Stantec

Debris Flow Runout Model: North Shore Cowichan Lake

LABS Model Results 2021

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Prepared for:

Cowichan Valley Regional District

Prepared by:

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In association with
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PROFESSIONAL PROVINCE OF R.H. GUTHRIE 24849 BRITISH COLUMBIA GEOSCIENTIST

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Revision History

In 2020, Stantec identified a model bug that caused deposition on steep slopes in the CVRD study area using LABS (the debris flow runout model that provides the results reported herein). Upon detailed review of the model, Stantec found and fixed the source of the error. As a result of the fix, more debris flow mass reaches the lower slopes. Additional properties are reached by the slightly extended runouts, so Stantec and Palmer felt that it was important to release an updated copy of this report.

In the process of cleaning the program, Stantec updated several features that make communication of the results more precise. Appendices B and D are both more specific than the previous version.

This report relied on LABS version 1.8.

Other changes to this report include:

- An updated section on model limitations, and the methods whereby Stantec reduces potential model errors
- Updated discussion about the model calibration and the runout results
- Updated figures for the terrain occupied by model runs, for the modeled debris flow runout limit, and the modeled damage. Appendices B through D contain more details.

The reader is advised that this report and the updated figures and maps supersede any previous reports.

Glossary

Agent	A sub-routine that is born (or spawned), interacts with the surface model and with other agents, and ultimately dies, in series of successive timesteps. Rules governing birth, behavior, and termination are imbedded in the sub-routine.
Channelized Debris Flow	An extremely rapid (~ 5 m/s) landslide involving the downslope flow of rock, sediment, and debris, where the landslide is structurally confined within a steep channel. Channelized debris flows may become debris floods based on the ratio of water to solid material.
Debris Avalanche	An extremely rapid (~ 5 m/s) shallow landslide involving the steep downslope flow of rock, sediment, and debris, whether saturated or not. Internal structures are not preserved (Hungr & Picarelli, 2014).
Debris Flood	Debris flood: Very rapid to extremely rapid flow of water, heavily charged with debris, in a steep channel. Peak discharge comparable to that of a water flood (Hungr & Picarelli, 2014).
Debris Flow	An extremely rapid (~ 5 m/s) landslide involving the downslope flow of rock, sediment, and debris, along an established path such as a gully, or a first or second order drainage channel. Internal structures are not preserved (Hungr & Picarelli, 2014).
Debris Slide	Sliding of sediment and debris along a clearly defined rupture surface, either rotational or translational. Internal structures are typically preserved. Shallow translational debris slides on the west coast of British Columbia frequently transform into debris avalanches over a short distance (Hungr & Picarelli, 2014).
Encounter Probability	The likelihood that a hazard will be encountered in any location within a defined zone such as a mapped hazard polygon.
Supply Limited	A term that implies that the potential energy available to transport material and sediment from a position on a landscape exceeds the potential energy required to generate that sediment (typically through weathering). Supply limited sites with little or no surficial deposits.

1.0 INTRODUCTION AND BACKGROUND

The steep North Shore of Cowichan Lake is part of the Cowichan Valley Regional District (CVRD), home to approximately 4,000 people (Statistics Canada, 2020) and includes the village of Youbou, and the town of Lake Cowichan. Glacially-oversteepened slopes on the north shore end abruptly in paraglacial alluvial and colluvial fans that terminate in the lake itself. These fans are themselves underlain by thick sequences of stratified gravels and glacial sediments. Development along the North Shore occurs primarily on the lower portions of these fans.

A hazard assessment of the North Shore (Palmer, 2018) identified 462 historic landslides, mostly debris flows and debris slides, and subsequently divided the landscape into discrete polygons whereby each polygon was assigned an annualized landslide encounter probability (Figure 1-1). Encounter probability in this instance described the annual likelihood that any given location within the polygon will be affected by a landslide.

The encounter probability was determined by measuring the proportion of terrain polygons that contained landslides over a visual record of about 70 years (the air photograph record and the persistence time of debris flows in that record). Encounter probabilities varied from approximately 1:100, to 1:100,000 (Figure 1-1).

Despite the landslide inventory, terrain polygons existed with insufficient visual history to assign an encounter probability. In this case, the landslide hazard model was extrapolated to similar polygons based on terrain attributes in a manner consistent with other studies on southwestern Vancouver Island (Rollerson, Millard, & Thomson, 2002).

Palmer (2018) acknowledged that encounter probability varies within their study polygons depending on runout characteristics that were undifferentiated at the study scale. Similarly, they identified that hazards were likely to be distributed unevenly across the paraglacial fans whereby distal locations on the fan would be affected less frequently.

A cursory calculation of probabilities corroborates the study limitations. Approximately 240 homes are within polygons assigned a 1:3,000 encounter probability. The probability that at least one home would encounter a landslide somewhere along its path in any given year is about 8%. The probability that at least one home would encounter a landslide somewhere along its path in a run of 50 years is 98%. These odds are somewhat higher than anecdotal experience of residents whose homes are in the polygons (potential debris floods notwithstanding).

Palmer (2018) recommended, among other things, that runout modelling be conducted for the landslide types identified in their study (primarily debris flows and debris slides) to better discretize the hazard.

The existing hazard model formed the basis for a subsequent risk model (Ebbwater and Palmer, 2019) wherein approximately 1700 people were estimated to live within the study area (the area in Figure 1-1), and be exposed to a greater or lesser extent, to landslide hazards off the steep adjacent North Shore slopes.

