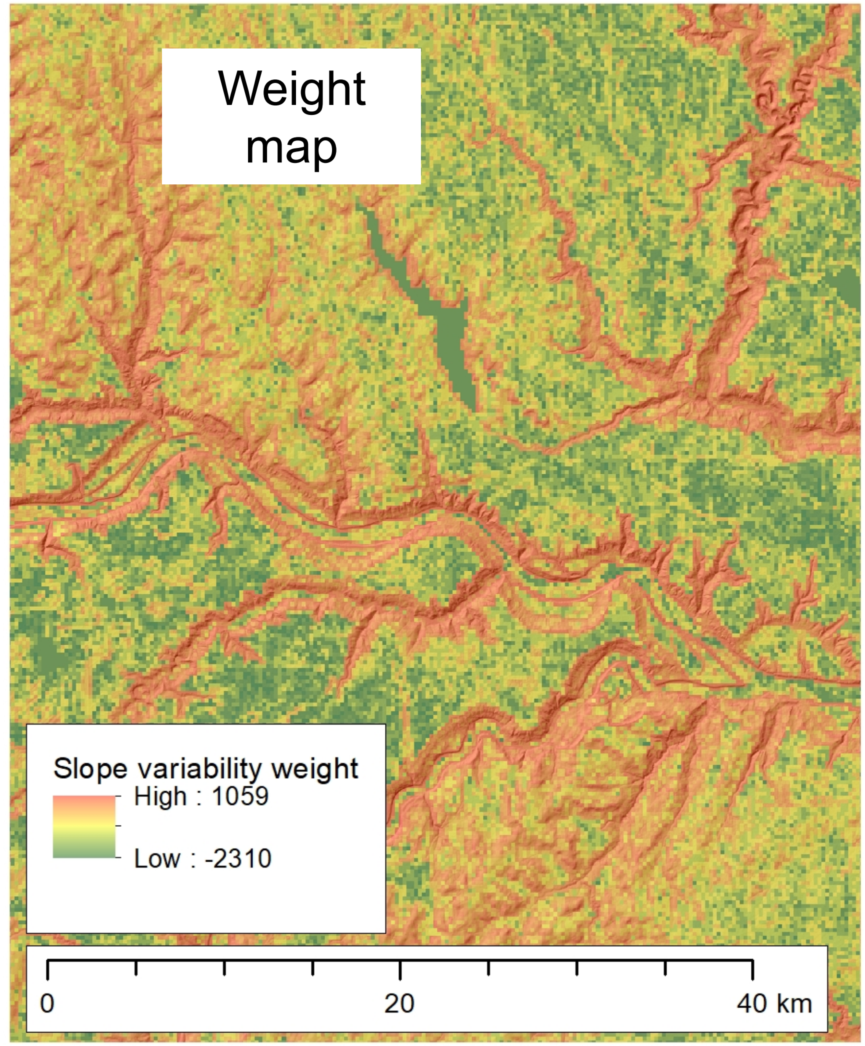

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Topographic interpretations generated from Canadian Digital Elevation Data: Natural Resources Canada. Laval, Quebec. [computer file]. National Topographic Database, 1:50 000, map code 31H/12, version 3.10. Ottawa: Natural Resources Canada, Geomatics Canada, 1995.
3. Slope variability is taken as the standard deviation of slope angle over an area of 10 x 10 map pixels (220 x 220 m).

PREPARED BY:	FIGURE TITLE		
PQ	Slope variability		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 17

