# Slope Stability Study Using LiDAR Imagery
# Williams Lake and Surrounding Fringe Area

*Prepared for:*

**Cariboo Regional District**
Suite D – 180 North 3rd Ave.
Williams Lake, BC  V2G 2A4
Attention: John MacLean

*Prepared by:*

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June 30, 2022
File No. 021-069

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# 1 Introduction and Scope

As requested by the Cariboo Regional District (CRD), Westrek Geotechnical Services Ltd. (Westrek) has completed a limited landslide study within the City of Williams Lake (the City) limits, parts of the surrounding fringe area within the CRD limits, and parts of the Williams Lake First Nation (the Nation) IR lands. The approximate extent of the study area is shown on Figure 1 (attached).

The scope of this study is to:

- Conduct a change detection analysis using the 2019 and 2021 LiDAR imagery to identify areas that underwent detectable movement during this time period. In areas where small movement may have occurred, i.e., less than 10 cm horizontally and/or vertically, the change detection is unlikely to record the movement.

  For the area known as the *"Hodgson Road Slide"*, a change detection analysis using the 2017 and 2021 LiDAR imagery was also undertaken, to better understand the slopes that underwent detectable movement during this time period.

- Identify slopes from the LiDAR imagery where the City, CRD and Band should consider requesting an assessment of the overall stability[1] when considering development or redevelopment applications. This work was primarily based on identifying the typical landform characteristics where the stability of the slopes, from the imagery, may be uncertain; for discussion purposes in this report only, we refer to these slopes as the "the slopes where the stability maybe questionable". It is important to note that where the ground surface has been modified by urban development, the slope stability characteristics may not be evident. Limited ground truthing was undertaken in some areas, as part of other work done for either the City or CRD.

This work was requested by the CRD, in conjunction with the City and the Nation, following recent slope movement on several of the large-scale, slow moving landslides within the City and surrounding fringe area, during the springs of 2020 and 2021. A similar study was completed for the City of Quesnel and surrounding fringe area; this is presented under a separate cover.

This study may be referenced by governmental bodies when forming their approach to managing development (both existing and proposed) on or adjacent to slopes where the stability may be questionable, within their boundaries. It is expected that this study may form part of a continuum of work that governmental bodies and private property owners complete over time.

[1] As a minimum, this work should be done in accordance with Engineers Geoscientists BC's 2010 *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC*.

The services provided by Westrek are subject to the terms and conditions set out in the *Interpretation and Use of Study and Report and Limitations,* which is attached in Appendix A and incorporated herein by reference.

# 2 Background Information

The following background information was reviewed to aid in this study:

- A copy of the *Landslides in the CRD* memorandum, prepared by Havan Surat (Manager of Development Services), dated September 4, 2019 (CRD file # 6410-04).
- A copy of the *Floodplain and Landslide Report – Committee of the Whole – June 18, 2020*, prepared by Nigel Whitehead (Senior Planner) (CRD file # 6410-01).
- A copy of *Reference Map* showing the approximate extent of the *Hodgson Road Slide*; the date, scale and who prepared this image is not known.
- A copy of the *Hodgson Road Landslide Williams Lake* memo to the City and CRD, prepared by Evergreen Geotechnical Inc. (EGI) and dated December 23, 2015 (CRD file # 6410-04).
- A copy of the *Hodgson Road Landslide* report to the City and CRD, prepared by Golder Associates (Golder) and dated December 22, 2015 (CRD file # 6410-04).
- A copy of the *Hodgson Road Landslide – Inferred Boundaries* (part of the Golder December 22, 2015 report), dated December 21, 2015.
- A copy of the *Hodgson Road Landslide* report, prepared by Scouten Engineering, dated December 16, 2015 (CRD file # 6410-04).
- A copy of the *Geotechnical Hazard Map April 2011*, part of the City's Official Community Plan; it is not known who prepared this map or the date.
- A copy of the *Geotechnical Hazard Mapping for the Williams Lake Fringe Area Official Community Plan* report, prepared by Golder for the CRD and dated July 5, 2006.

# 3 LiDAR Imagery

The study area for the change detection analysis in the Williams Lake and the surrounding fringe areas is approximately 295 $km^2$.

Three LiDAR datasets were used for this analysis; the 2017 (for the Hodgson Road Slide area only), 2019 imagery (referred to as the baseline dataset) and the 2021 imagery (referred to as the active dataset). The data for these sets was provided as LAS point clouds.

## 3.1 2017 Imagery

2017 data was obtained from McElhanney, on behalf of the CRD; it was flown on May 20, 2017.

The specifications for this imagery are as follows:

- The LiDAR point density was approximately 1 point per $m^2$.

- Ground points were pre-classified in the LAS files.
- The coordinate system used was NAD83 (CSRS), UTM 10-N, i.e., to match the 2019 dataset.

## 3.2 2019 Imagery

The 2019 data was obtained from LidarBC's Open LiDAR Data Portal[2], under BC's Open Government Licence. It was flown on behalf of the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development between July 21 and October 11, 2019. Additional tiles (part of the same project but not available through the portal) were supplied by the CRD.

The specifications for this imagery are as follows:

- The LiDAR point density ranged from 8 to 12 points per $m^2$.
- Ground points were pre-classified in the LAS files.
- The coordinate system was NAD83 (CSRS) 2002, UTM 10-N[3].

## 3.3 2021 Imagery

2021 data was collected by Aeroquest Mapcon/Airborne Imaging, on behalf of the CRD. The Williams Lake area LiDAR was flown on June 22, 2021.

The specifications for this imagery are as follows:

- The LiDAR point density was approximately 20 points per $m^2$.
- Ground points were pre-classified in the LAS files.
- The coordinate system used was NAD83 (CSRS) 2002, UTM 10-N, i.e., to match the 2019 dataset.

# 4 Change Detection Analysis

The purpose of this analysis is to delineate where significant ground movement (primarily on slow-moving landslides) took place between 2019 and 2021. The results show the spatial extent and approximate magnitudes of the movement (horizontally and vertically), and using the principles of landslide movement, it allows the direction of the movement to be determined.

The results are presented as colour-contoured images, illustrating the vertical distance change calculated between the baseline and active datasets. Positive model differences can be interpreted as material accumulation or bulging, and negative model differences can be interpreted as a loss of material (material removal, erosion or slumping). Zones of negative model difference are coloured yellow to red; zones of positive model difference are coloured light blue to purple.

[2] https://governmentofbc.maps.arcgis.com/apps/MapSeries/index.html?appid=d06b37979b0c4709b7fcf2a1ed458e03.
[3] Specifications for LiDAR for the Province of BC, v4.0.

There are several limitations with point cloud change detection, which include:

- The inability to detect translational movement where the ground and slip surfaces are parallel; in this instance, the ground surface appears unchanged between the two datasets.
- Because the point cloud data represents the surface topography at the date of each flight, the analysis reflects surface changes only and cannot necessarily be extrapolated to interpret slide movements at depth.
- Positive or negative changes represent the amount of change that occurred along the shortest distance vector between the two datasets, and not necessarily the maximum magnitude of the deformation. This limits the ability to accurately measure landslide displacement where the movements are parallel to the slope.

Change detection results are also limited by the temporal and spatial resolution of the three-dimensional (3D) datasets and the relative accuracy of the points between each dataset (also referred to as data precision, or local accuracy). Slope deformations that occurred outside these time windows are not detected or shown in the analysis.

## 4.1 Methodology

### 4.1.1 Point Cloud Alignment

The process of assessing 3D surface change with point cloud data involves four main steps:

- Align the active dataset to the baseline dataset. This is conducted by adjusting the spatial position of the active dataset to minimize the difference relative to the baseline dataset. During the alignment, areas of known or suspected changes are ignored to improve the accuracy of the alignment and improve the limit of detectable change. The initial step of realigning the point cloud data reduces georeferencing errors resulting from poor GPS or ground control at the time of data collection. This process maximizes the ability to detect real change between datasets.
- Calculate the limit of detectable change (LOD 95%); this is defined as the 2.5% and 97.5% cumulative alignment interval of the model differences between the non-changing regions of the active and baseline point cloud models. The alignment error between datasets is a function of the alignment, data precision, resolution, and the presence of non-changing sections of the datasets to control the alignment. Model differences within the LOD 95% may represent noise, error, or real change, if changes are too small to identify. Because of the variability in the 2019 dataset and large spatial extent of the study area, it was not feasible to formally calculate the LOD; instead it was estimated visually. Generally, model outputs outside of the LOD may represent noise, error, or real change.
- Conduct a 3D vertical distance change analysis using the complete active and baseline datasets.
- Interpret the results of the change detection as real change, spurious change, or error.

To minimize error between the data sets, the active dataset was aligned by Aeroquest Mapcon to the same datum as the baseline dataset. A preliminary comparison of stable open areas with high ground point densities, such as road surfaces, confirmed that the horizontal error between the two sets was nominal, i.e., the differences would not significantly alter the results of the analysis.

Differences in the data quality between the 2019 tiles were also noted, i.e., primarily the density of ground-classified points. Some tiles had denser ground-point coverage, but were "noisier", i.e., there was higher variability in the interpolated ground surface. This suggests that the classification parameters used were not consistent across the entire 2019 dataset.

In areas of with dense vegetation, the ground classified points in both datasets were sparser, but particularly in the 2019 data set. This resulted in relatively more error between the interpolated ground surfaces.

### 4.1.2 Change Detection

To complete a change detection analysis, the following two methods can be used:

- The DEM[4] of Difference (DOD); and
- The Multiscale Model to Model Cloud Comparison (M3C2).

The DOD method is a common approach and is used when the large-scale geometry of a study area is roughly planar. The two point clouds are gridded to generate DEMs, which are then differentiated on a pixel-by-pixel basis, which amounts to measuring a vertical distance, i.e., displacement along a vertical surface normal.

This method was used for the Williams Lake area because it is computationally less intense than the M3C2 method, and the study area is relatively large.

In previous studies, we have found that the DOD method is as effective as the M3C2 method in identifying areas with slope movement; we recommend using the M3C2 method for more detailed site-specific follow-up analysis as it provides more information.

Using the DOD method, the DEMs were created from the LiDAR data at a 1 m pixel resolution. The model output, a point cloud, was then also gridded at a 1 m resolution for visualisation.

## 4.2 Model Outputs

The model results were classified into 10 cm increments between -2 m and 2 m, and in 1 m increments beyond this range. To classify an area where a difference in elevation was detected as movement on a slide or slide complex based on the mechanics of slope movement, a decrease in elevation (i.e., at a headscarp) has a corresponding increase in elevation in close proximity, (i.e., at the toe).

[4] Digital elevation model.

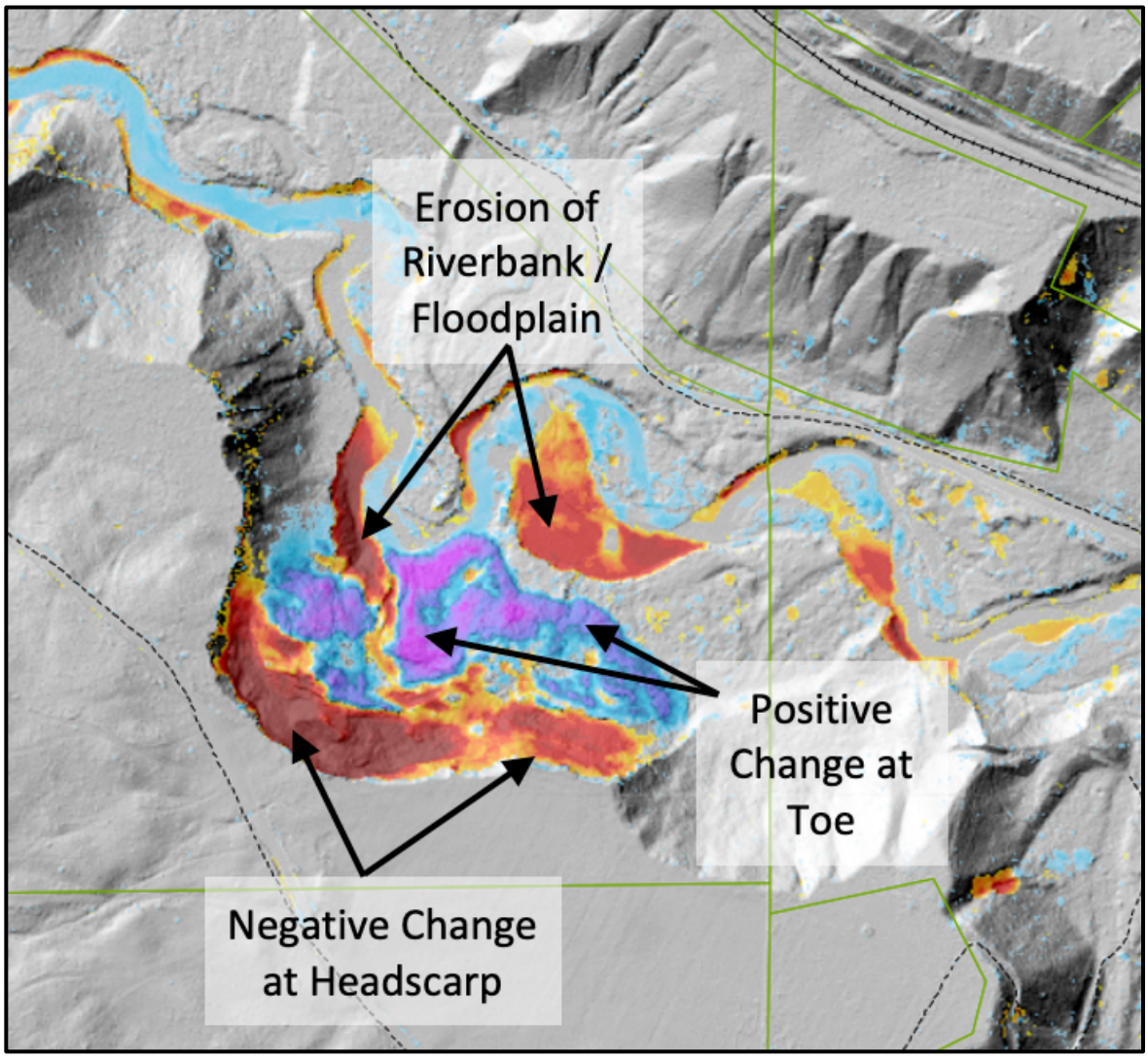



***Figure 2:*** *An excerpt from the output showing landslides with a decrease in elevation at the headscarp, and a corresponding increase in elevation downslope due to the slide debris.*

Figure 2 depicts an output sample showing this; it is taken from a slide in the Williams Lake River valley:

- The yellow to red colours represent areas where the elevation change was negative, i.e., the elevation dropped between 2019 and 2021; and
- The blue to purple colours represent areas where the elevation change was positive, i.e., the elevation increased between 2019 and 2021.

The slope morphology (or signature) on the LiDAR bare earth image was also used to assist in correlating the change detection results as landslide or slope movement.