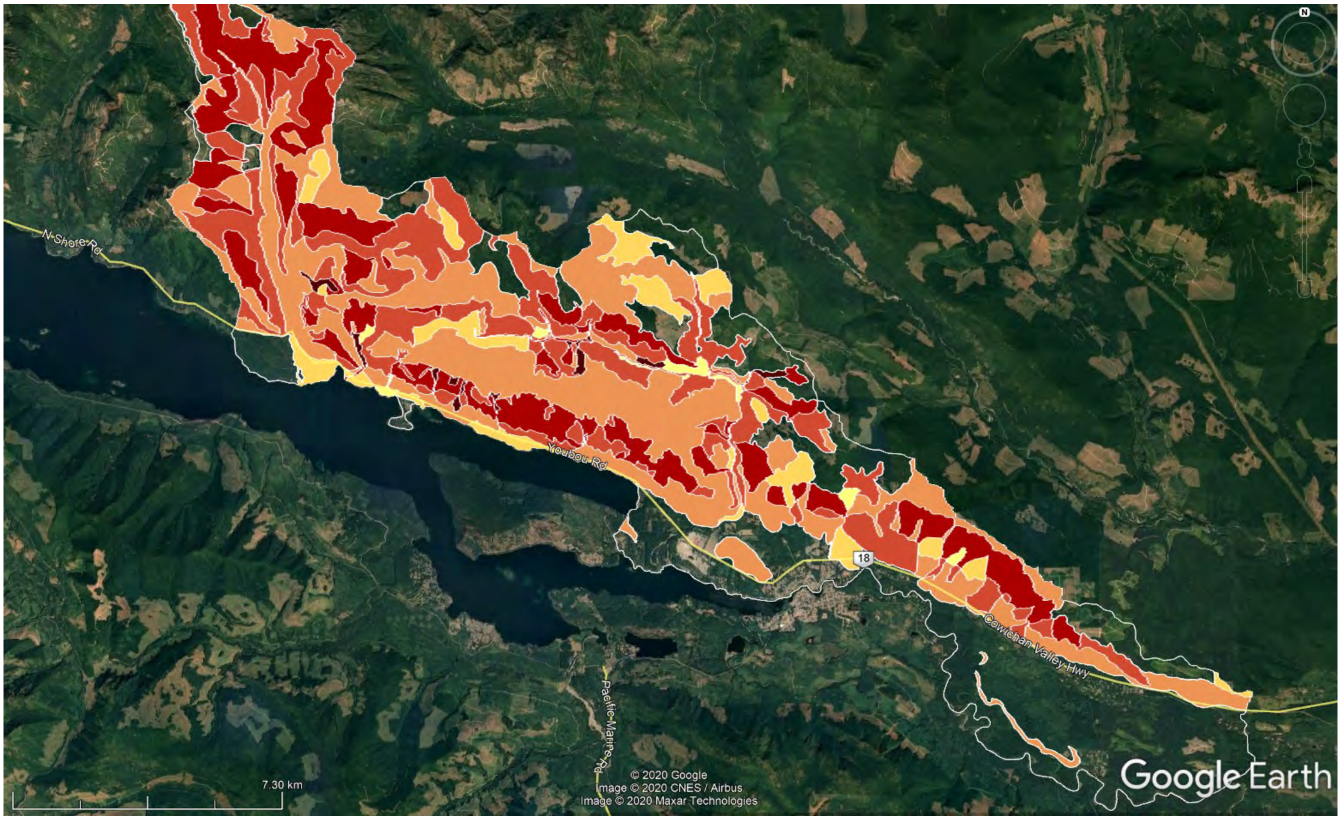

Figure 1-1. The results of Palmer's Encounter Probability map (Palmer 2018) projected into Google Earth. Probability ranges from 1:100,000 (transparent polygons) to 1:100 (darkest red-brown polygons). The reader is directed to the original report for more information.

1.1 SCOPE OF WORK

Stantec, in association with Palmer, proposed to conduct debris flow and debris avalanche runout modelling to better discretize the encounter probability map and refine the hazard component of risk to the residents of the North Shore of Cowichan Lake. Landslide runout was therefore using LABS software (Section 2.0).

This report comprises the main deliverable of that effort.

2.0 LABS RUNOUT SOFTWARE

"All models are wrong, but some are useful." – George E.P. Box

LABS (Landslides: Agent Based Simulation) is landslide runout software that, at its root, predicts landslide travel paths, and erosion and deposition along those paths. An early version of LABS was built to answer questions about the magnitude-frequency characteristics of open-slope debris flows and debris avalanches (Guthrie, Deadman, Cabrera, & Evans, 2008). The original cellular automata-based model showed realistic runout path selection, distance, and landslide magnitudes, when compared to mapped landslides.

LABS was developed by Stantec in 2018 and is now a fully functional software program (Guthrie & Befus, 2020). LABS is predicated on the idea that shallow landslides of the flow-type (debris flows and debris avalanches) exhibit similar aggregate behavior, based largely on slope, independent of geology, triggering event, rheology, or other secondary and tertiary order effects. Consequently, implementation of LABS is easy and requires only a digital elevation model (DEM). Calibration for local differences can be done experimentally by running LABS and comparing results to existing landslides.

2.1 MODEL LIMITATIONS

LABS incorporates peer-reviewed techniques to predict dynamic behavior in the physical world. Representation of that behavior assumes complete and accurate information about the environments for which the models are developed. There are practical limitations to meeting this standard, and the user must note that those limitations can affect the results.

There may be elements that are not known or not available to Stantec that can affect predictions including local physical conditions that are not resolvable at the model scale, or inputs and interactions that arise dynamically through behavior that are not included in model dynamics.

Stantec does its best to mitigate or address these limitations and uncertainties by obtaining representative environmental data, where agreed under the scope of work, using mapping techniques, field programs, intrusive investigations, referencing published literature, and reviewing previous studies. In this manner, Stantec includes available and accepted environmental models to reduce epistemic uncertainty.

Stantec runs, multiple predictive simulations to identify credible outcomes. These probabilistic models do not mean that any particular outcome will occur in any real-world event, nor do they mean that unpredicted outcomes will not occur. The predicted outcomes are Stantec's best effort to identify the locations and magnitudes of the most credible events. Interpretation of these predictions require an understanding of these uncertainties, high level of subject matter expertise, and good professional judgment.

Assumptions that apply specifically to the use of LABS.

- Local topography smaller than the DEM resolution or not captured by the DEM (due to DEM quality or the difference between ground conditions when the DEM was captured and existing ground conditions) may affect the path selection or landslide behavior in a manner not resolvable by LABS.
- Landslide behavior including inundation, runout, scour, deposition, spread, and path selection, may vary from modeled behavior for several reasons including: stochastic variability in the landsliding process (natural or modeled), controlling factors that defy parameterization within the model, generalizations used to make the model practical and applicable across large areas.
- LABS does not model debris floods and may underestimate runout of channelized debris flows that are transitional to debris floods. However, LABS will show which channels are likely to be charged with sediment that may in turn be susceptible to debris floods. Nonetheless, the distinction should be recognized by the reader.
- LABS simplifies extremely complex behavior to provide reasonable predictions of outcomes. Should there be a perceived difference between modeled results, and on-the-ground evidence, the ground-based evidence should take priority. LABS does not relieve professionals from using their experience, training and education to make good judgments when assessing actual ground conditions, but provides additional understanding of processes, and credible outcomes.

2.2 HOW LABS WORKS

LABS estimates sediment volume (erosion and deposition) along a landslide path by deploying '*agents'*, or *autonomous sub-routines* over a 5 m spatial resolution DEM. The DEM surface provides basic information to each agent, in each time-step, that triggers the rule set that comprises the subroutine. In this manner, agents interact with the surface and with other agents. Each agent occupies a single pixel in each timestep.

2.2.1 Agent Generation

The user defines a starting location by injecting a single agent (5 m x 5 m), a group of nine agents (15 m x 15 m initiation zone), or by painting a user defined zone (unlimited size) as indicated by field morphology. Multiple agents may be generated at the same time using any of these methods, or any combination of these methods. LABS can automatically create 15 m x 15 m source zones (nine agents) for each point in an imported point file.

The starting location of a single agent, or a group of connected agents, represents the initiation of a landslide.

2.2.2 Agent Mass

Agents follow probabilistic rules for scour (erosion) and deposition at each timestep based on the underlying slope. Rules for scour and deposition are independent probability distributions for 12 slope classes (bins), modified from Guthrie, et al. (2008) to account for a wider range of slopes than the original study. They are based on data gathered for coastal BC by Wise (1997) and by Guthrie et al. (2008; 2010).