0 5 10 mm in ANSI A sized paper

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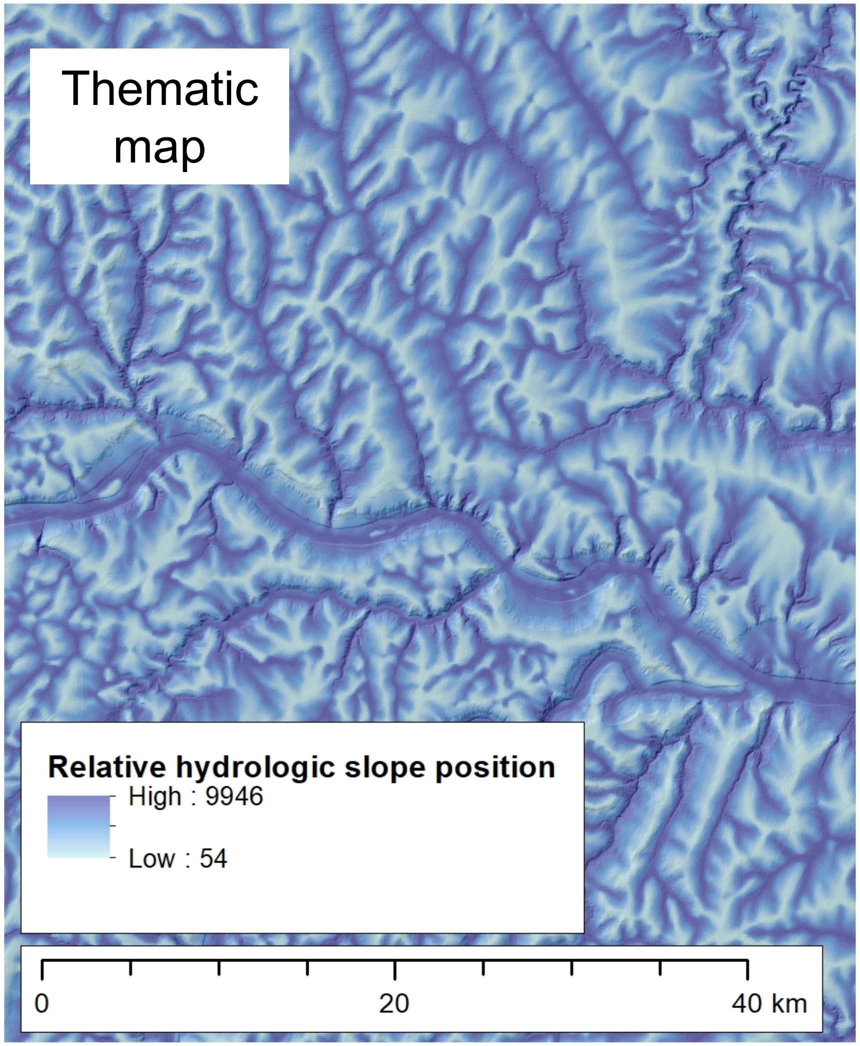
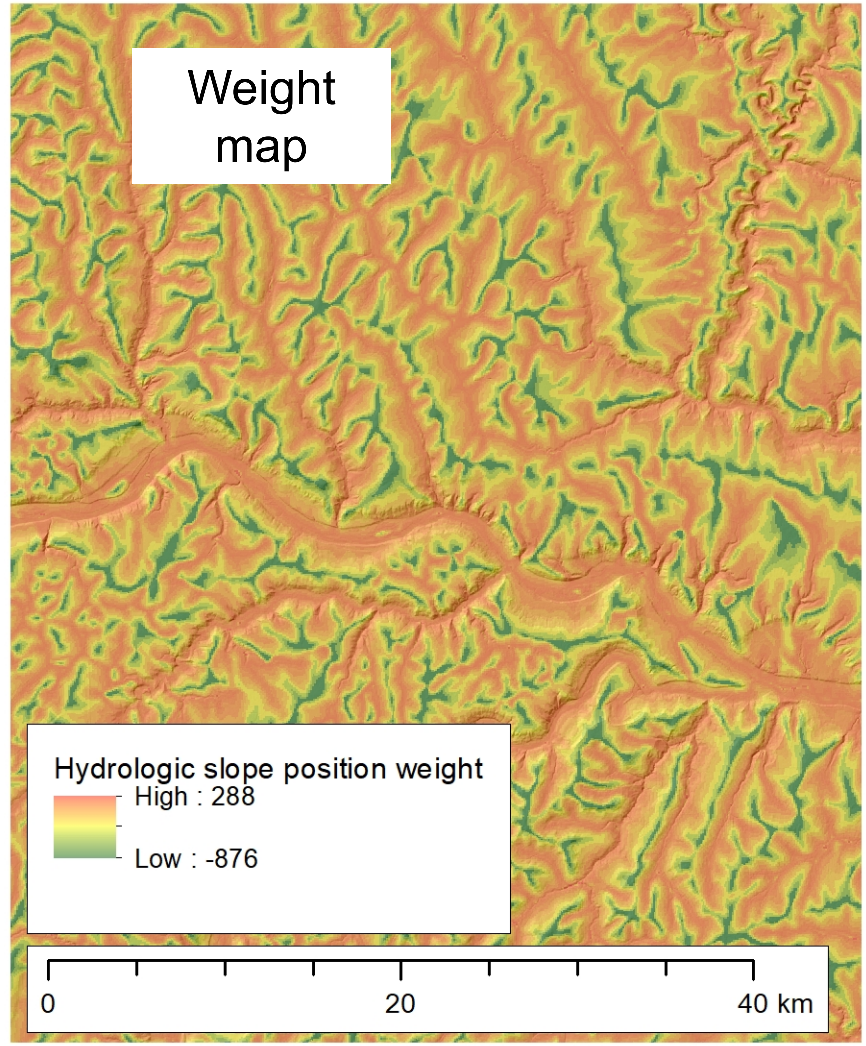




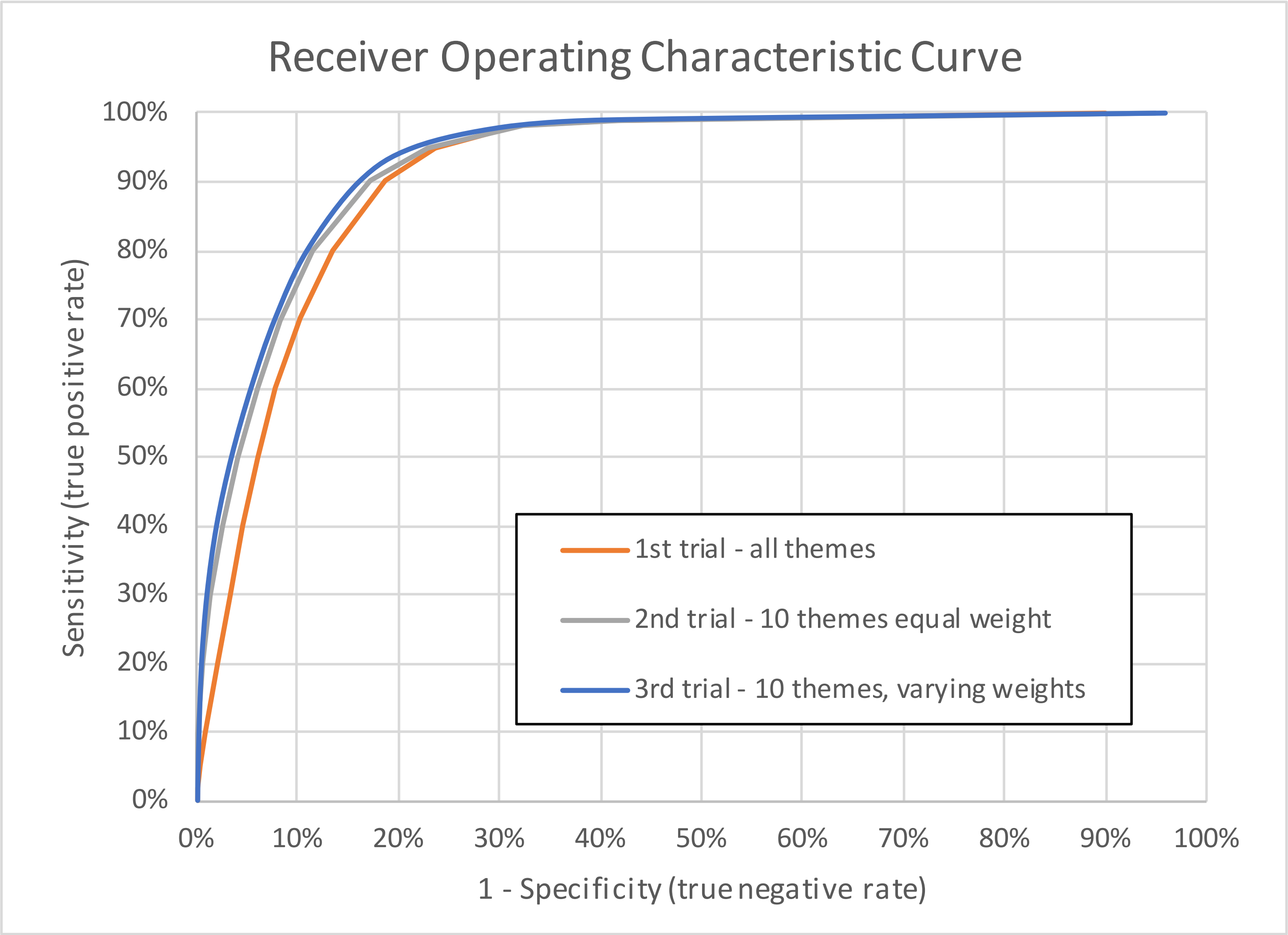
NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Thematic data obtained from Hectares BC at www.hectaresbc.org.
3. The relative hydrologic slope position is a unitless measure that describes the hydrologic position of a cell within its local flow path and is determined by dividing the cell's catchment area into the total catchment area for both the upslope and downslope local flow paths.