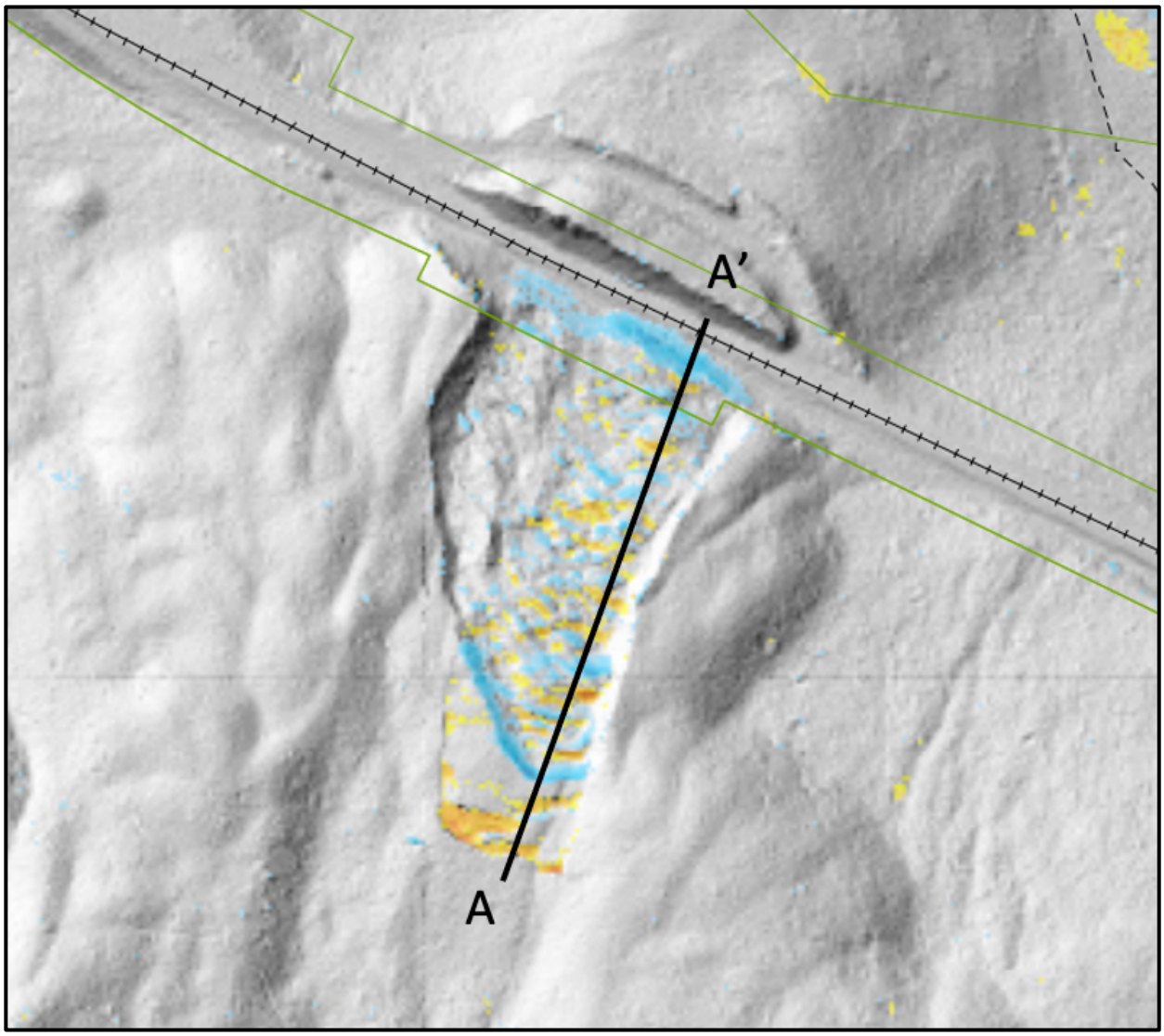



***Figure 3:*** *Part of the recent slope movement next to CN Rail Line southeast of Williams Lake showing the transverse ridges and troughs from the change detection analysis, which delineate the slope movement that occurred from 2019 to 2021.*

In some cases, the landslide/slope movement observed on the change detection output contained transverse ridges and troughs (Figure 3). A translational shift perpendicular to the ridges (i.e., generally down the fall-line) will appear as alternating bands of negative and positive vertical change, i.e., the leading edge of the ridge will appear to have gained elevation, while the trailing edge will appear to have lost elevation.

The slope profile (Figure 4) generated along line A-A′ (Figure 3) illustrates this by showing the relative elevation changes in red (negative) and blue (positive). The black arrows depict the probable overall displacement direction, i.e., the slope movement was from A to A′.

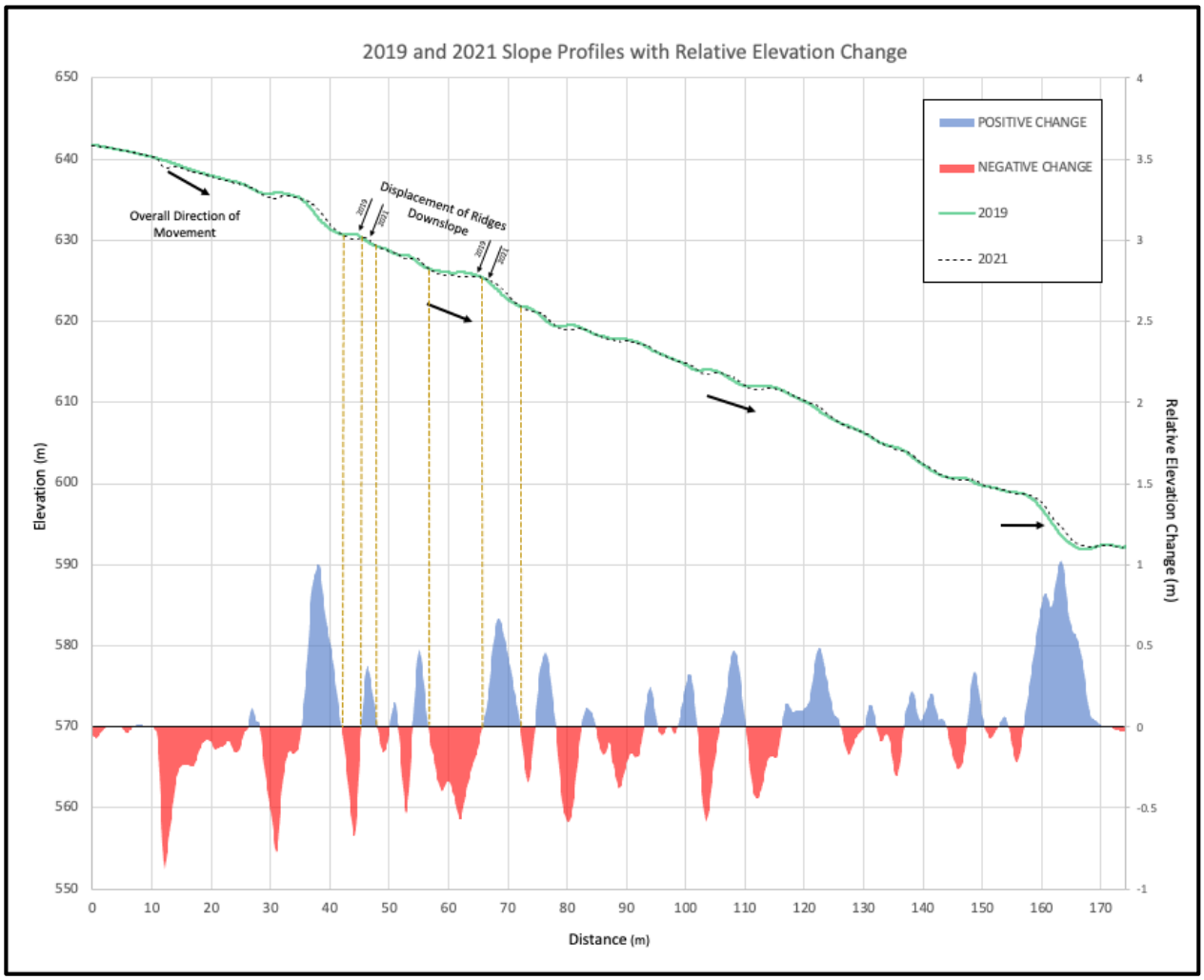



***Figure 4:*** *The slope profile along the slope traverse from A to A' showing the slope movement from 2019 to 2021, both horizontally and vertically.*

## 4.3 Summary

The limit for vertical elevation changes was estimated to be about - 30 cm for negative changes, and about + 20 cm for positive changes. More noise/error was detected in the negative direction, i.e., the 2021 DEM was lower in elevation than the 2019 DEM. This was observed primarily in heavily vegetated areas, and could be the result of the lower density of LiDAR ground-returns in the 2019 dataset.

For the analysis, the LOD limits were sufficiently precise to detect landslide/slope movement[5].

[5] For areas where more detail or more precise measurements are required, a formal calculation of the LOD for subsets of the data should be undertaken.

## 4.4 Results

The majority of the slope movement detected between 2019 and 2021 was generally confined to eleven (11) areas, which included[6]:

- The Hodgson Road Slide (the detection of movement extended from 2017 to 2021 on this slide).
- The Dog Creek Road Slide.
- Paxton Road Slide.
- The Williams Lake River valley.
- White Road Slide area.
- The CN Rail Slide.
- The Borland Creek area.
- The upper Asahai Creek area.
- Around Highway 97 across from the Williams Lake Airport.
- The upper reaches of Missioner Creek, above Mackenzie Ave.
- The Coyote Rock area.

The change detection results in these areas are shown on Figures 5 through 23 (attached).

The Hodgson Road Slide and the numerous landslides/slide complexes in the Williams Lake River valley are large-scale features that occurred in very thick sequences of either morainal, glaciolacustrine and/or glaciofluvial sediments.

Movement on these features is:

- Usually associated with either (i) longer term changes in the regional groundwater regime, affected by climatic trends, and/or (ii) loss of toe support due to erosional scour created by rivers, creeks and streams or construction.
- Complex and sometimes differential, i.e. different parts of the slide can move at different rates. Certain zones of the slide may activate and continue to move, while others can be seemingly stable for decades.
- Difficult to determine without detailed investigation, slope monitoring and analysis. The results of the current change detection analysis provide a "snap shot in time" for the movement between 2019 and 2021 (for the Hodgson Road Slide and surrounding slopes, the "snap shot in time" for the movement between 2017 and 2021).

The Dog Creek Road Slide and the slides in the Coyote Bluff area are smaller and appear to have occurred more rapidly; movement on these features is also ongoing, i.e., the Dog Creek Road Slide was noted in Golder's 2006 report. No information was made available to us for the slides in the Coyote Bluff area, although we understand that this movement may have commenced after the 2017/2018 wildfires in the Williams Lake area; we have not confirmed this.

[6] Where possible, we have used the landslide names from Golder's 2006 report to identify these areas.

No detectable movement was visible on the change analysis for the ancient landslides identified in the Golder 2006 report.

# 5 Slopes Where the Stability Maybe Questionable

## 5.1 Golder 2006 Report

In their 2006 report to the CRD, Golder prepared geotechnical hazard maps for consideration by the regional district and City in preparing development approval policy[7]. To do this, Golder utilized the following methodology:

- Conducted a review of the available reports and mapping for landslides and other natural hazards.
- Reviewed and interpreted historic stereo air photo coverage of the study area[8].
- Ground truthed select areas to confirm, supplement and refine the results of the air photo interpretation.
- Used GIS modelling to prepare ARC View format base maps, which included:
    1. The study area;
    2. The bedrock geology;
    3. Slope maps; and
    4. Locations of previous geohazard studies.

From this study, the following geotechnical hazards were identified by Golder:

- Steep slopes;
- Rockfall/rolling rock hazards;
- Recent landslides within known earth movement;
- Ancient landslides with no record of modern earth movement;
- The Williams Lake River valley and escarpment; and
- The Asahai Dam Inundation area.

The limitations identified by Golder included:

- The study focused on large-scale geotechnical hazards, i.e., it was an overview level assessment and this type of work is generally not comprehensive and does not identify all the geotechnical hazards in a study area.

[7] That is, provided geotechnical input to the Official Community Plan (OCP) process by identifying terrain hazards that may represent constraints on future land development.
[8] Refer to the Golder 2006 report for a list of the air photos reviewed.

- The identification of the geotechnical hazards involved the interpretation of air photos, which is subjective.
- The list of hazards identified is representative at a regional scale, although at the property scale, it may not be fully comprehensive.

## 5.2 The Current Study

To better delineate the extent of the "slopes where the stability maybe questionable" in the study area, and to improve on the earlier work completed by Golder (2006), the LiDAR bare earth image created from the 2021 DEM, combined with the results from the change detection analysis, were analyzed.

The 2021 LiDAR bare earth image allowed the ground surface morphology to be reviewed once the vegetative cover was removed. This effectively depicts what has happened to the ground surface since the last period of deglaciation, around +/- 10,000 years ago. Numerous landslides have occurred during this period and in some cases, historic slope movement can also generally be seen, although the imagery does not allow either an estimate as to when a landslide or slope movement(s) occurred or sometimes how frequently they may have occurred.

Using this approach, the extent of "slopes where the stability maybe questionable" within the City limits and adjacent fringe area can be better identified (Figure's 24 and 25). Unfortunately, for several of the ancient landslides complexes identified by Golder (2006), the extent was not able to be better defined.

The surface morphology "signature" for active or recent slope movement on a bare earth image is generally clearer and can be more distinct, allowing for more reliable identification. It is important to note that while actively unstable slopes can be easier to identify using this imagery, urban development can mask the ground morphology and give the impression that the ground could be stable on large-scale landslides and slide complexes.

Older slope movement (i.e., ancient) and potentially unstable slopes, where the slope movement either may not be as clear, may have either been smoothed over, or have some characteristics of slope movement (Figure 26), may not be as clear to identify.

For this study, we have grouped all of these slope conditions together. The rationale for this is to convey the extent of the potential problems facing development and re-development, both existing and proposed, within the study area. These slopes could be further delineated in a more detailed study.

With this approach, the City, CRD and the Nation should be aware that:

- Potentially unstable slopes can become more unstable over time, especially in the context of climate change.
- Movement on active landslides or unstable slopes can change (i.e., increase or decrease) over time.

- The stability of a slope can change over short distances.