In addition, mass loss occurs when agents change cardinal direction. This is a user defined parameter that mimics frictional deposition. In this study, mass loss was limited to 5% for each 45º turn.

In each timestep an agent scours, deposits, then checks its mass balance. Mass balance is recorded by the agent in each timestep, and agents are terminated when their mass equals zero.

2.2.3 Agent Path Selection

Agents with mass move downslope in successive timesteps by calculating the elevations of the Moore neighbors (the surrounding eight squares in a grid), determining the lowest three pixels and moving to the lowest unoccupied pixel of the three. Should the lowest three pixels be occupied, or should some of the pixels be equal elevation, the agent will merge with one of the cells based on similar internal decision-making rules.

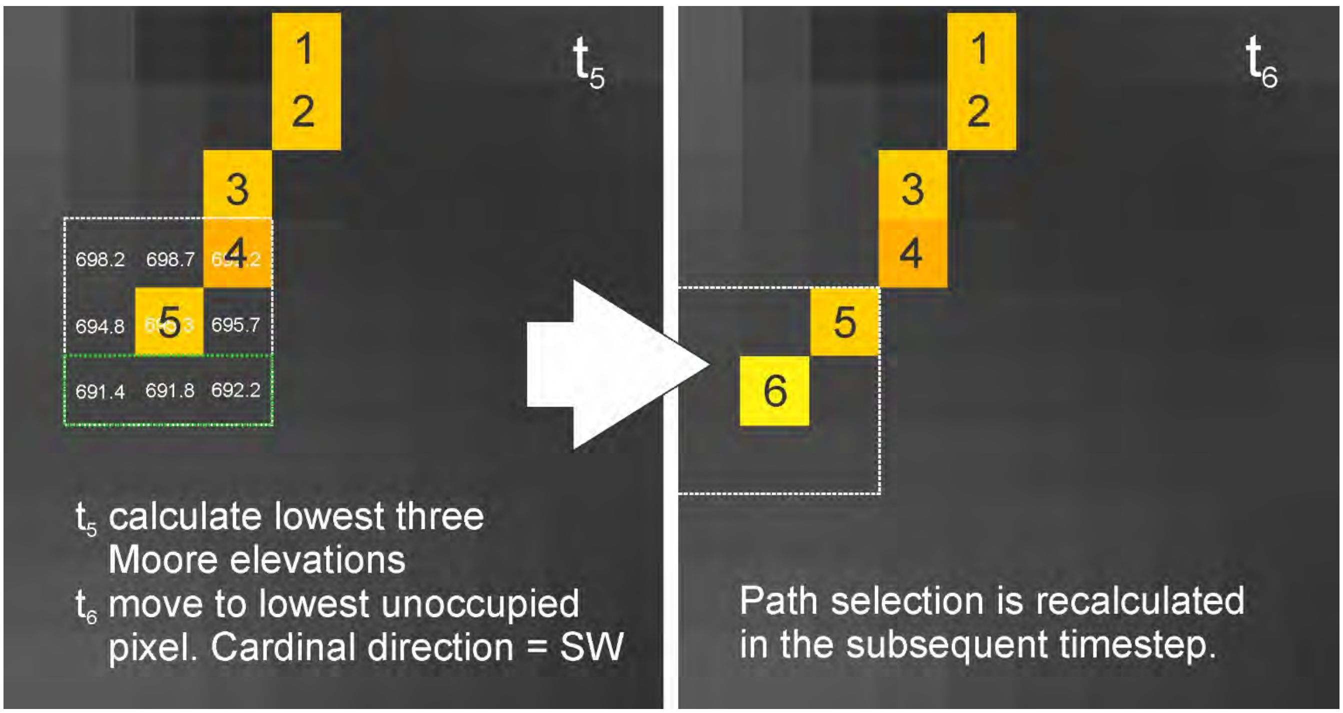

Figure 2-1. Path selection based on aspect determined by Moore neighbors. Black numbers represent timesteps, and white numbers represent actual elevations. DEM is from the North Shore of Cowichan Lake. Pixel resolution is 5 m.

2.2.4 Agent Spread

LABS software has functions that control the spreading behavior of landslides. Spreading behavior causes landslides to redistribute mass by generating new agents described by a probability density function where the mean is centered around the facing direction of an individual agent (accounting for the local slope by way of the Moore neighbors) and the standard deviation, σ, is defined by:

$$\sigma = \left(\left(\frac{m_{MAX} - m}{m_{MAX}}\right)^n * \left((\sigma_L - \sigma_S) + \sigma_S\right)\right) \quad \textbf{(1)}$$

Where: m_{MAX}=Fan Maximum Slope, m=DEM slope, n=Skew coefficient , σ_L=σ Low Slope coefficient, σ_S=Steep Slope coefficient

Conceptually, this function creates a Gaussian normal distribution over the surface (Figure 2-2) where the shape of the Gaussian surface is controlled by the user inputs within the program. Those inputs include the Fan Maximum Slope, above which agents will not spawn, and shape controls that determine how steep and narrow the curve, or alternatively how low and broad the curve, for both steeper and flatter slopes.

Spread is calibrated experimentally based on empirical or observed behaviors of actual landslides. For this study, spread was limited to slopes at or below 34º.

Spread behavior produces realistic results related to underlying topography such that mass is redistributed at sudden changes in slope (e.g. Figure 2-3), or through gradual slope change where landslides tend to widen and deposit.

Spawned agents immediately perform the same rules as other agents in each timestep (including the timestep in which they were spawned).

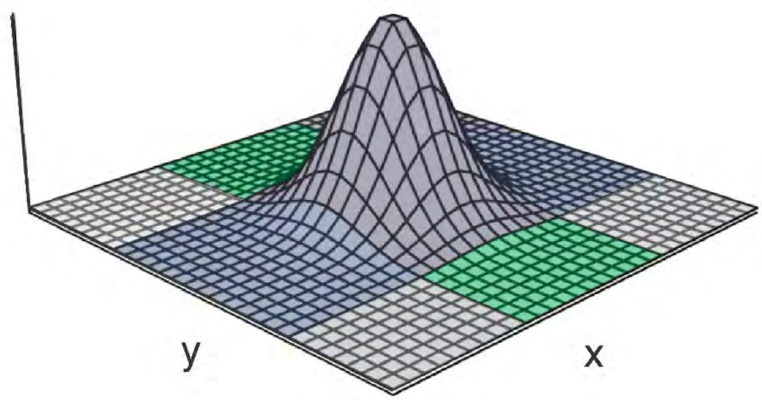

Figure 2-2. An example surface plot of a normal probability density function where mass from the center pixel (each pixel is uniformly colored) might be redistributed (spawning new agents) amongst adjacent pixels.