PREPARED BY: PQ	FIGURE TITLE: Relative Hydrologic Slope Position			
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society			
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 18	

0 5 10 mm in ANSI A sized paper

December 2020



NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.

PREPARED BY: PQ	FIGURE TITLE: Model Performance – Receiver Operating Characteristic Curves		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 19

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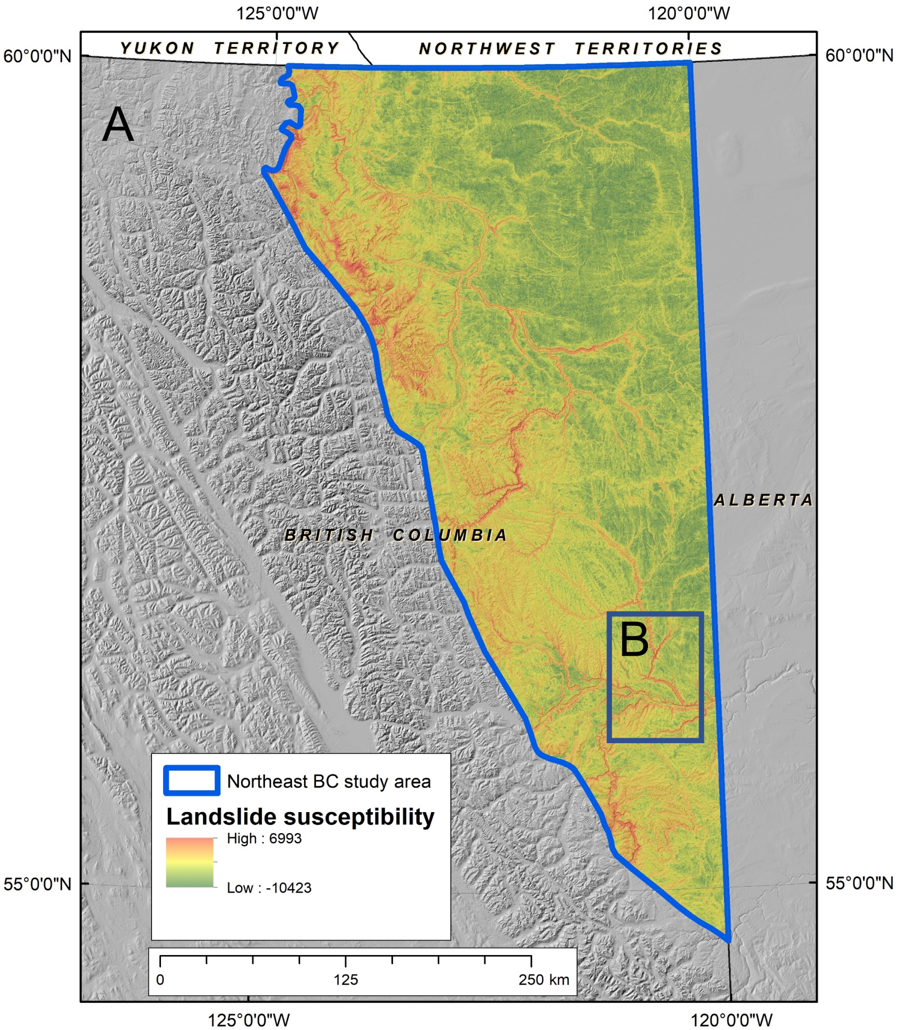