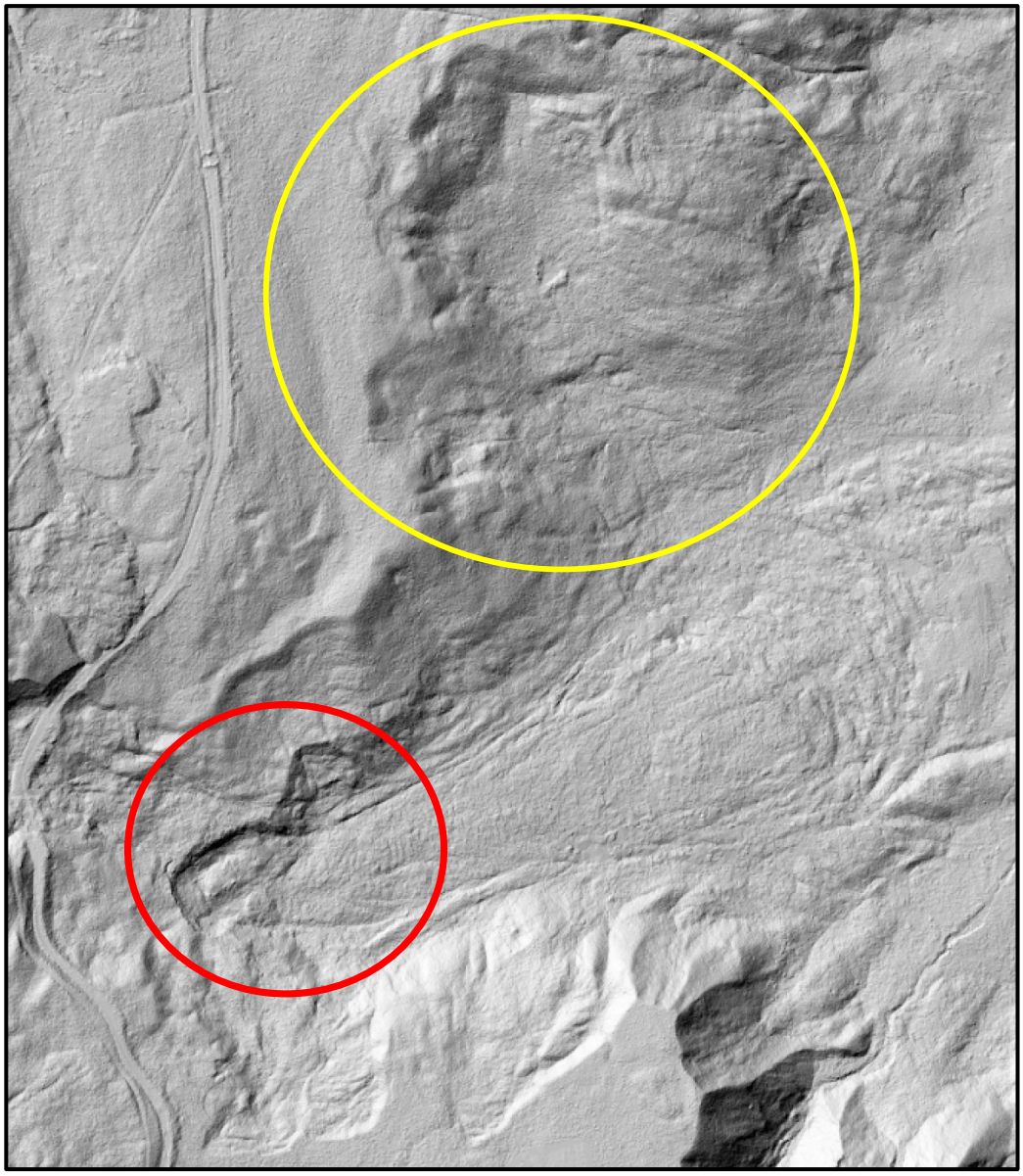


***Figure 26:*** *An excerpt from the 2019 LiDAR bare earth image (taken from the Quesnel study area) showing the distinct slope morphology from an example of actively unstable slopes (the red circle) and the more subdued morphology from an example of potentially unstable slopes (the yellow circle).*

It is possible that:

- Not all "slopes where the stability maybe questionable" have been identified in this study.
- Some areas identified  where the stability maybe questionable, may not be.

Additional and more detailed investigation is required to better understand these limitations.

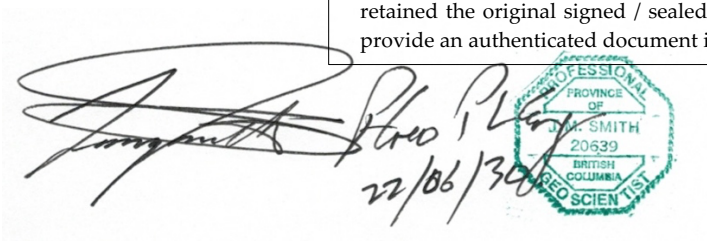
# 6 Closure

We trust that this report is complete for your present requirements. Please contact the undersigned if you have any questions.

Yours truly,

***Westrek Geotechnical Services Ltd.***

This is an electronic replica of the original signed and sealed report and has been provided for convenience. Westrek has retained the original signed / sealed report on file and can provide an authenticated document if required.




Timothy Smith PGeo, PLEng
*Principal and Senior Engineering Geologist*

# APPENDIX A
# INTERPRETATION AND USE OF STUDY AND REPORT AND LIMITATIONS

1. STANDARD OF CARE.

This study and Report have been prepared in accordance with generally accepted engineering and geoscience practices. No other warranty, express or implied, is made. Geological and geotechnical studies and reports do not include environmental consulting unless specifically stated in the report.

2. COMPLETE REPORT.

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report which is of a summary nature and is not intended to stand alone without reference to the instructions given to us by the Client, communications between us and the Client, and to any other reports, writings, proposals or documents prepared by us for the Client relative to the specific site described herein, all of which constitute the Report.

IN ORDER TO UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. WE CANNOT BE RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

3. BASIS OF THE REPORT.

The Report has been prepared for the specific site, development, design objectives and purpose that were described to us by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the document are only valid to the extent that there has been no material alteration to or variation from any of the said descriptions provided to us unless we are specifically requested by the Client to review and revise the Report in light of such alteration or variation.

4. USE OF THE REPORT.

The information and opinions expressed in the Report, or any document forming the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT OUR WRITTEN CONSENT. WE WILL CONSENT TO ANY REASONABLE REQUEST BY THE CLIENT TO APPROVE THE USE OF THIS REPORT BY OTHER PARTIES AS "APPROVED USERS". The contents of the Report remain our copyright property and we authorise only the Client and Approved Users to make copies of the Report only in such quantities as are reasonably necessary for the use of the Report by those parties. The Client and Approved Users may not give, lend, sell or otherwise make the Report or any portion thereof, available to any party without our written permission. Any uses, which a third party makes of the Report, or any portion of the Report, are the sole responsibility of such third parties. Westrek accepts no responsibility for damages suffered by any third party resulting from unauthorised use of the Report.

5. INTERPRETATION OF THE REPORT.

(i) Nature and Exactness of Soil and Description: Classification and identification of soils, rocks, geological units, and engineering estimates have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature and even comprehensive sampling and testing programs, implemented with the appropriate equipment by experienced personnel, may fail to locate some conditions. All investigations utilising the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarising such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and all persons making use of such documents or records should be aware of, and accept, this risk. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. Where special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

(ii) Reliance on Provided information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to us. We have relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, we cannot accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations or fraudulent acts of any persons providing representations, information and instructions.

(iii) To avoid misunderstandings, Westrek should be retained to work with the other design professionals to explain relevant geotechnical findings and to review the adequacy of their plans and specifications relative to engineering issues. Further, Westrek should be retained to provide field reviews during the construction, consistent with generally accepted practices.

6. LIMITATIONS OF LIABILITY.

Westrek's liability will be limited as follows:

(a) In recognition of the relative risks and benefits of the Services to be provided to the Client by Westrek, the risks have been allocated such that the Client agrees, to the fullest extent permitted by law, to limit the liability of Westrek, its officers, directors, partners, employees, shareholders, owners, subconsultants and principals for any and all claims, losses, costs, damages of any nature whatsoever or claims expenses from any cause or causes, whether arising in contract or tort including negligence, including legal fees and costs and disbursements (the "Claim"), so that the total aggregate liability of Westrek, its officers, directors, partners, employees, shareholders, owners, subconsultants and principals:

i. if the Claim is satisfied by the re-performance of the Services proven to be in error, shall not exceed and shall be limited to the cost to Westrek in re-performing such Services; or

ii. if the Claim cannot be satisfied by the re-performance of the Services and:

1. if Westrek's professional liability insurance does not apply to the Claim, shall not exceed and shall be limited to Westrek's total fee for services rendered for this matter, whichever is the lesser amount. The Client will indemnify and hold harmless Westrek from third party Claims that exceed such amount; or

2. if Westrek's professional liability insurance applies to the Claim, shall be limited to the coverage amount available under Westrek's professional liability insurance at the time of the Claim. The Client will indemnify and hold harmless Westrek from third party Claims that exceed such coverage amount. Westrek shall maintain professional liability insurance in the amount of $2,000,000 per occurrence, $2,000,000 in the aggregate, for a period of two (2) years from the date of substantial performance of the Services or earlier termination of this Agreement. If the Client wishes to increase the amount of such insurance coverage or duration of such policy or obtain other special or increased insurance coverage, Westrek will cooperate with the Client to obtain such coverage at the Client's expense.

It is intended that this limitation will apply to any and all liability or cause of action however alleged or arising, including negligence, unless otherwise prohibited by law. Notwithstanding the foregoing, it is expressly agreed that there shall be no claim whatsoever against Westrek, its officers, directors, partners, employees, shareholders, owners, subconsultants and principals for loss of income, profit or other consequential damages howsoever arising, including negligence, liability being limited to direct damages.

(b) Westrek is not responsible for any errors, omissions, mistakes or inaccuracies contained in information provided by the Client, including but not limited to the location of underground or buried services, and with respect to such information, Westrek may rely on it without having to verify or test that information. Further, Westrek is not responsible for any errors or omissions committed by persons, consultants or specialists retained directly by the Client and with respect to any information, documents or opinions provided by such persons, consultants or specialists, Westrek may rely on such information, documents or opinions without having to verify or test the same.

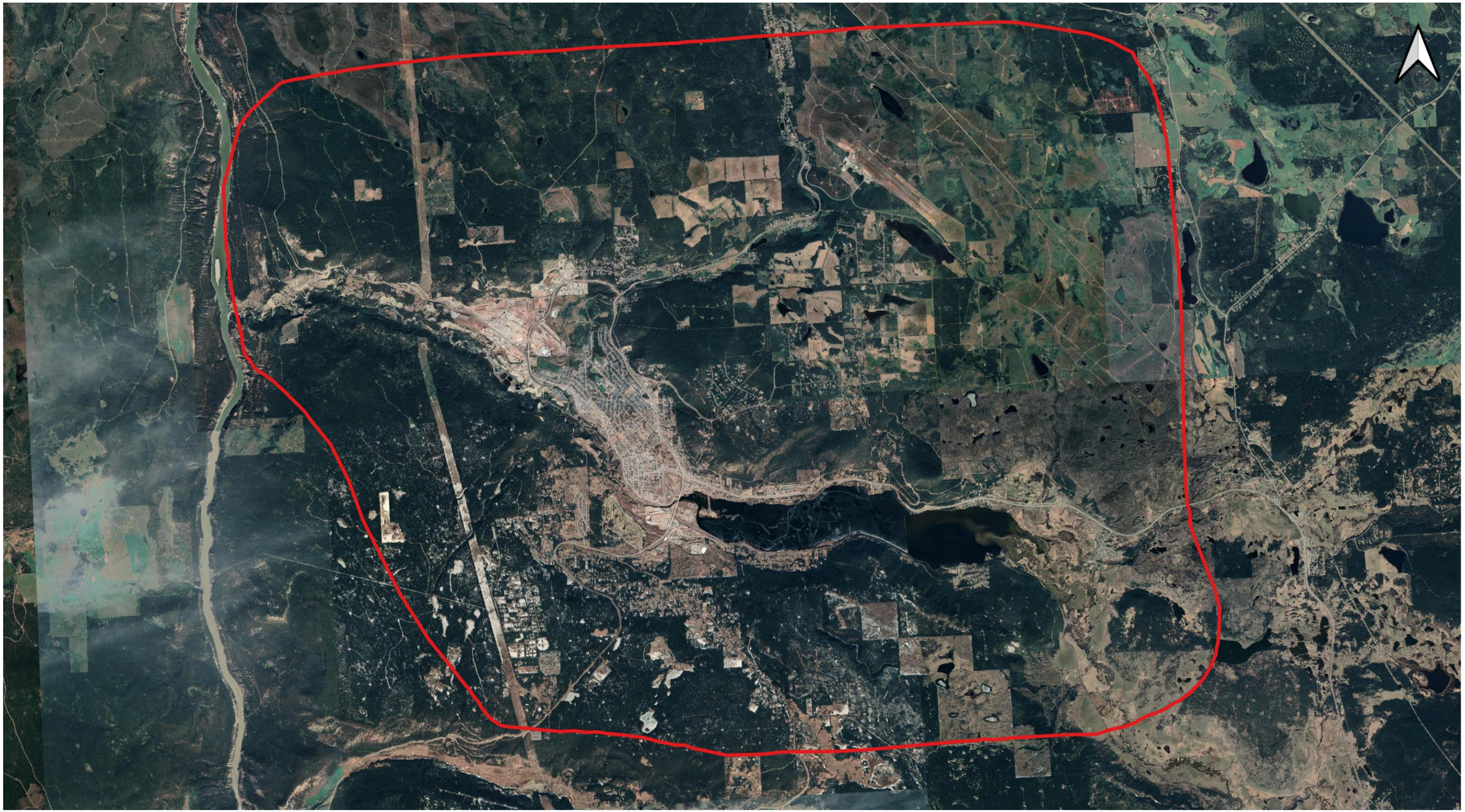
(c) Notwithstanding the provisions of the Limitation Act, R.S.B.C. 2012 c. 13, amendments thereto, or new legislation enacted in its place, Westrek's liability for any and all claims, including a Claim as defined herein, of the Client or any third party shall absolutely cease to exist after a period of two (2) years following the date of:

i. Substantial performance of the Services,

ii. Suspension or abandonment of the Services provided under this agreement, or

iii. Termination of Westrek's Services under the agreement,

whichever shall occur first, and following such period, the Client shall have no claim, including a Claim as defined herein, whatsoever against Westrek.



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|---|---|---|---|
| westrek geotechnical services ltd.<br>*100 -1383 McGill Road, Kamloops, BC V2C 6K7* | SCALE: 1 : 80000 | **Overall Extent of Study Area for Williams Lake** | **FIGURE 1** |
| | **Source:** Oct 16, 2021; Satellite Imagery provided by Google Earth | | |
| | Project: 021-069 | | |

Elevation Change 2019 to 2021 (m)

| Positive | Negative |
|---|---|
| 0 - 0.1 | < -5 |
| 0.1 - 0.2 | -5 - -4 |
| 0.2 - 0.3 | -4 - -3 |
| 0.3 - 0.4 | -3 - -2 |
| 0.4 - 0.5 | -2.0 - -1.9 |
| 0.5 - 0.6 | -1.9 - -18 |
| 0.6 - 0.7 | -1.8 - -1.7 |
| 0.7 - 0.8 | -1.7 - -1.6 |
| 0.8 - 0.9 | -1.6 - -1.5 |
| 0.9 - 1 | -1.5 - -1.4 |
| 1.0 - 1.1 | -1.4 - -1.3 |
| 1.1 - 1.2 | -1.3 - -1.2 |
| 1.2 - 1.3 | -1.2 - -1.1 |
| 1.3 - 1.4 | -1.1- -1.0 |
| 1.4 - 1.5 | -1.0 - -0.9 |
| 1.5 - 1.6 | -0.9 - -0.8 |
| 1.6 - 1.7 | -0.8 - -0.7 |
| 1.7 - 1.8 | -0.7 - -0.6 |
| 1.8 - 1.9 | -0.6 - -0.5 |
| 1.9 - 2.0 | -0.5 - -0.4 |
| 2 - 3 | -0.4 - -0.3 |
| 3 - 4 | -0.3 - -0.2 |
| 4 - 5 | -0.2 - -0.1 |
| > 5 | -0.1 - 0 |