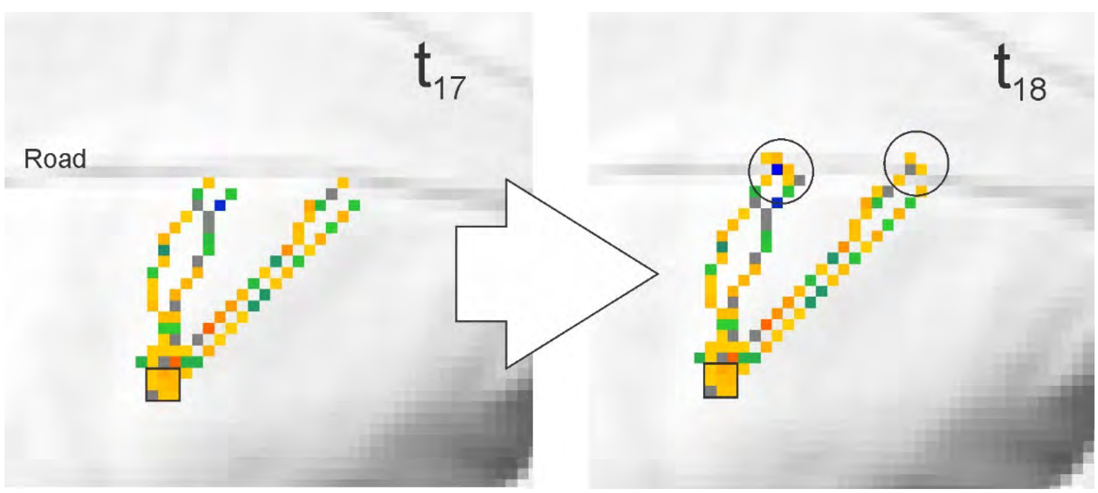

Figure 2-3. Agent spawning (inside circles) due to a topographic change at a road that is reached in timestep 18. Elevation decreases from bottom to top of figures and the initiation zone is a 15 x 15 m square outlined in black.

2.3 LABS OUTPUTS

Within the software, LABS produces results from: a single run, single landslide; single run, multiple landslides; multiple runs, single landslide; or multiple runs, multiple landslides. Following a run or set of runs, each pixel can be queried to provide information about the debris depth (net deposition) at that location, the landslide number, the pixel facing direction, and basic topographic information such as elevation and location. Multiple runs also provide some basic statistics including the number of times a pixel was occupied by an agent, and the minimum and maximum debris depth over all runs.

Each pixel is colored to represent scour or deposition. Red through yellow represent net scour (red being deeper than yellow), and green through blue represent net deposition (blue being deeper than green).

Figure 2-4 demonstrates the difference in scour and deposition along a landslide path. The reader can see that road(s) tend to accumulate sediment, consistent with observations on Vancouver Island (Guthrie, et al., 2010). Similarly, scour on the fill slope side of the road, where it is locally steeper, are also easily observed.

Figure 2-5 shows an example of LABS output within the software, in this case, for multiple landslides. Once again, colors relate to erosion and deposition.

Landslide predictions are probabilistic and thus vary between runs. Individual landslides can be shorter than those observed in the field in any given run, but the runout over multiple runs (e.g. 50) tends to be longer than those mapped since it includes more iterations of landslides. That being said, LABS does not model debris floods, and runout is not meant to encapsulate that process.

2.3.1 Export to Excel

Landslide specific information (landslide number, area, volume) can be exported as an excel file. The output allows the user to analyze magnitude frequency characteristics of the modeled landslides and confirm credible results.

2.3.2 Export to Shapefile

LABS can export the results directly to a shapefile (converting the raster results to points with the full set of attributes attached), or it can append shapefiles directly in the program.

2.3.3 Export to Geotiff

LABS exports the modeled landslides as geotiffs to enable viewing in other software and visual comparison with existing ground conditions.

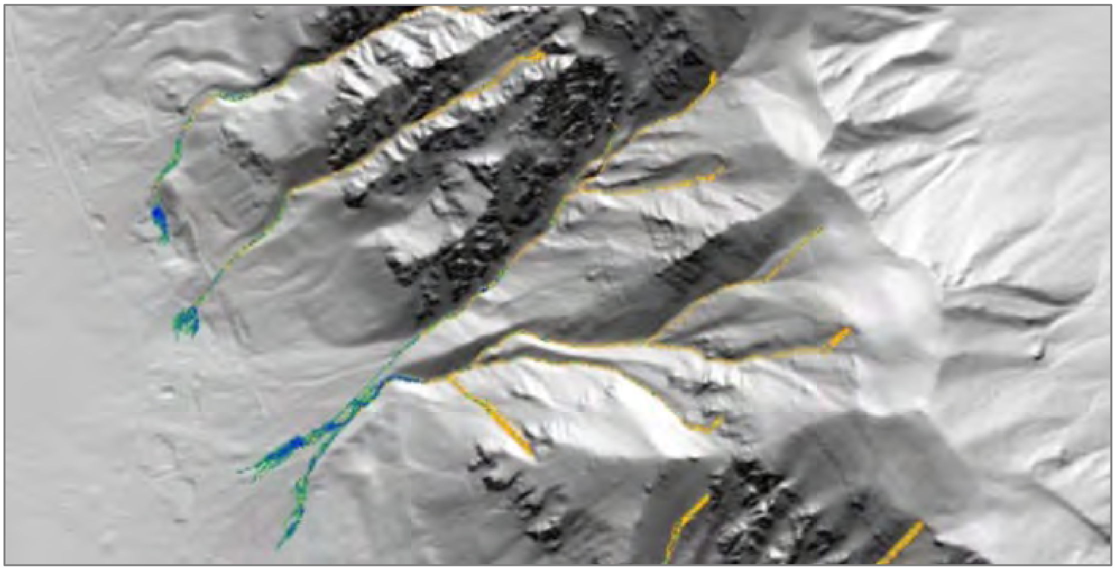

Figure 2-4. Modeled landslides in LABS showing scour (yellow and red) and deposition (green and blue). Example location is in Utah.