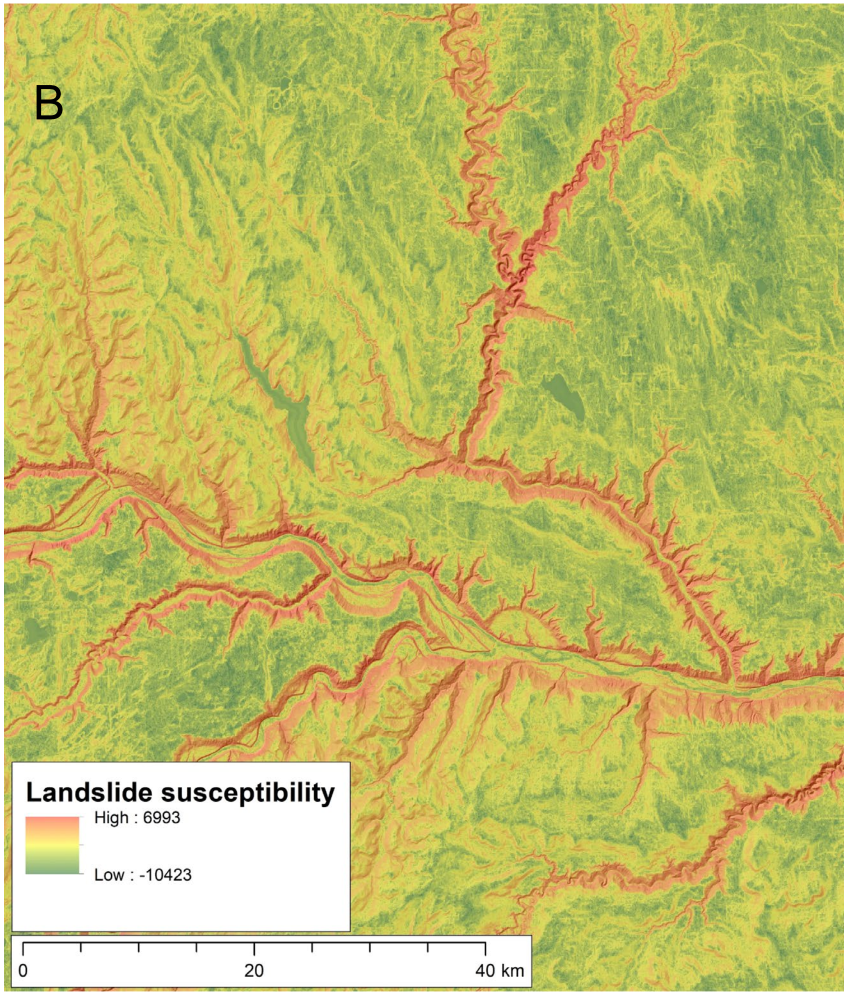

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. The right image (B) represents the same area as shown in the left images (A) in Figures 23 and 24.

PREPARED BY: PQ	FIGURE TITLE: Landslide susceptibility model: raw output			
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society			
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 20	

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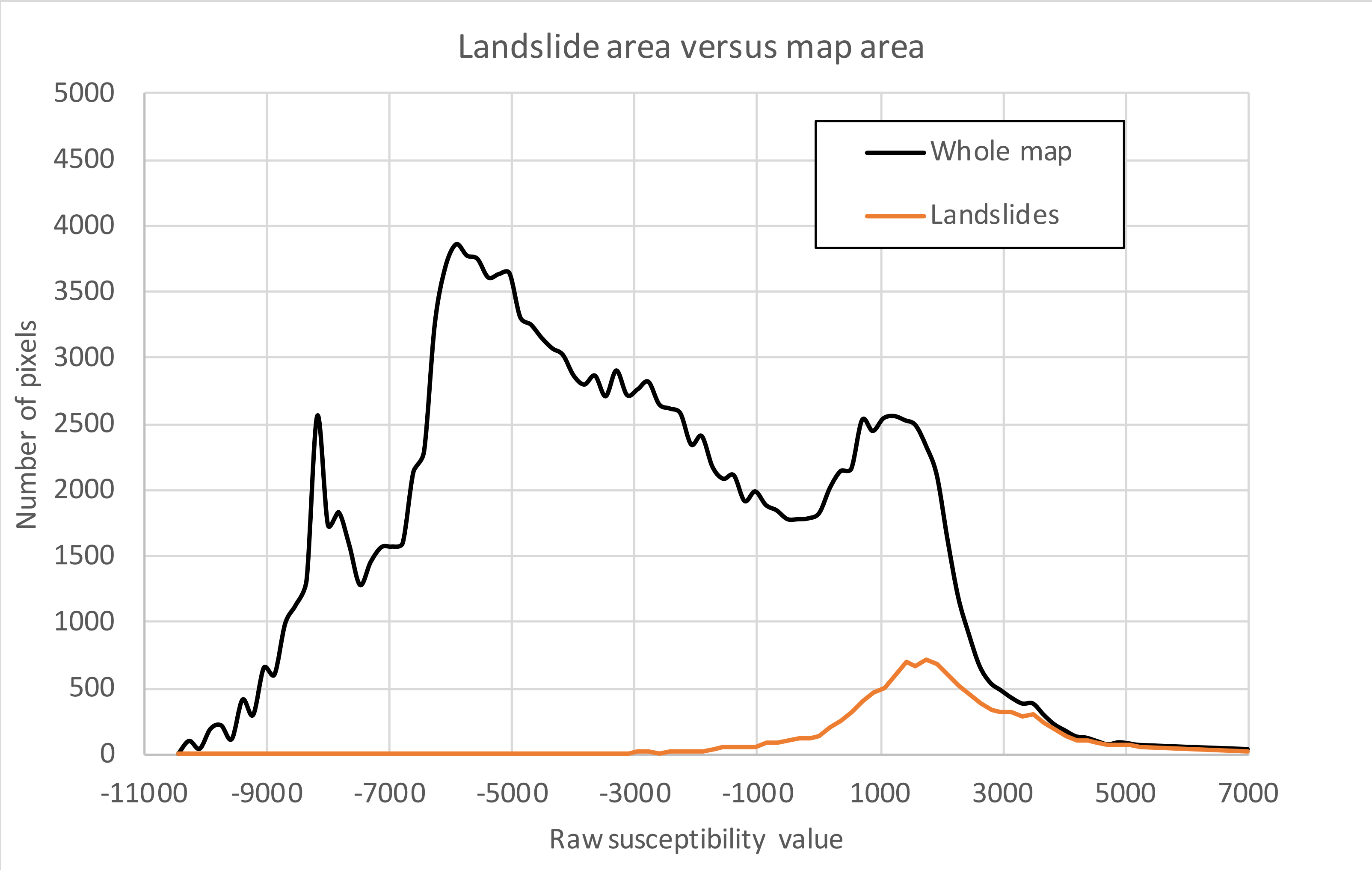

NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.