Elevation change projected onto 2021 LiDAR Hillshade

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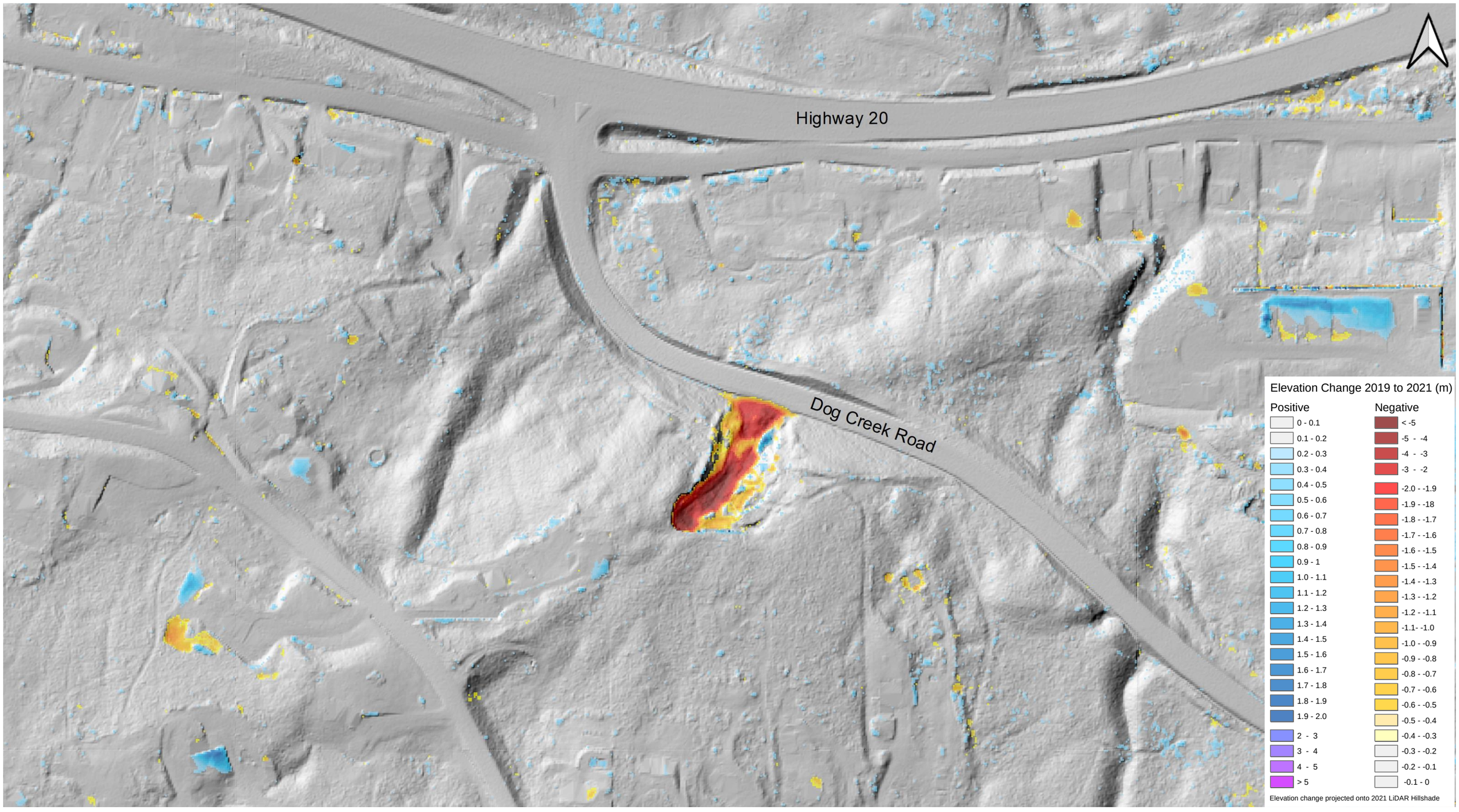
# The Results of the Change Detection Analysis using the 2017 and 2021 LiDAR Datasets for the Slopes around Hodgson Road Slide

**Source:** 2017 (purchased from McElhanney)/ 2021 LiDAR Imagery provided by CRD

Project No. 021-069

SCALE: 1 : 1500

**Figure 5**

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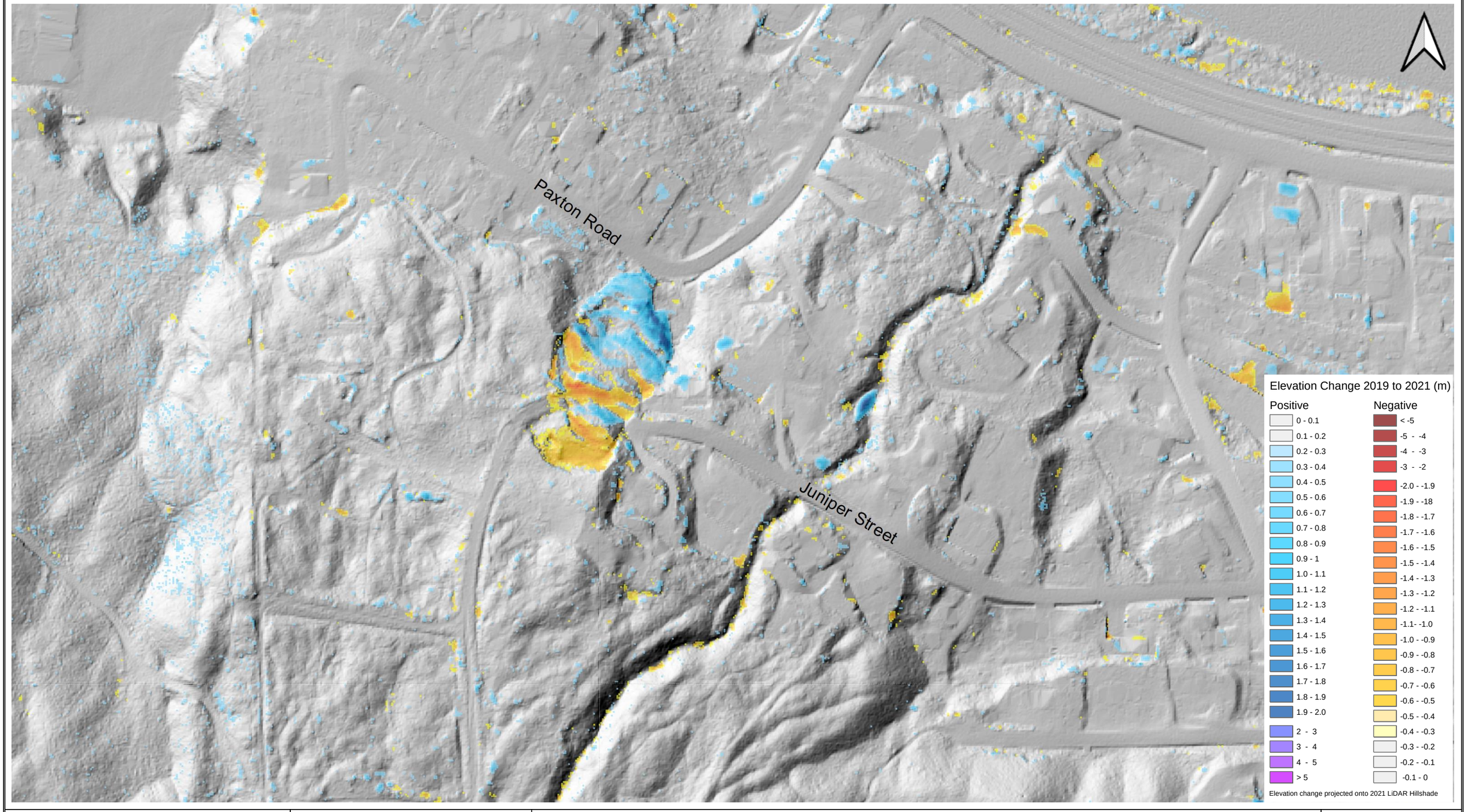
SCALE: 1 : 2000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around the Dog Creek Road Slide**

**FIGURE 6**

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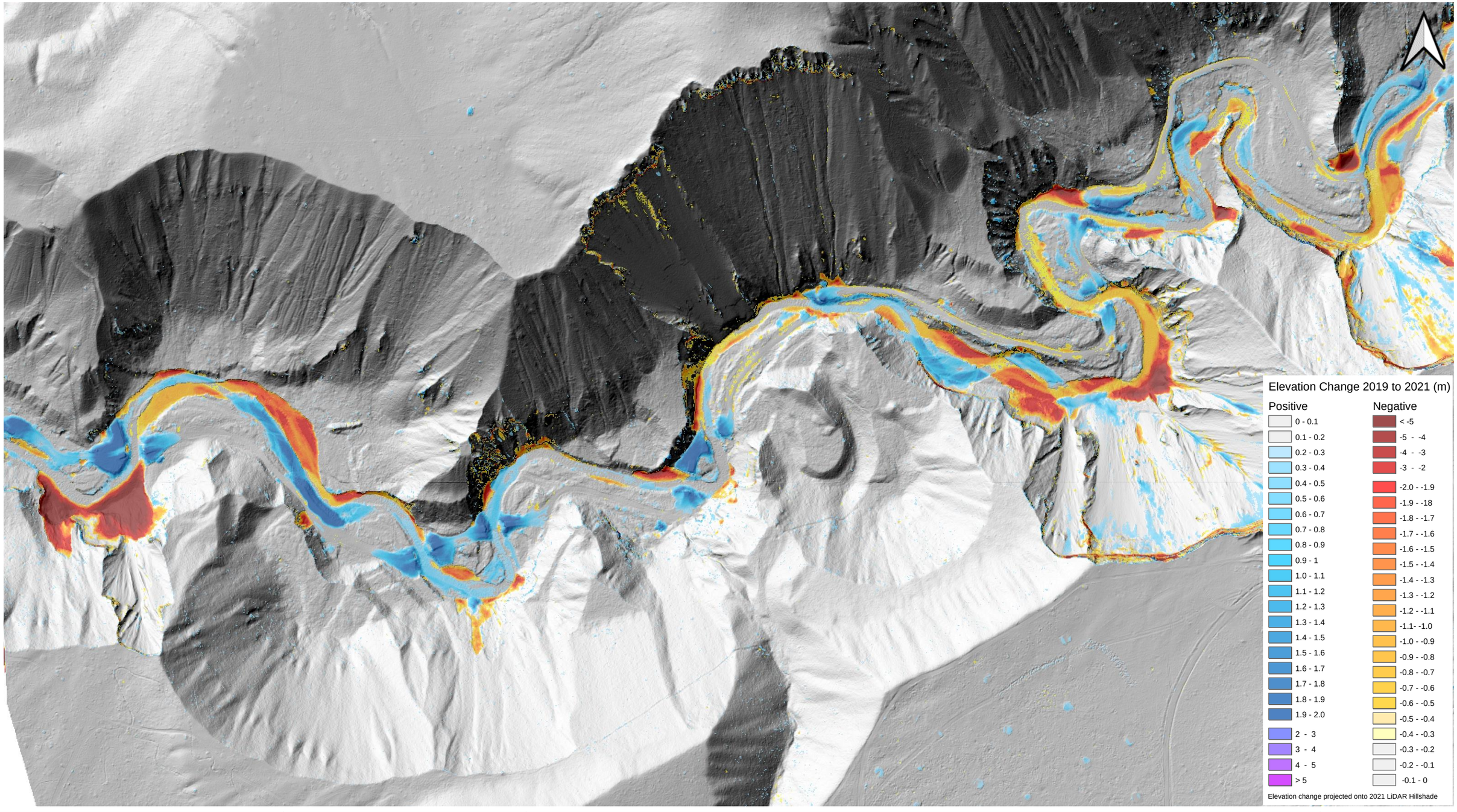
Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around the Paxton Road Slide**

**FIGURE 7**

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SCALE: 1 : 4000

Imagery Date is June 22, 2021
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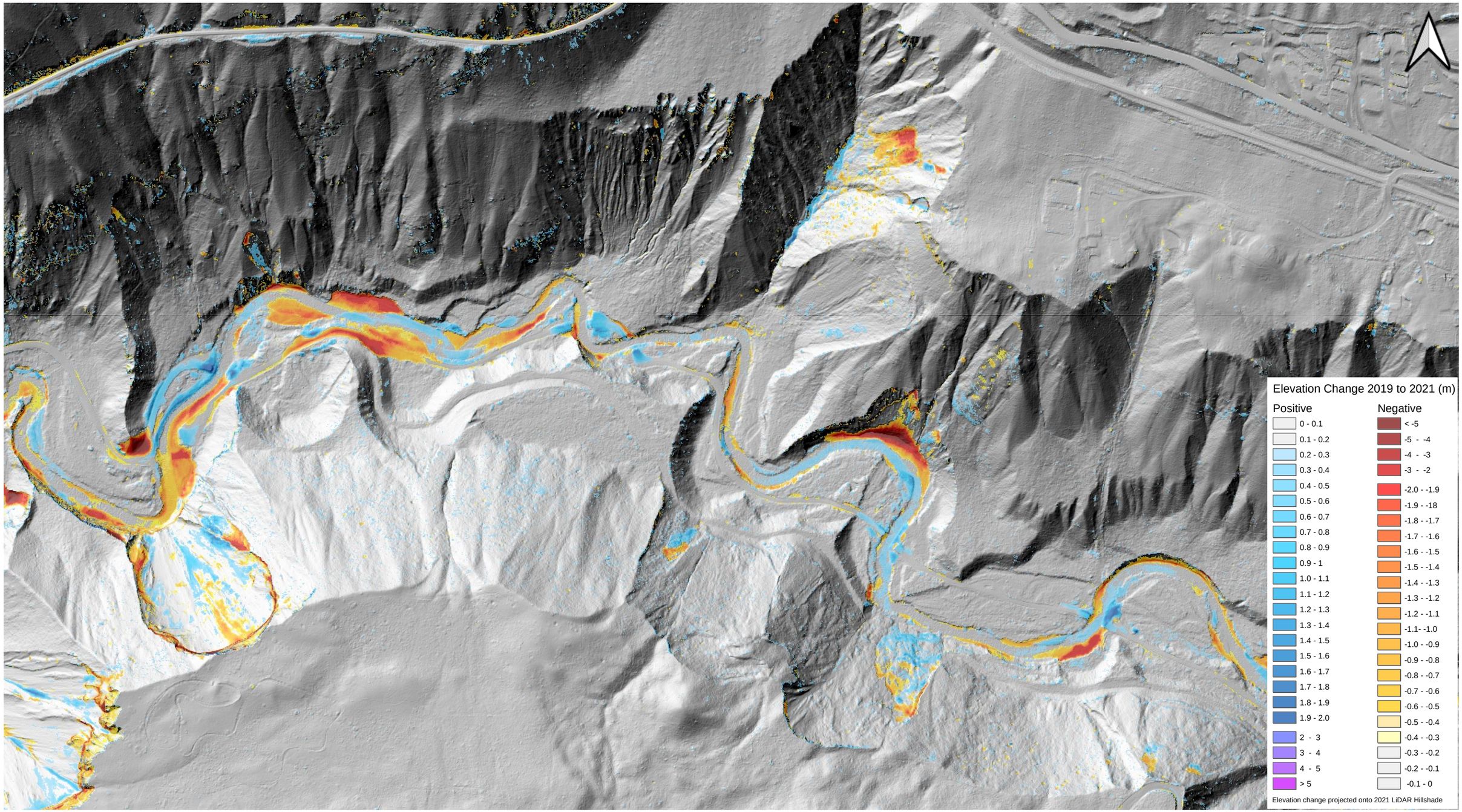
Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Williams Lake River Valley (1)**