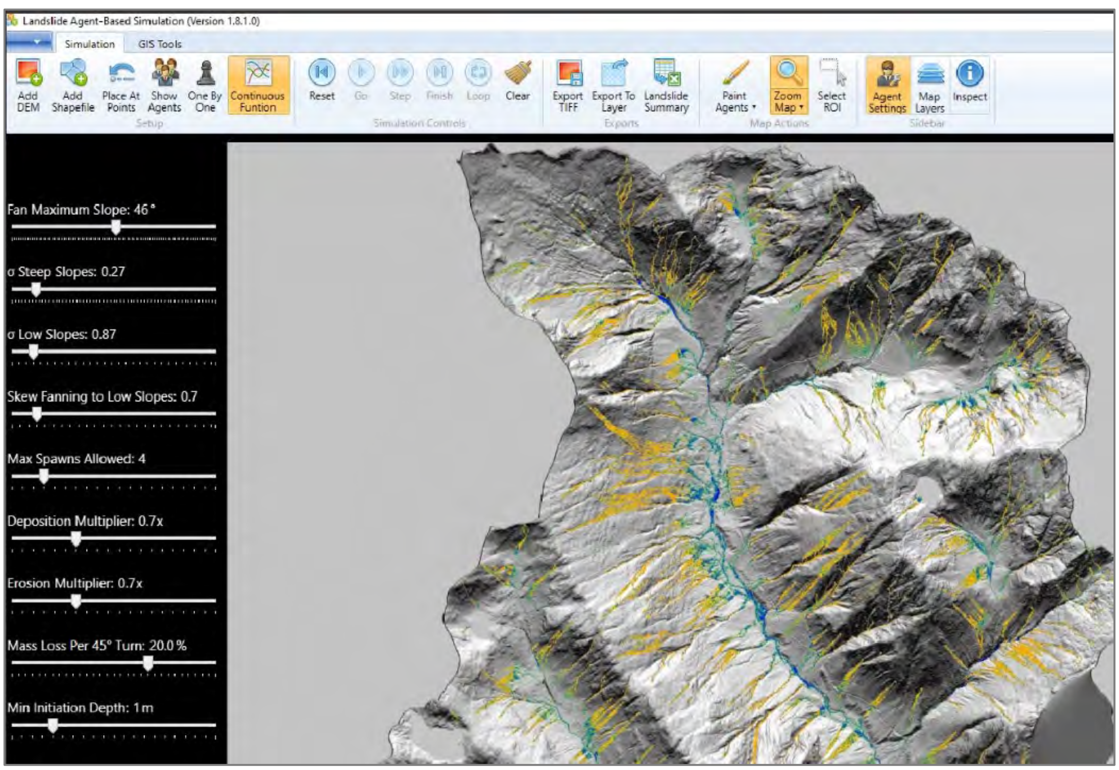

Figure 2-5. LABS output for multiple landslides in a coastal BC watershed.

3.0 PROJECT METHODS

Landslide initiation points were created by importing randomly distributed points, a uniform distribution of points, and manually in the GIS tool within LABS by looking at the LiDAR image and choosing initiation zones based on experience in similar areas. The results of each run were compared in a calibration exercise. The expert-based method was selected for the model runs used in the study as this method resulted in landslides somewhat more frequently than randomly or uniformly generated points.

No special consideration was given to existing anthropogenic disturbances.

A higher density of points was initially placed in polygons with higher exceedance probabilities, and landslide path was considered (landslide paths need not be unnecessarily duplicated). Obvious deposition zones were not selected as they tend not to produce landslides. This was confirmed in the 1:10,000 to 1:100,000 encounter probability zones, where landslides did not initiate when given the opportunity in the modelling process.

3.1.1 Calibration

The model was calibrated by running 703 randomly generated landslides within the study area and comparing the results to mapped and expected landslide behavior. In addition, modeled landslides on the north shore of Cowichan Lake were compared directly to mapped landslides on the north shore of Cowichan Lake.

Once calibrated, 1,364 landslide initiation points were selected in the 1:100, 1:300, 1:1,000, and 1:3,000 encounter probability zones (Figure 3-1 and Table 3-1).

The following parameters were used for running the model:

- Fan Maximum Slope = 34º
- σ Steep Slopes = 0.35
- σ Low Slopes = 1.35
- Skew Fan Coefficient = 1.1
- Max Spawns Allowed = 4
- Deposition Multiplier = 1 x
- Erosion Multiplier = 0.7 x
- Mass Loss Per 45º Turn = 20%
- Min Initiation Depth = 0 m

The first 4 terms dictate the type and nature of spreading behavior as per Equation **(**1**)**. Max spawns limits the programs ability to create new agents; the deposition and erosion multipliers adjust the rule outcomes to create more realistic behavior (in the case of North Cowichan, erosion was reduced to accommodate the shallow depth to bedrock); mass loss dictates the percent of mass held by the agent that is lost in sharp corners; minimum initiation depth determines whether the landslide is started purely using the controls within the program (0 m) or whether a user defined depth is used (for areas where landslide initiation depths are known or can be reasonably estimated).

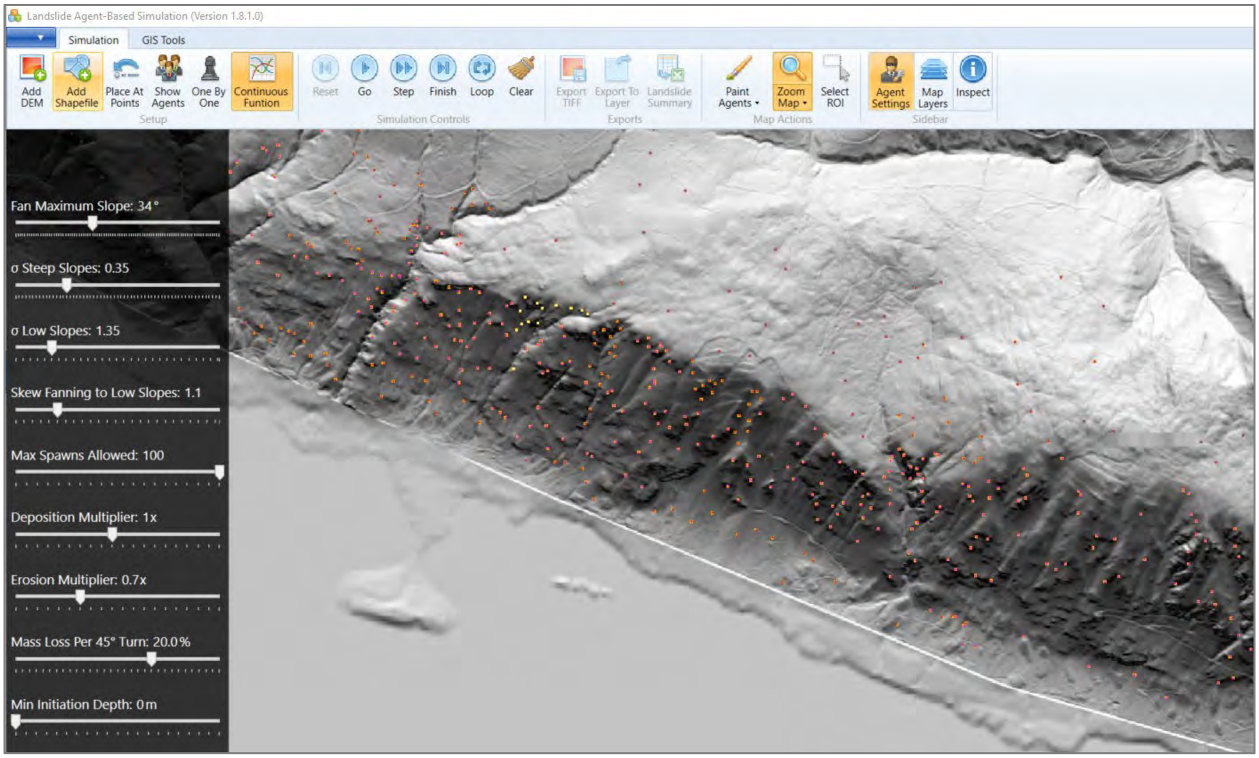

Figure 3-1. Landslide initiation points (colored dots) from the steep slopes of the North Shore of Cowichan Lake.