PREPARED BY: PQ	FIGURE TITLE: Landslide area versus map area with raw susceptibility value		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 21

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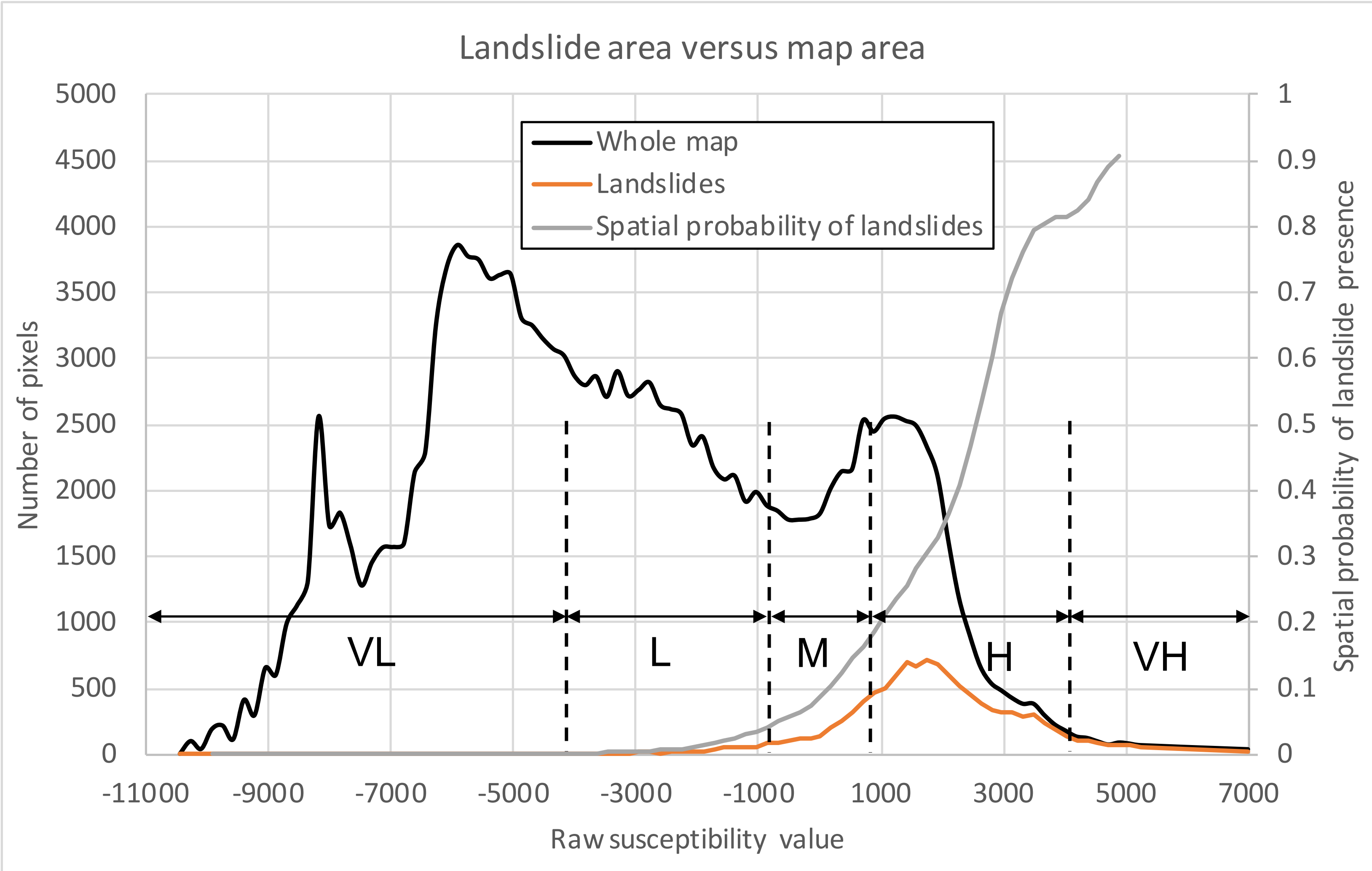
December 2020



NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. Qualitative susceptibility classes are shown with their approximate raw susceptibility value thresholds:
   - VL to L -4297
   - L to M -891
   - M to H 902
   - H to VH 4059

PREPARED BY:	FIGURE TITLE		
PQ	Reclassification of landslide susceptibility		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 22