**FIGURE 8**

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Imagery Date is June 22, 2021
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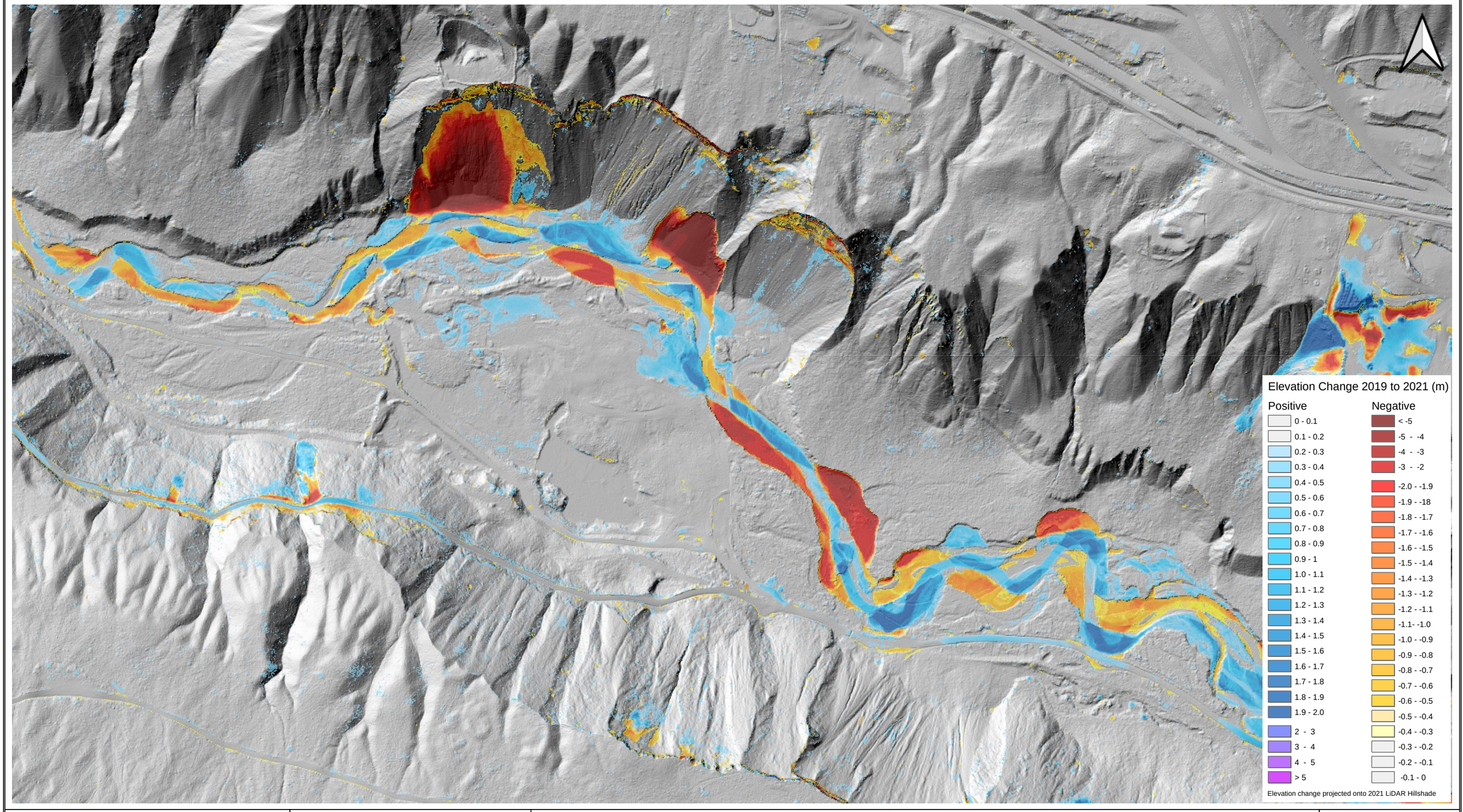
Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Williams Lake River Valley (2)**

**FIGURE 9**

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SCALE: 1 : 4000

Imagery Date is June 22, 2021
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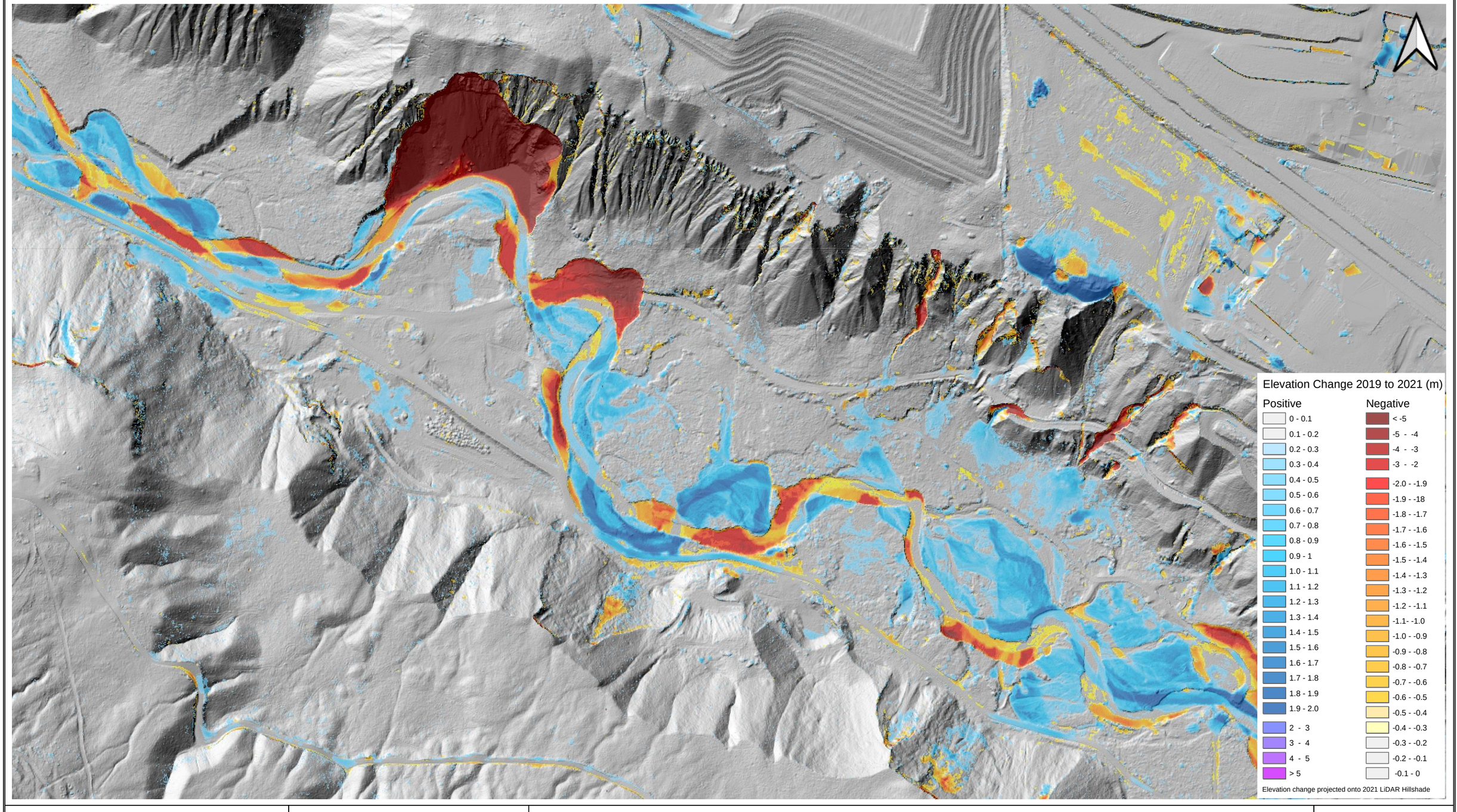
Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Williams Lake River Valley (3)**

**FIGURE 10**

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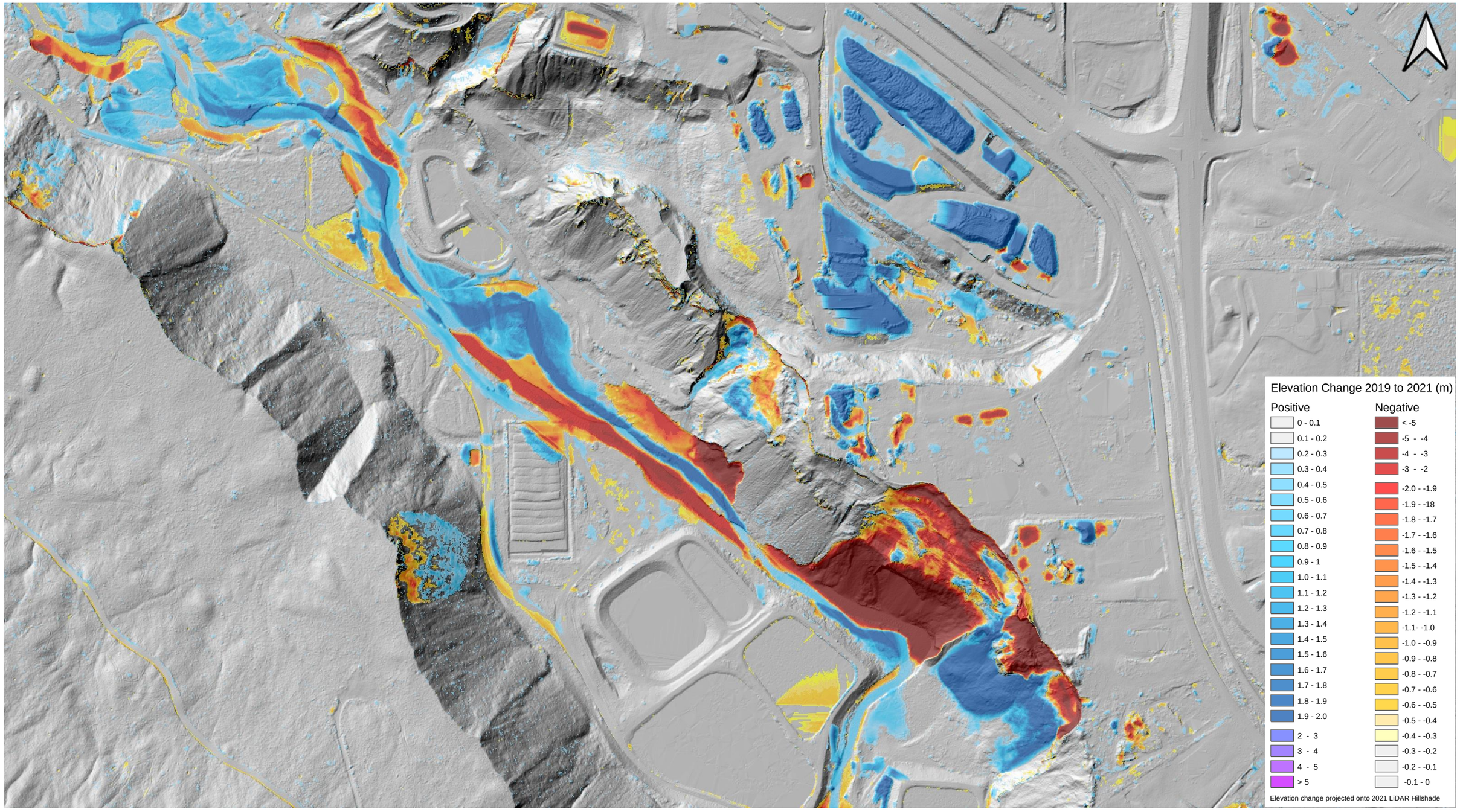
SCALE: 1 : 4000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Williams Lake River Valley (4)**

**FIGURE 11**

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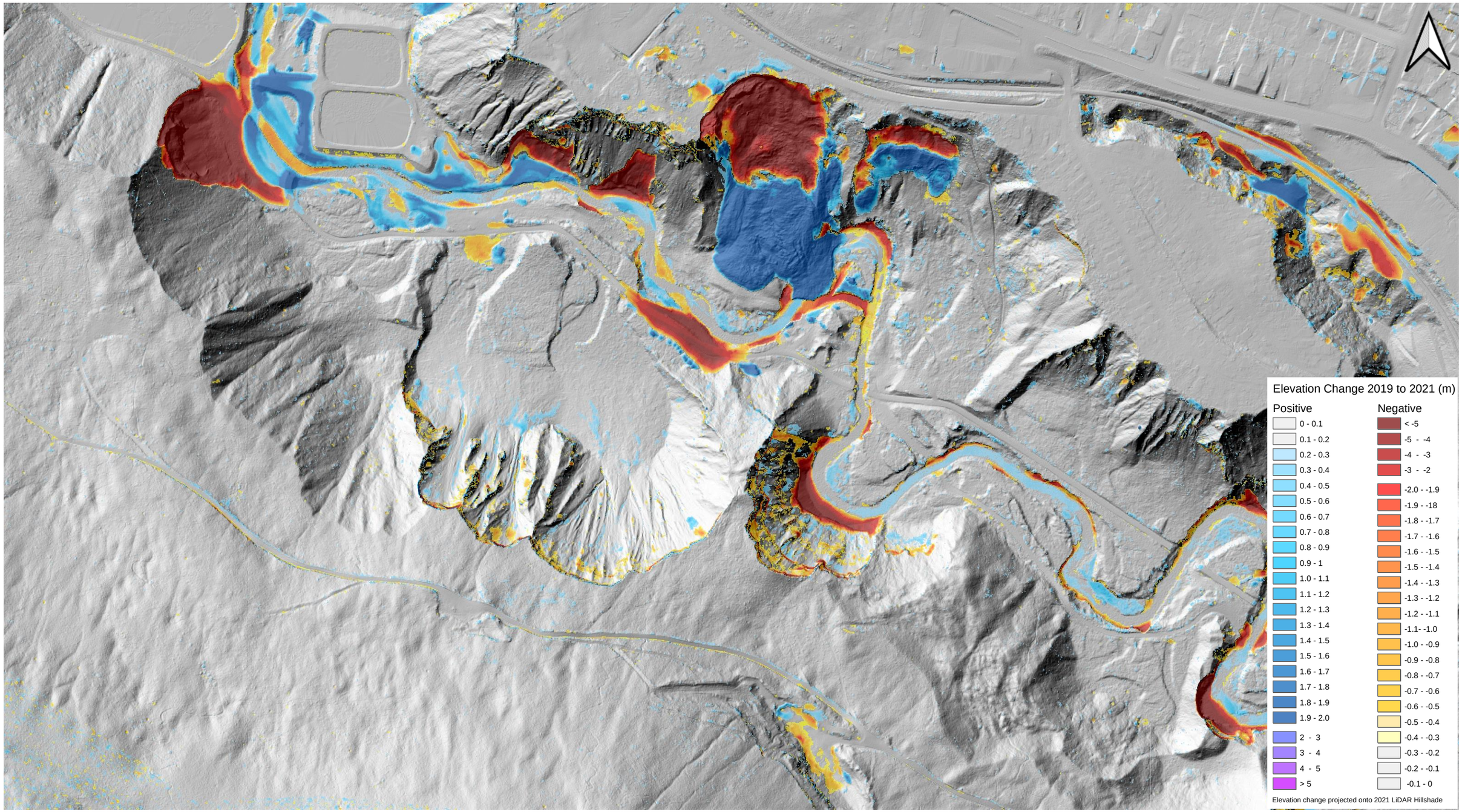
SCALE: 1 : 4000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Williams Lake River Valley (5)**