Figure 3-2. Number of landslides model runs on the North Shore of Cowichan Lake

Encounter Probability	1:100	1:300	1:1000	1:3000	Total
Number of landslide initiation points	59	567	378	360	1,364
Number of landslides for 50 modeled runs	2,950	28,350	18,900	18,000	68,200

3.1.2 Model Initiation

Nine agents were placed at each landslide initiation site, creating an initiation zone of 15 m x 15 m (Figure 3-2).

A single run of all landslides was conducted to check that the expected landslide magnitude-frequency characteristics roughly matched the mapped landslide magnitude-frequency characteristics.

Fifty landslides were then modelled from each landside initiation zone and those results were exported as Geotiffs to enable viewing in Google Earth and ArcGIS software.

Pixels in the landslide path were examined for net change to the DEM, and for the number of instances that a landslide inundated that pixel (out of 50).

Encounter probability zones were then manually redrawn in ArcGIS based on the results. Where reasonable, the original linework was preserved. However, where landslides overran downslope polygons, Stantec redrew the polygons based on the attributes of the initiated landslides.

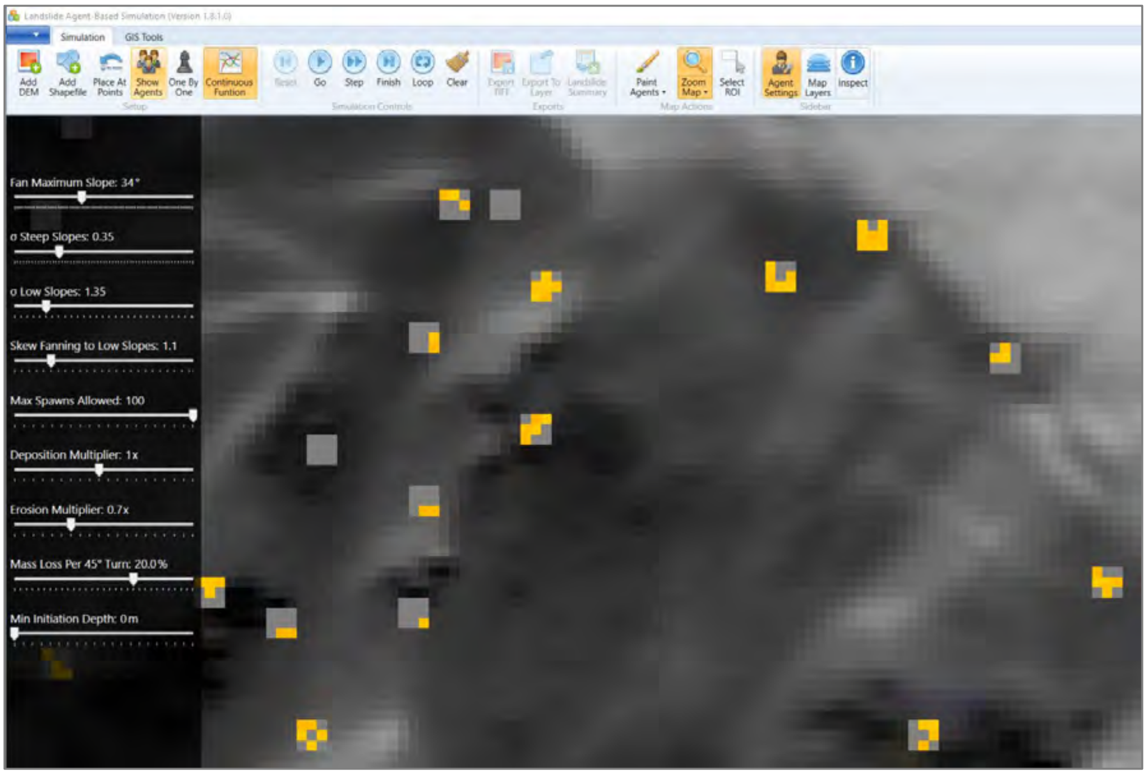

Figure 3-3. A screen capture showing 15 m x 15 m landslide initiation zones in the study area. Each cluster of nine pixels has already acted according to the rules for t=0.

4.0 RESULTS AND DISCUSSION

4.1 CALIBRATION

A single run of 703 random landslides was generated for the calibration phase, as well as model runs from the mapped (Palmer, 2018) landslide initiation zones (Figure 4-1 to Figure 4-3).

Some differences emerged.

Modeled landslides, using the chosen parameters, tended to run further than mapped landslides in almost all cases (Figure 4-2). Despite this, the modeled landslides occupied about half the area of mapped landslides for a given probability of occurrence (Figure 4-3). In addition, the model exhibited fanning behavior that was not widely present in the mapped landslides, but that did match the underlying LiDAR (unavailable during Palmer's (2018) original mapping) and was reflected in patterns of vegetation on the slopes over which the model ran.

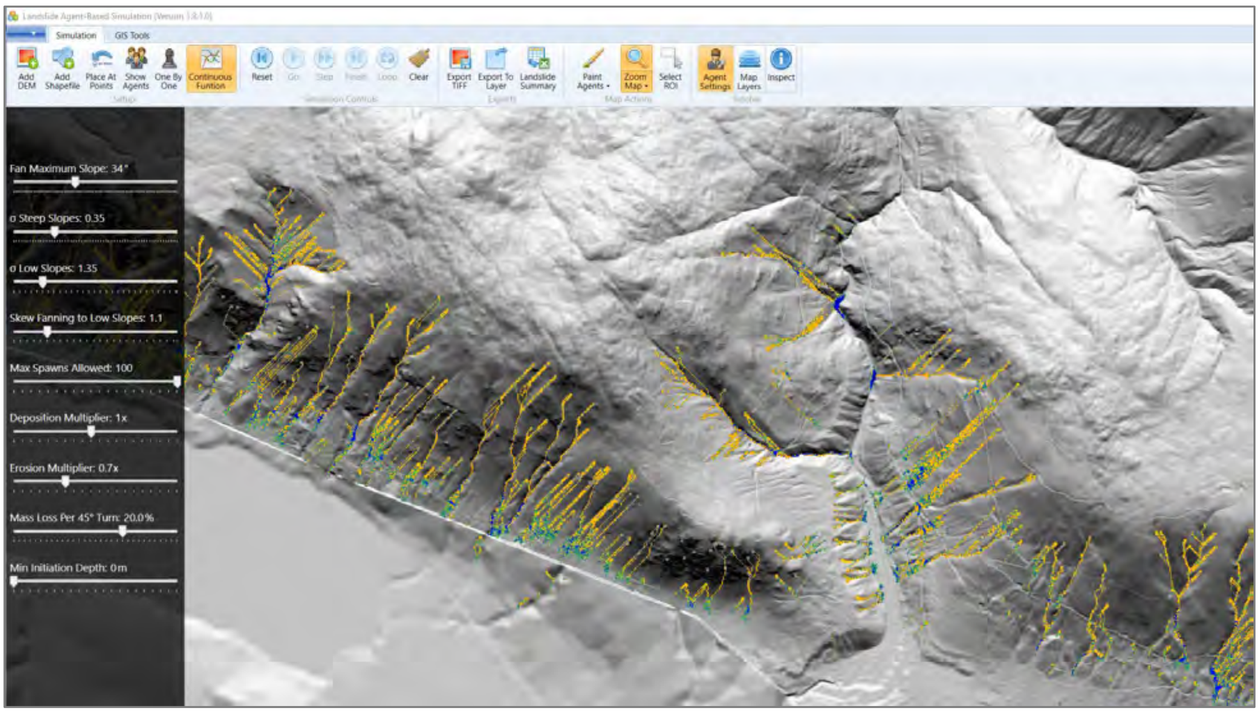

Figure 4-1. Calibration run of landslides in LABS.