0 5 10 mm in ANSI A sized paper

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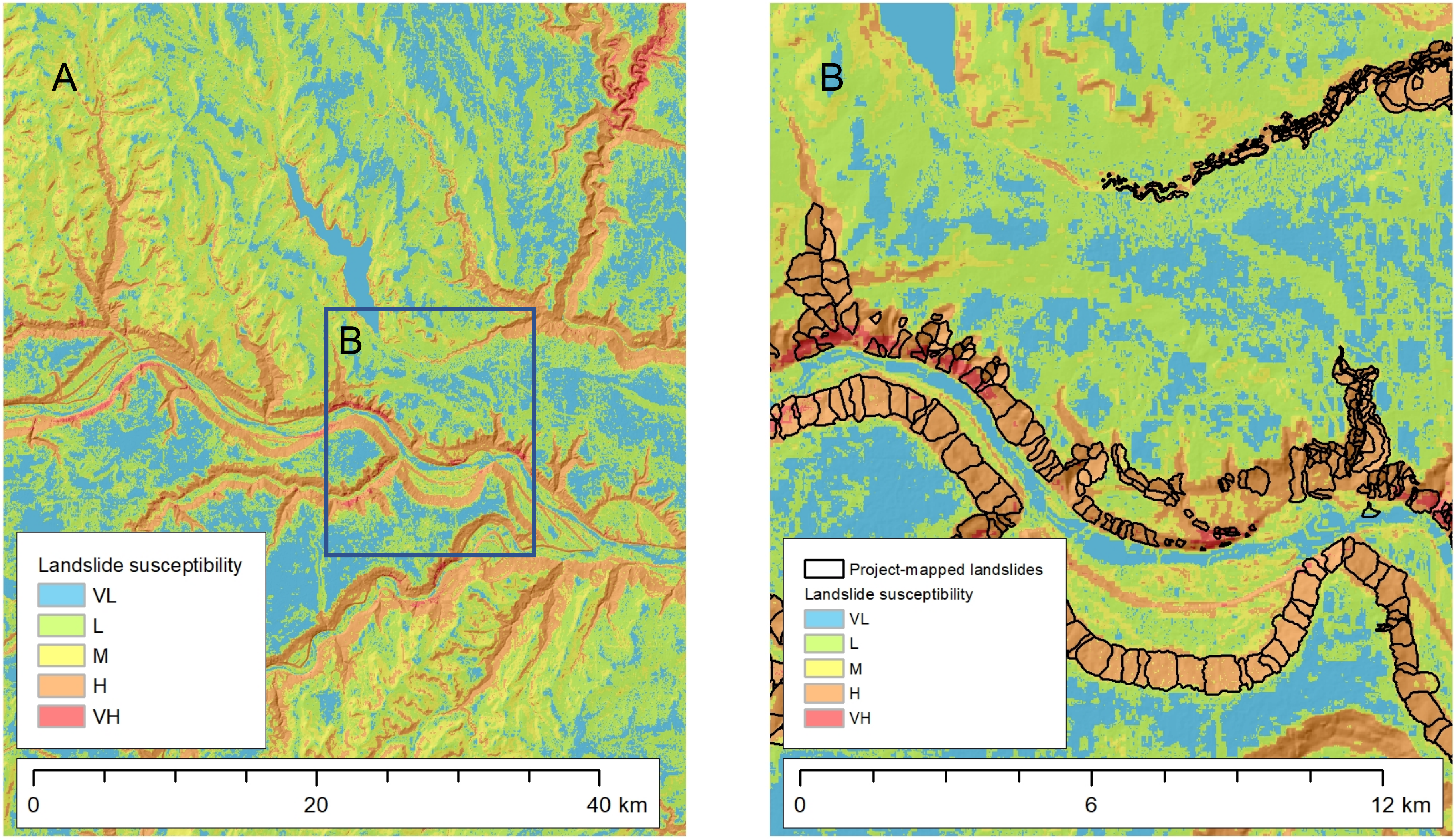
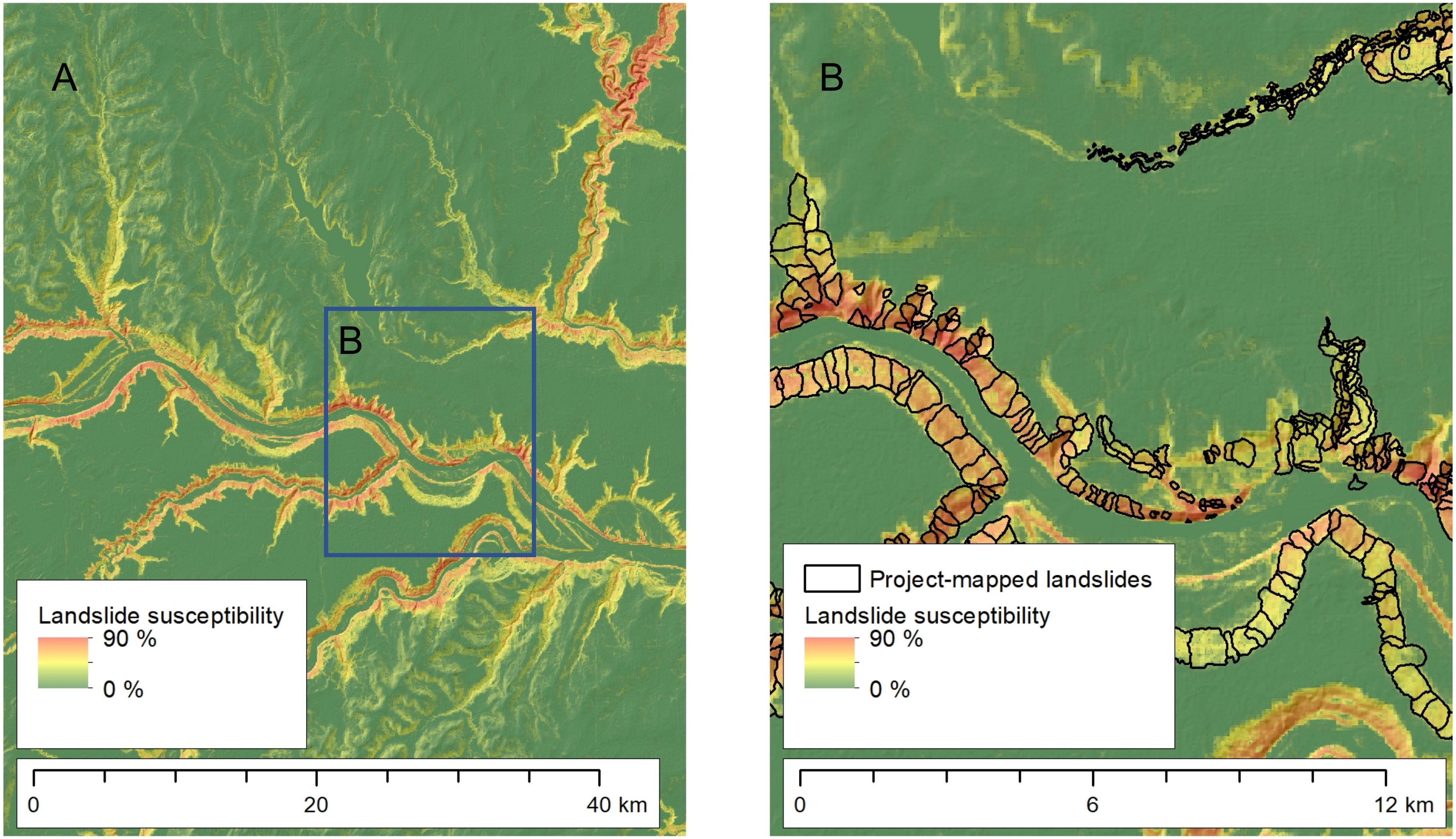


NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. The left image (A) shows the same area as illustrated in the right image (B) of Figure 20.