**FIGURE 12**

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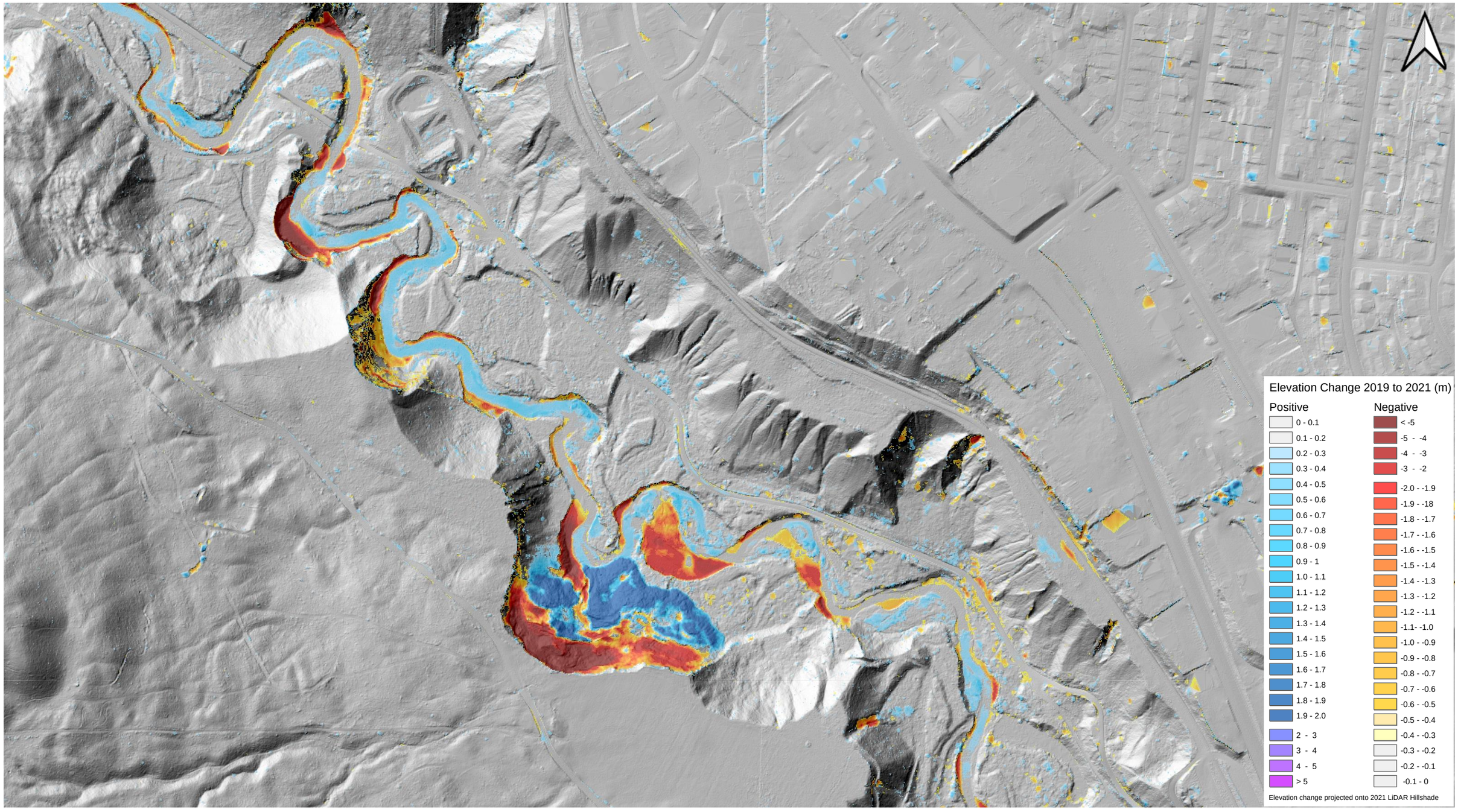
SCALE: 1 : 4000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Williams Lake River Valley (6)**

**FIGURE 13**

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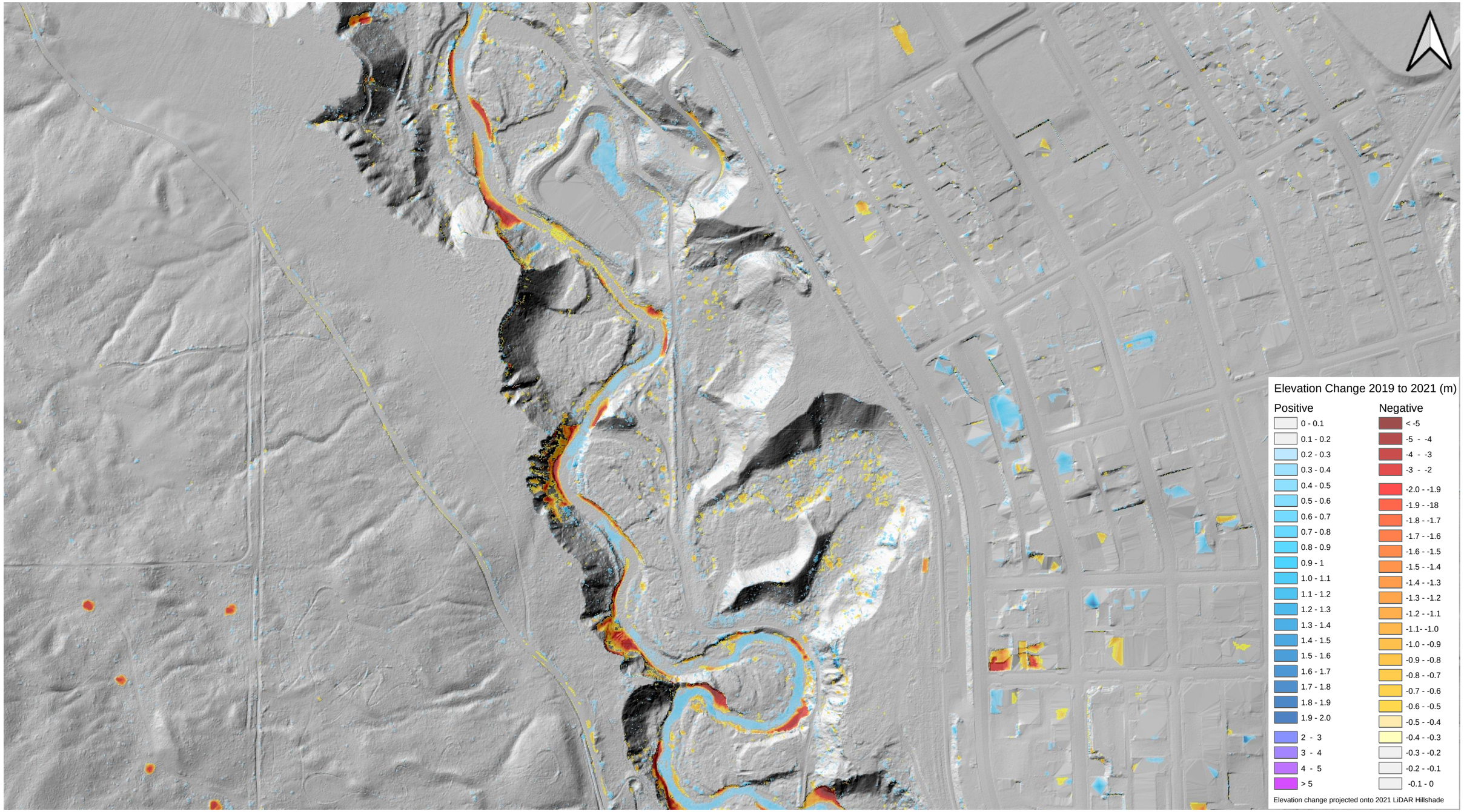
SCALE: 1 : 4000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Williams Lake River Valley (7)**

**FIGURE 14**

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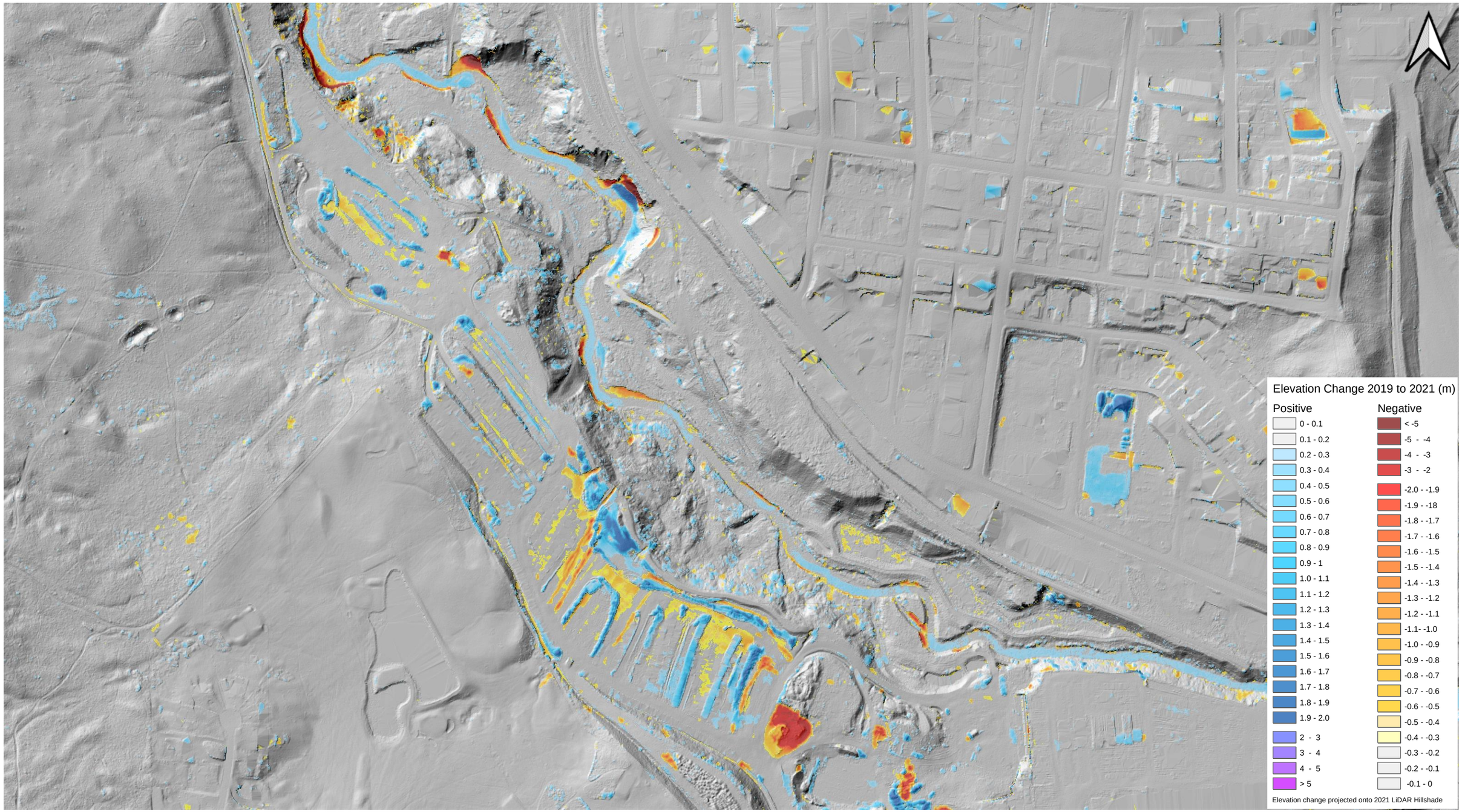
SCALE: 1 : 4000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Williams Lake River Valley (8)**

**FIGURE 15**

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SCALE: 1 : 4000

Imagery Date is June 22, 2021
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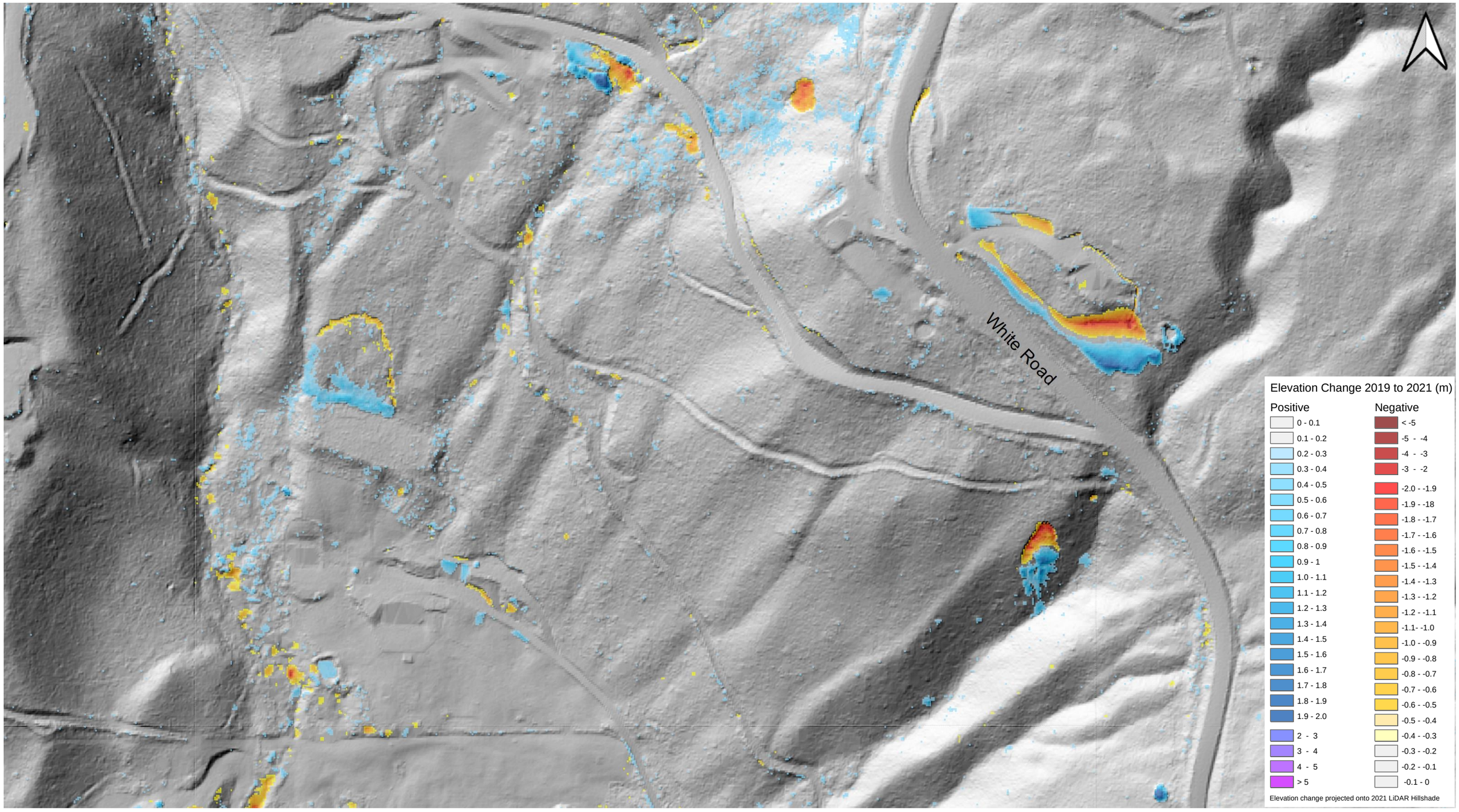
Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Williams Lake River Valley (9)**