Figure 4-2. Landslides modeled and mapped (pink outlines) on the North Shore of Cowichan Lake. Background image is from Google Earth.

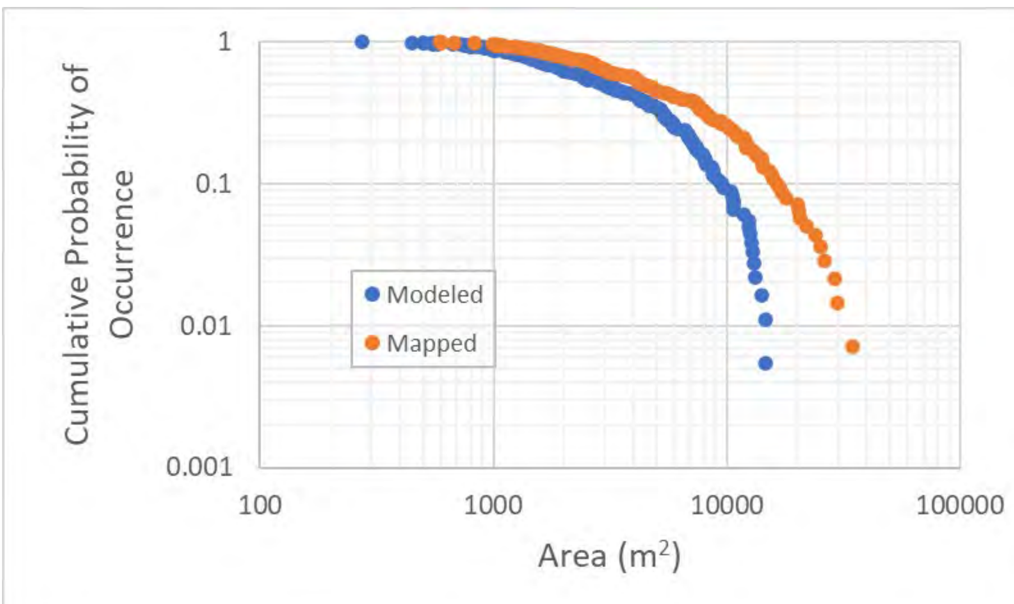

Figure 4-3. Magnitude-Frequency comparison between Modeled (blue) and Mapped (orange) landslides on the North Shore.

4.1.1 Magnitude and Frequency

The tangent of the slope at a given probability of occurrence (Figure 4-3) was approximately equal for both modeled and mapped landslides. Stantec Palmer thereby interpret that the model does a good job representing variability in landslide size distribution. However, mapped landslides generally occupied about twice the area of modeled landslides.

Mapping is, in and of itself, a model. There are restrictions related to level of detail and a practical mapping scale. The mapper must make a choice between outlining landslides that are inferred to exist on steep slopes and precisely following the limited path visible among trees. In this case, the model appears to have better limited the landslide width to the actual path (Figure 4-4). Mapped landslides include areas of steep gullies and slopes that are heavily forested after the identified event. We therefore interpret that the magnitudes of the mapped landslides are conservatively inflated and that is reflected in the curve in Figure 4-3.

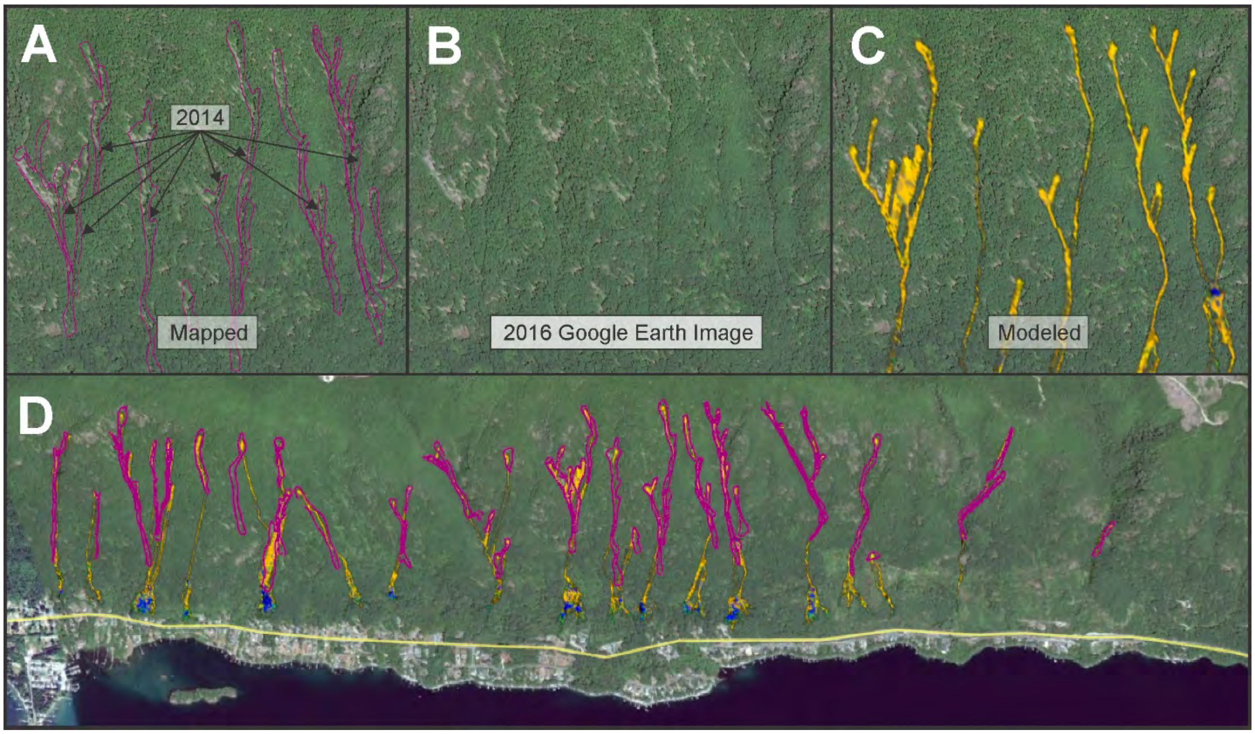

Figure 4-4. Mapped vs modeled landslide paths. Landslides mapped on the 2014 air photographs (A) are compared to similar modeled (C) landslides against the 2016 air photographs (shown in all instances here – imagery from Google Earth).