PREPARED BY: PQ	FIGURE TITLE: Landslide susceptibility model: five class model		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 23

0 5 10 mm in ANSI A sized paper



NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. The left image (A) shows the same area as illustrated in the right image (B) of Figure 20.

PREPARED BY: PQ	FIGURE TITLE: Landslide susceptibility model: spatial probability
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society
APPROVED BY: PQ	SCALE: NTS / PROJECT NO: 2178-001 / FIGURE NO: 24

0 5 10 mm in ANSI A sized paper

Confusion Matrix: Analytical Study area			
	Predicted non-landslide	Predicted landslide	*Sums:*
Actual non-landslide	True Negative	False Positive	*149069*
Actual landslide	False Negative	True Positive	*11390*
Sums:	*varies*	*varies*	***160459***

Confusion Matrix: "Low" threshold			
	Predicted non-landslide	Predicted landslide	*Sums:*
Actual non-landslide	69031	80038	*149069*
Actual landslide	57	11333	*11390*
Sums:	*69088*	*91371*	***160459***

Confusion Matrix: "Moderate" threshold			
	Predicted non-landslide	Predicted landslide	*Sums:*
Actual non-landslide	117189	31880	*149069*
Actual landslide	570	10820	*11390*
Sums:	*117759*	*42700*	***160459***

Confusion Matrix: "High" threshold			
	Predicted non-landslide	Predicted landslide	*Sums:*
Actual non-landslide	135561	13508	*149069*
Actual landslide	2846	8544	*11390*
Sums:	*138407*	*22052*	***160459***

Confusion Matrix: "Very High" threshold			
	Predicted non-landslide	Predicted landslide	*Sums:*
Actual non-landslide	148962	107	*149069*
Actual landslide	10819	571	*11390*
Sums:	*159781*	*678*	***160459***

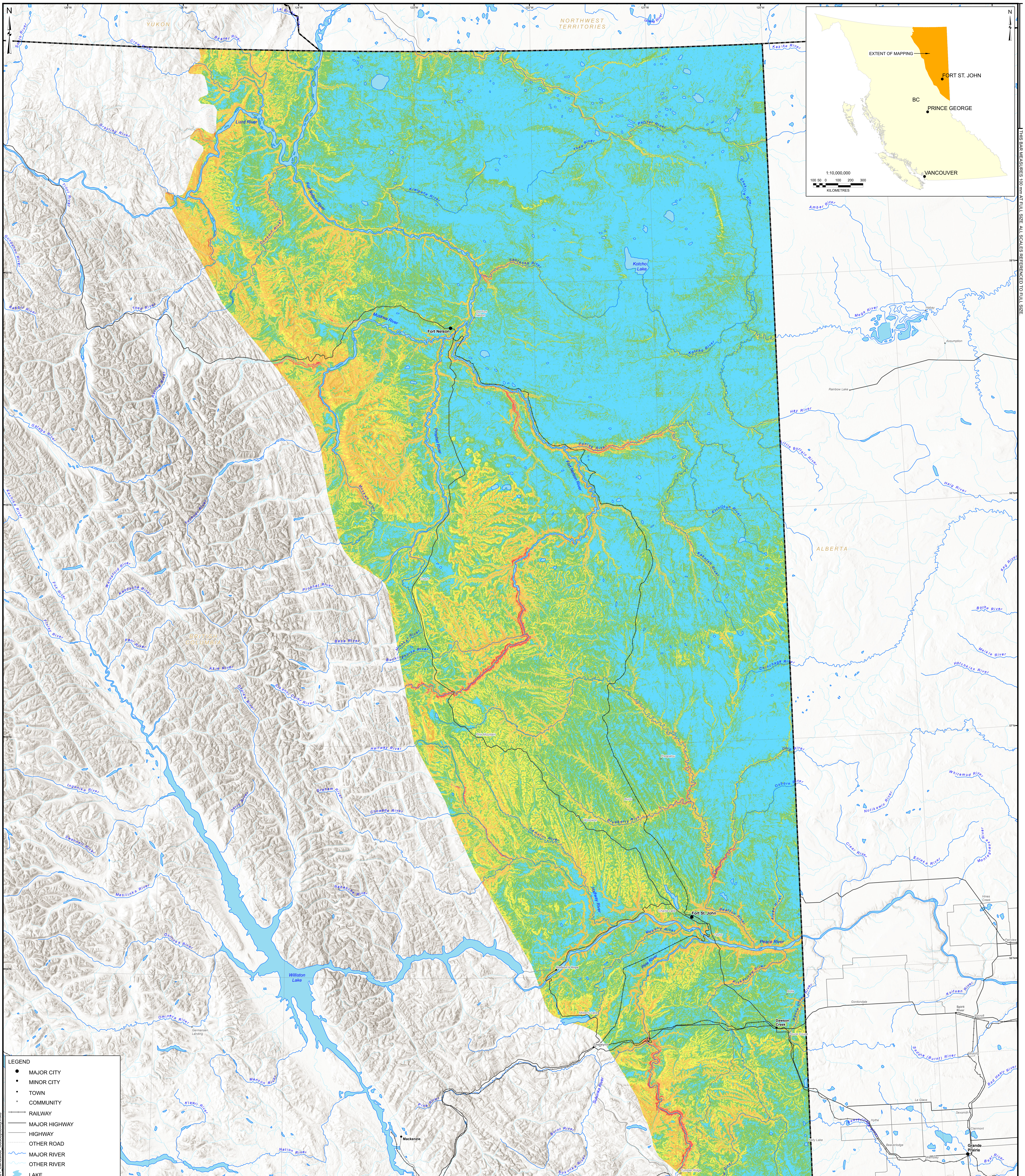
NOTES:

1. This Figure should be read in conjunction with BGC's report entitled "Northeast British Columbia Landslide Susceptibility Map" and dated December 2020.
2. The numbers represent numbers of pixels within the analytical study area.