**FIGURE 16**

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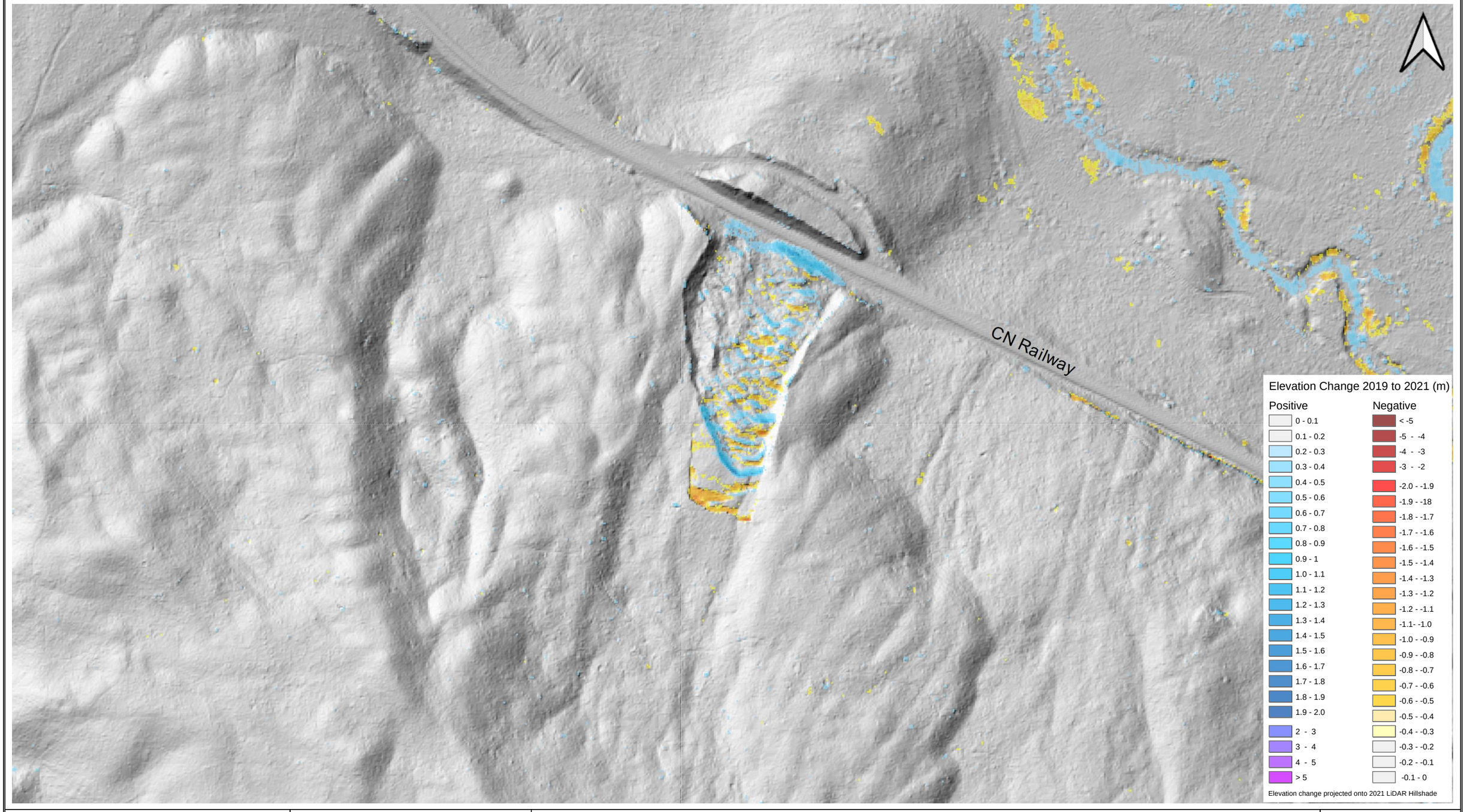
SCALE: 1 : 2000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around the White Road Slide Area**

**FIGURE 17**

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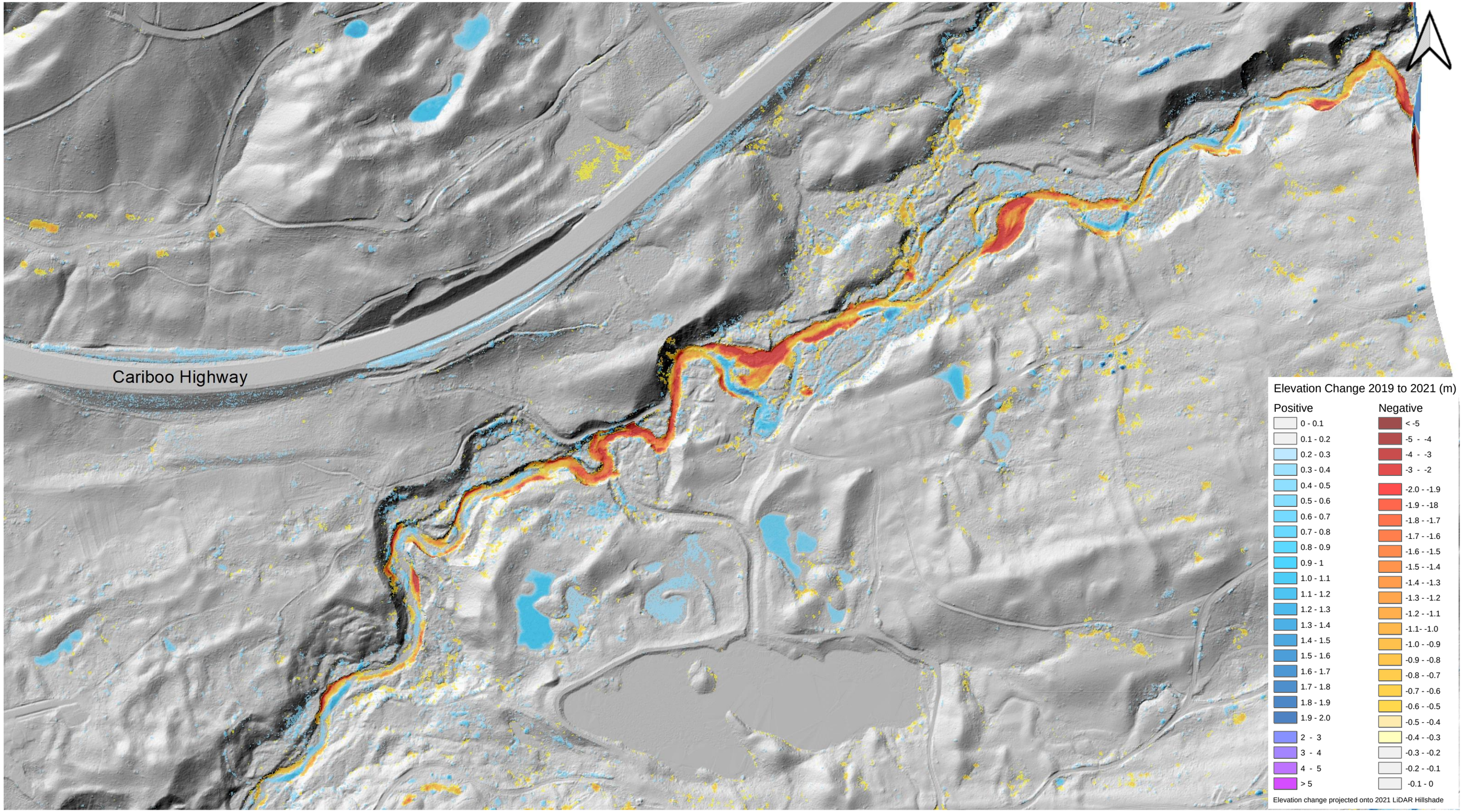
SCALE: 1 : 2000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the CN Railway Slide Area**

**FIGURE 18**

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SCALE: 1 : 4000

Imagery Date is June 22, 2021
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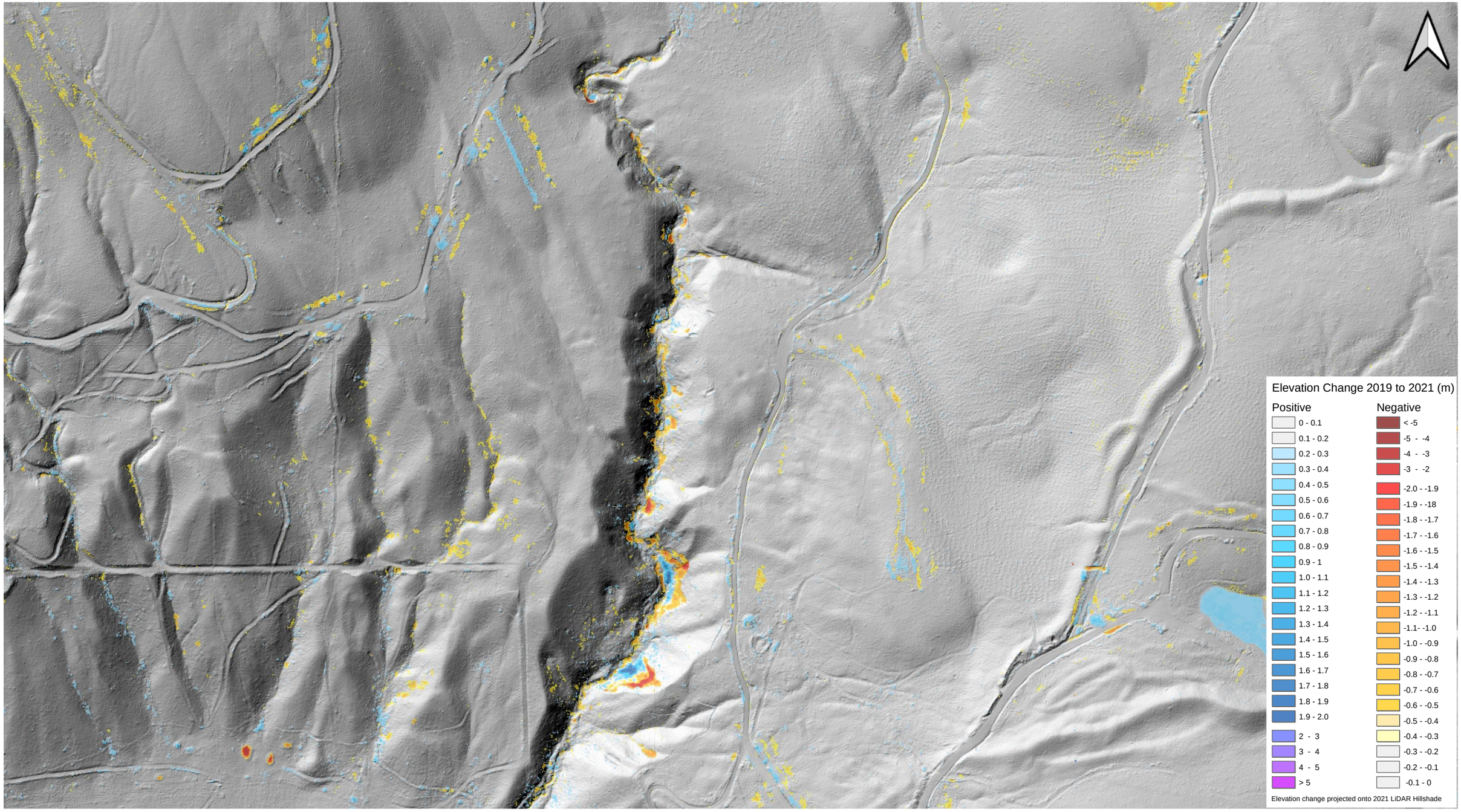
Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Area around Borland Creek**

**FIGURE 19**

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SCALE: 1 : 4000

Imagery Date is June 22, 2021
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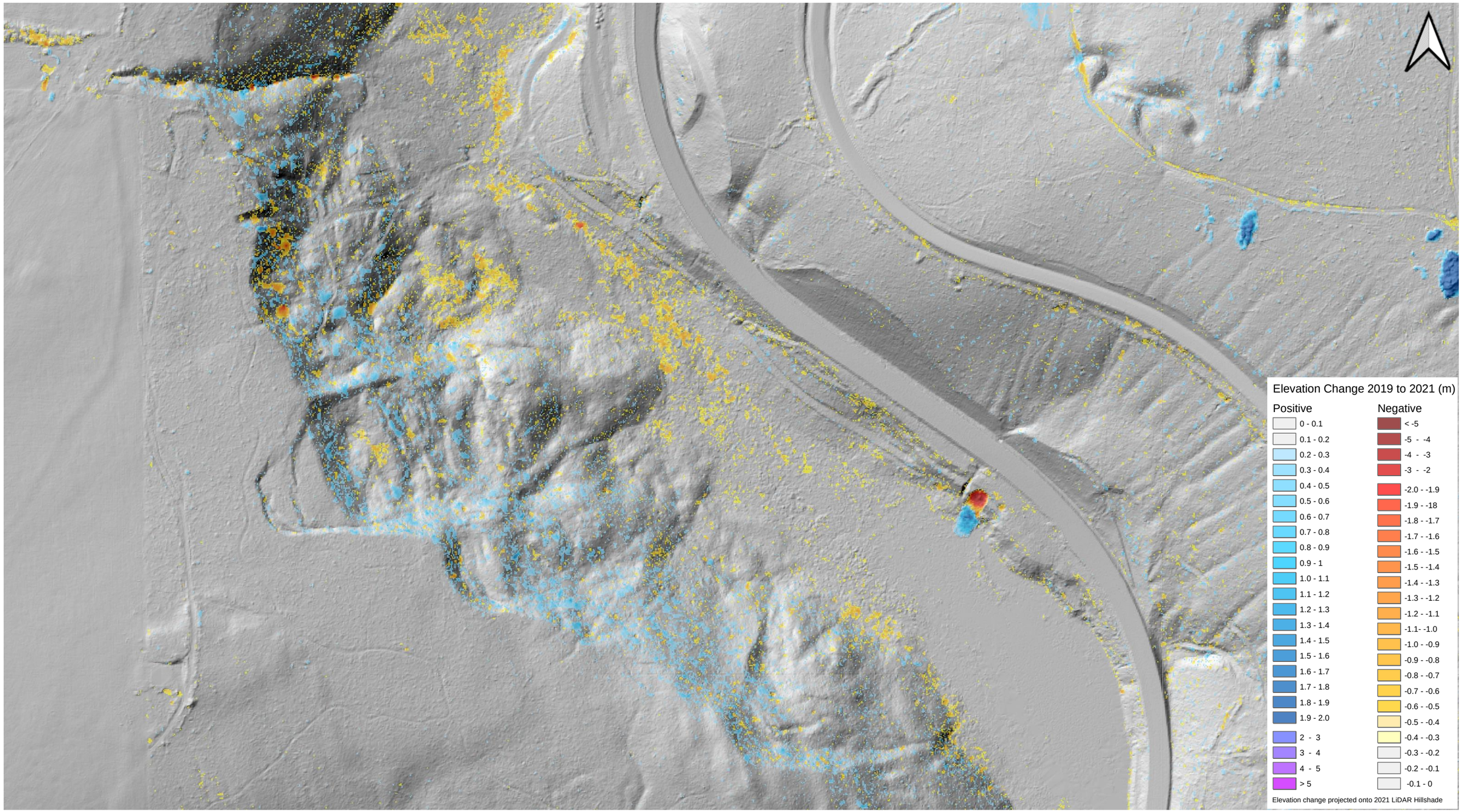
Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Area around Upper Asahai Creek**