PREPARED BY:	FIGURE TITLE		
PQ	Confusion Matrices		
CHECKED BY: CF	CLIENT: BC Oil and Gas Research and Innovation Society		
APPROVED BY: PQ	SCALE: NTS	PROJECT NO: 2178-001	FIGURE NO: 25

0 5 10 mm in ANSI A sized paper

DRAWINGS



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "NORTHEAST BRITISH COLUMBIA LANDSLIDE SUSCEPTIBILITY MAP", AND DATED DECEMBER 2020.
3. BASE HILLSHADE FROM WORLD HILLSHADE LAYER SUPPLIED BY ESRI.
4. COORDINATE SYSTEM IS NAD 1983 UTM ZONE 10N. VERTICAL DATUM IS UNKNOWN.
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DATE:	DEC 2020
DRAWN:	MIB
REVIEW:	CF
APPROVED:	PQ

CLIENT: BC OIL AND GAS RESEARCH AND INNOVATION SOCIETY

BGC

PROJECT: NORTHEAST BRITISH COLUMBIA LANDSLIDE SUSCEPTIBILITY MAP

TITLE: LANDSLIDE SUSCEPTIBILITY – CLASSIFIED

PROJECT No.: 2178001

DWG No.: 01

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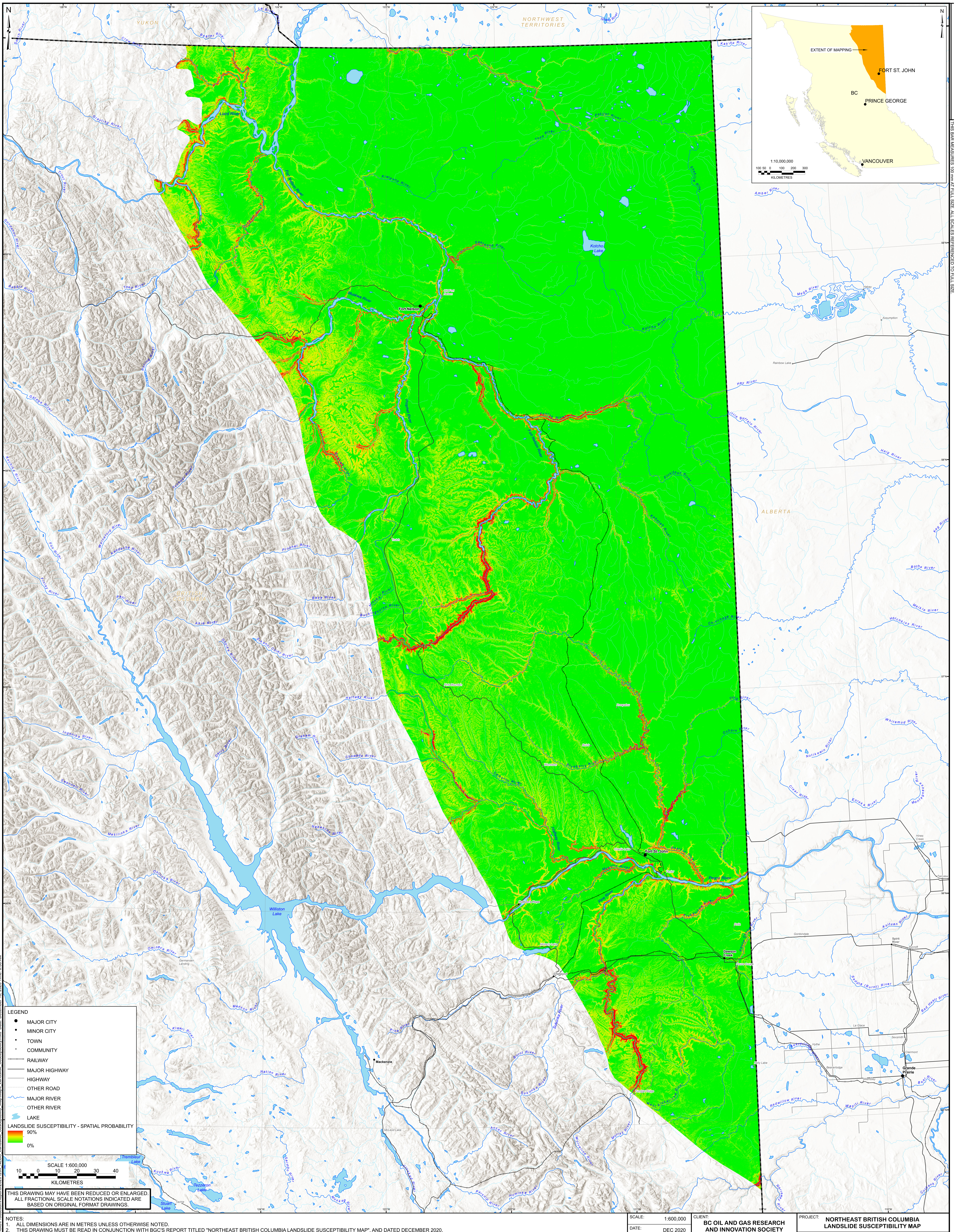

NOTES:

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "NORTHEAST BRITISH COLUMBIA LANDSLIDE SUSCEPTIBILITY MAP", AND DATED DECEMBER 2020.
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APPROVED:	PQ

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PROJECT: NORTHEAST BRITISH COLUMBIA LANDSLIDE SUSCEPTIBILITY MAP

TITLE: LANDSLIDE SUSCEPTIBILITY – SPATIAL PROBABILITY

PROJECT No.: 2178001 DWG No.: 02