**FIGURE 20**

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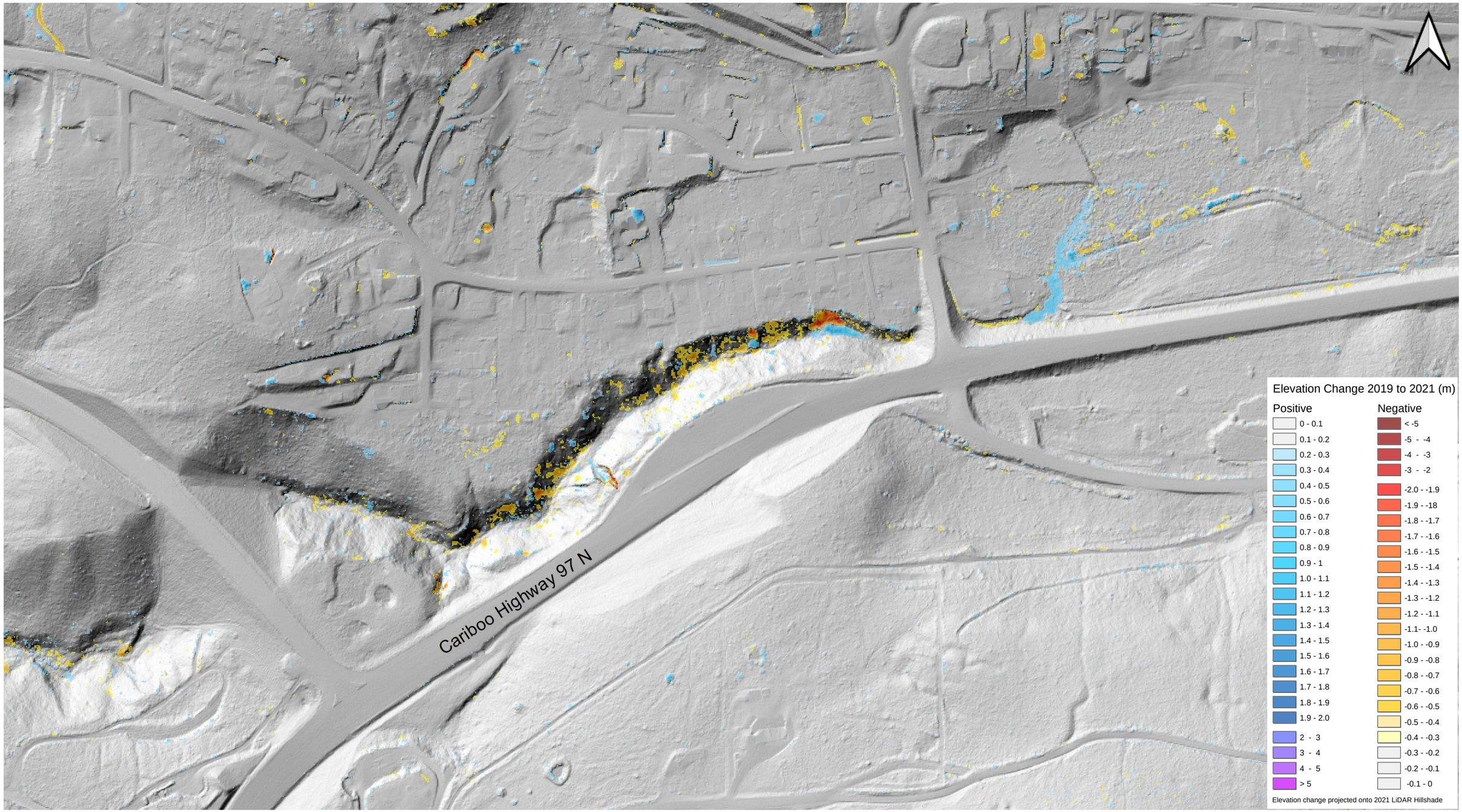
SCALE: 1 : 2000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Highway 97 near the Airport Access Road**

**FIGURE 21**

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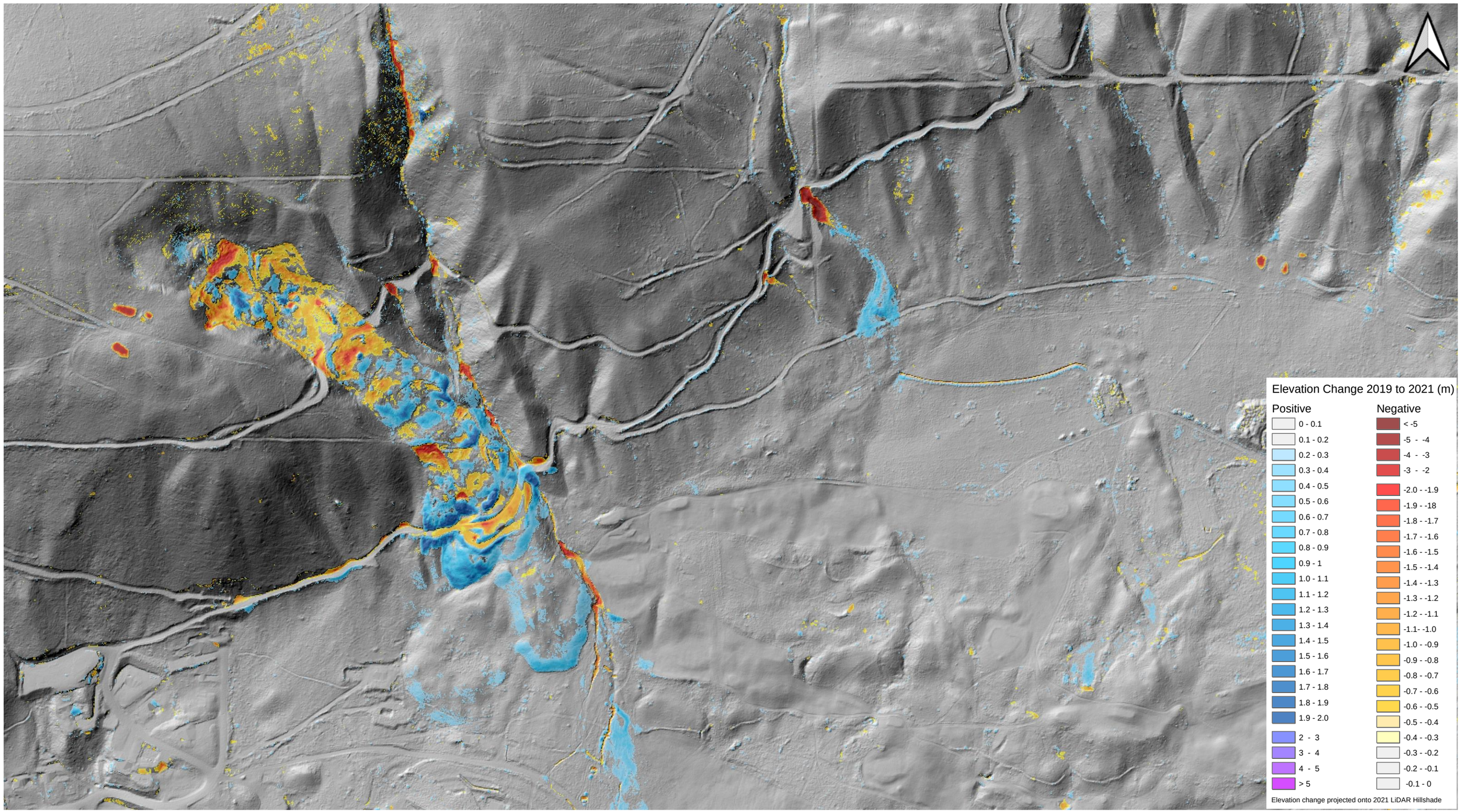
SCALE: 1 : 2000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Upper Missioner Creek (upstream from Mackenzie Ave)**

**FIGURE 22**

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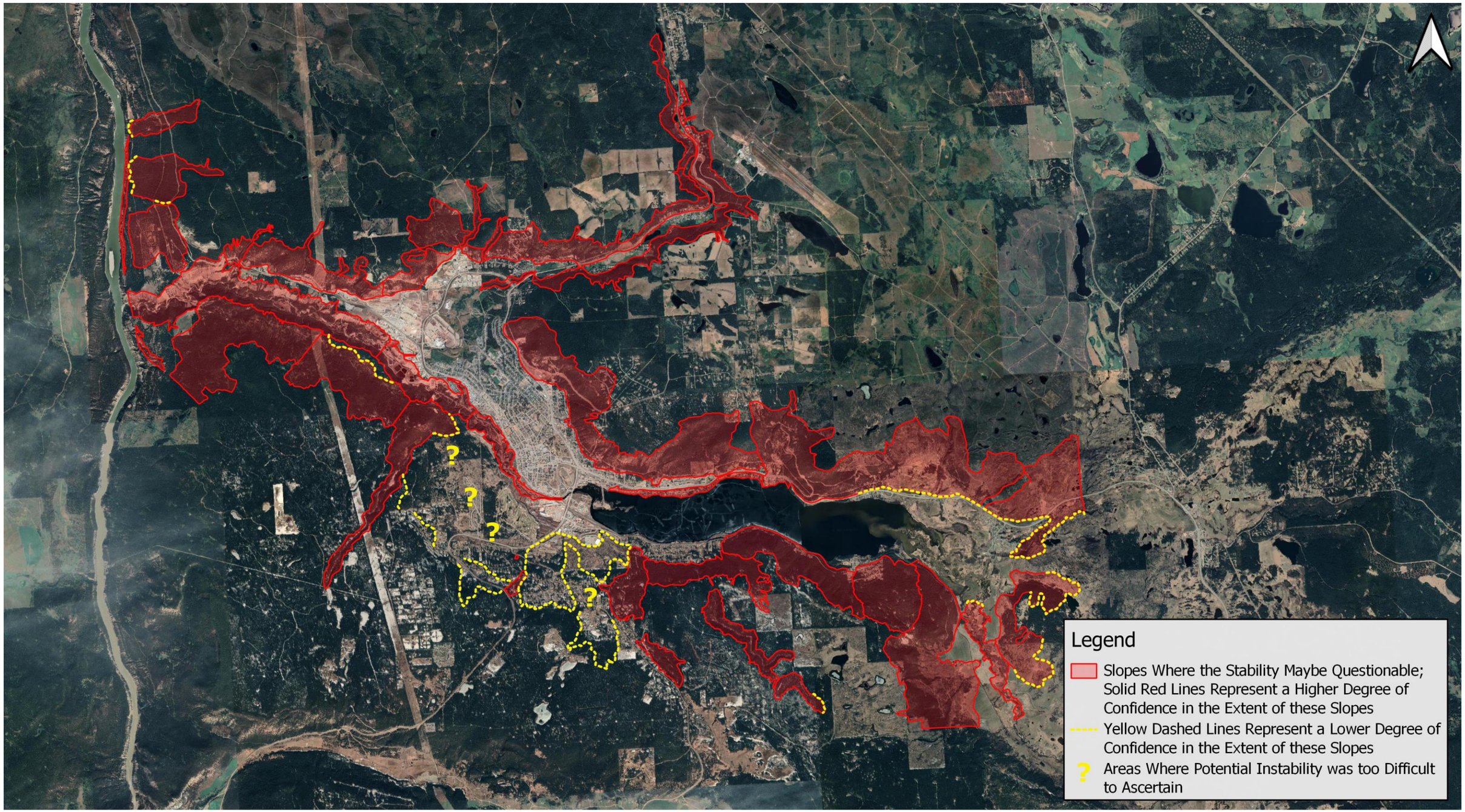
SCALE: 1 : 4000

Imagery Date is June 22, 2021
(provided by the CRD)

Project: 021-069

**The Results of the Change Detection Analysis using the 2019 and 2021 LiDAR Datasets for the Slopes around Coyote Bluffs**

**FIGURE 23**

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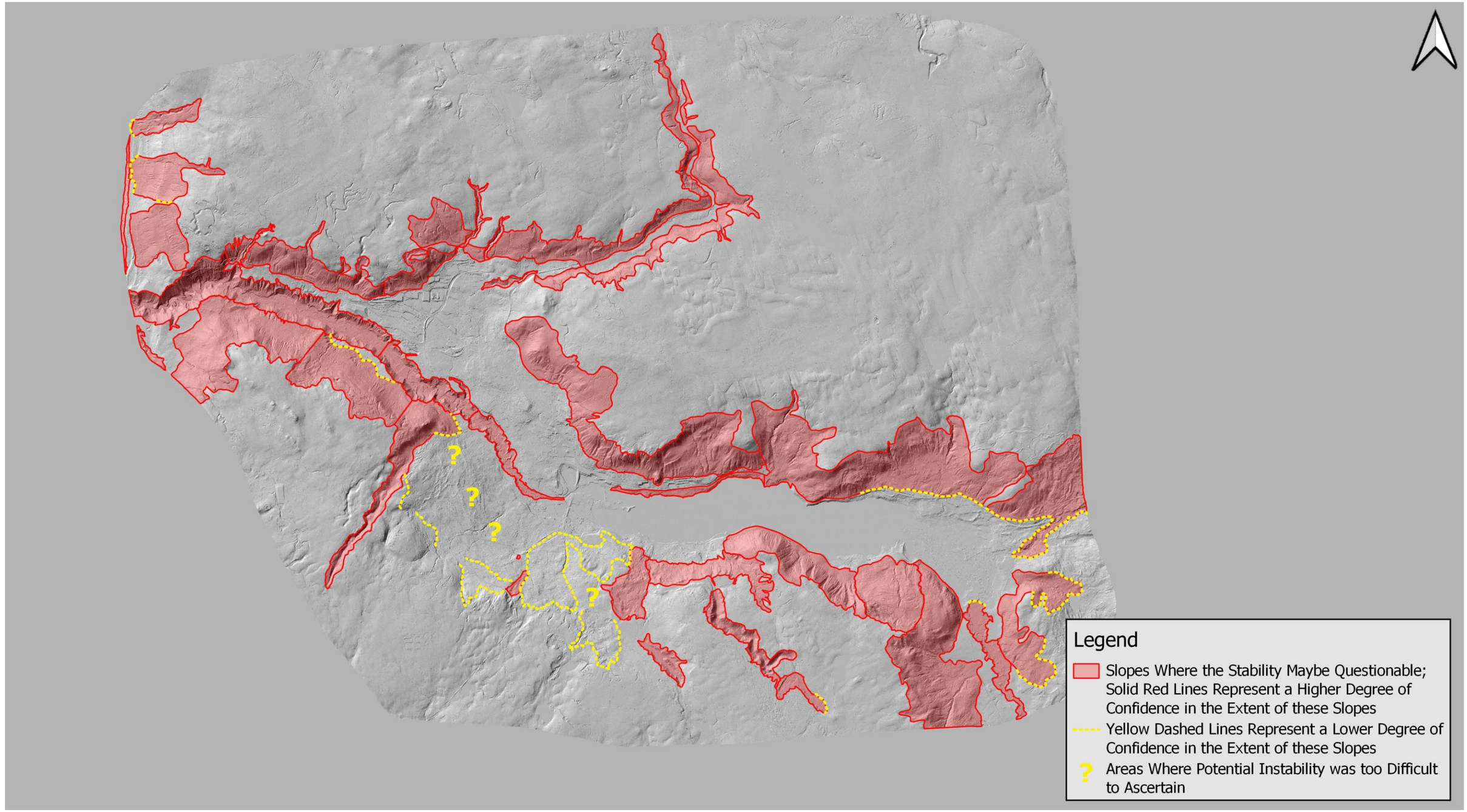
SCALE: 1 : 80000

**Source:** Oct 16, 2021; Satellite Imagery provided by Google Earth

Project: 021-069

**The Approximate Extent of Slopes Where the Stability Maybe Questionable Within the City of Williams Lake and Surrounding Fringe Area Based on the 2021 LiDAR Imagery Overlain on Google Earth Imagery**

**FIGURE 24**

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SCALE: 1 : 80000

**Source:** Imagery Date is June 22, 2021 (Provided by the CRD)

Project: 021-069

**The Approximate Extent of Slopes Where the Stability Maybe Questionable Within the City of Williams Lake and Surrounding Fringe Area Based on the 2021 LiDAR Imagery**

**FIGURE 25**