4.1.2 Runout Length

Modeled landslides, based on the chosen parameters, overran mapped landslides on the North Shore of Lake Cowichan. While the mapped landslide path lengths appear to be accurate, Stantec Palmer note the modeled landslide runout matches the vegetation patterns and the morphological evidence of fans. We interpret that insufficient sediment was available in the mapped cases for the debris flows to extend beyond the gullies, or that vegetation cover was too dense to confidently interpret farther-reaching runouts (the reader is once again reminded that LiDAR was not available for the original hazard mapping). Given the potential exposure to landsldies of residential buildings below, we elected to allow the additional runout distance and fanning behavior. The North Shore is relatively supply limited and the model results are interpreted to be conservative, however, the reader should note that should there be sources of sediment in excess of what is modeled here (typically < 1 m thick with occasional pockets of sediment < 1.5 m thick), additional runout is possible. Thicker sediments would need to be available in sufficient quantities to create a change. Model parameters were selected to be consistent with the field, air photograph, and LiDAR interpretations.

4.1.3 Runout Path

The landslide runout paths almost perfectly emulated the mapped landslide runout paths (Figure 4-5). When hundreds of paths are viewed at the same time, a strong linear orientation is apparent. This occurs when the DEM at the model resolution (5 m) is so steep that it overwhelms the path selection at each timestep and spreading has not yet occurred (recall that spreading is limited to slopes equal to 34^{o} or flatter).

Despite the DEM limitations, if only mapped initiation points are considered, the landslide runout paths appear to be credible and match the mapped runout paths. Results may nonetheless bypass local topographic effects and choose paths that vary somewhat from the real-world equivalent.

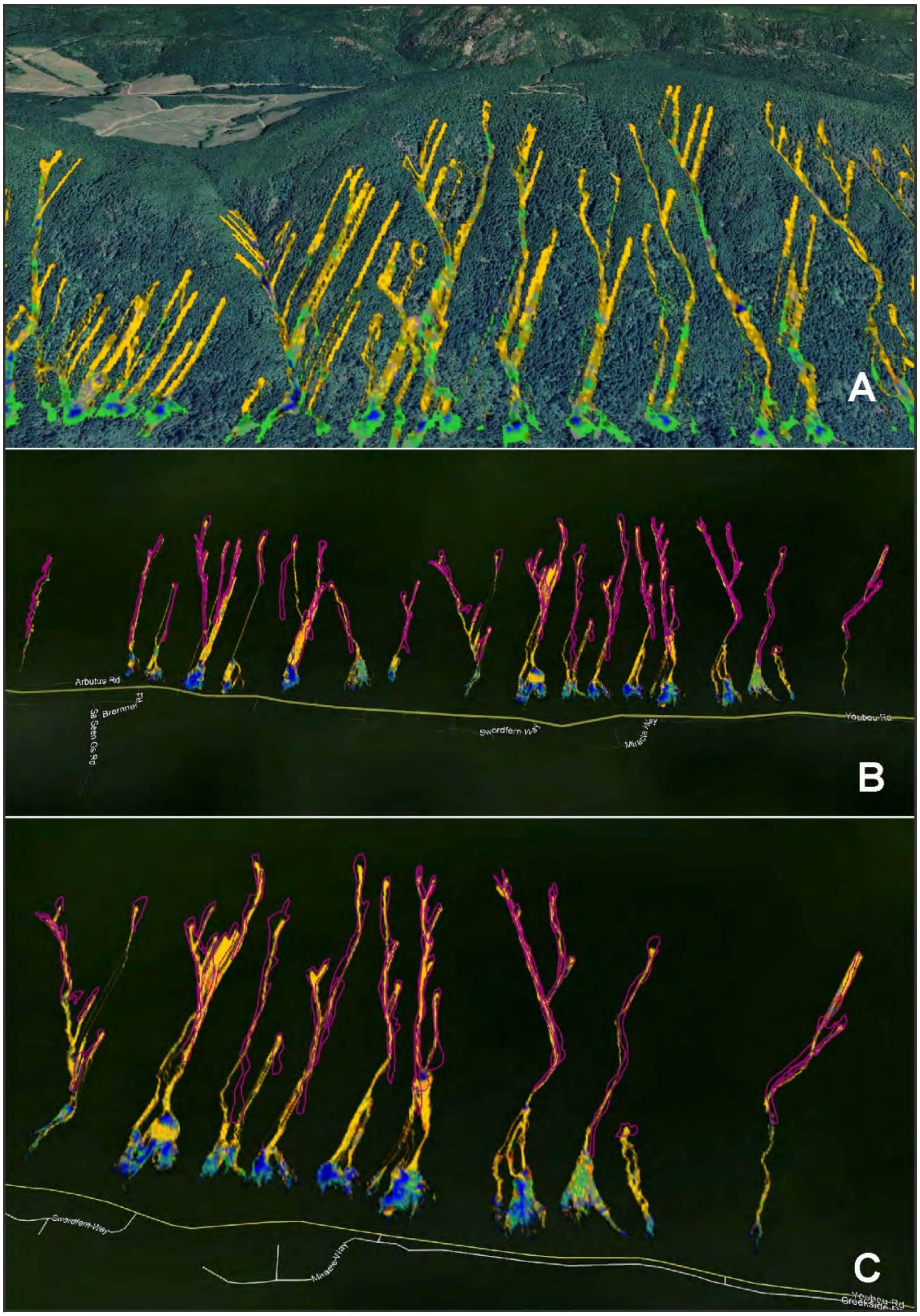

Figure 4-5. Strong linear orientation of modeled landslides on the North Shore when hundreds of landslides are viewed at once (A). The results look more reasonable (though still linear) when compared to just the mapped landslides (B) and (C). Google Earth image in the background of (A).

4.2 RUNOUT

The result of 68,200 landslide runs on the North Shore of Cowichan Lake was, with exceptions, that the cumulative footprint of modeled landslides did not reach most residential homes on the paraglacial fans. Instead, landslides deposited much of their mass before reaching the lower fans and tended to terminate on upper- and mid-fan slopes that were between 10 and 20 degrees (Figure 4-6 and Figure 4-7).

The likelihood that a modeled landslide occupies a position in the landscape is provided for landslides that were initiated from the 1:100, 1:300, 1:1,000, and 1:3,000 Annual Encounter Probability polygons in Appendix B. An example of the results for 1:100 and 1:300 AEP are shown in Figure 4-8.

The distal limit of modeled runout, regardless of the probability of a hazard initiating, is provided in Appendix C. With over 68,000 landslide runs, the modeled probability that a debris flow will exceed this line is less than 0.000015.

Properties above (north) of the distal limit of modeled runout can use the estimated Annual Encounter Probability and Damage Curves to inform subsequent investigation.

Despite the aforementioned, houses on the North Shore may be subject hazards that were not modeled here such as rock fall hazards within the rock fall shadow, notionally 27.5º between the top of a talus slope and the distal limit of rock fall (Evans & Hungr, 1993), and debris flood and channelized debris flow hazards adjacent to steep creeks.

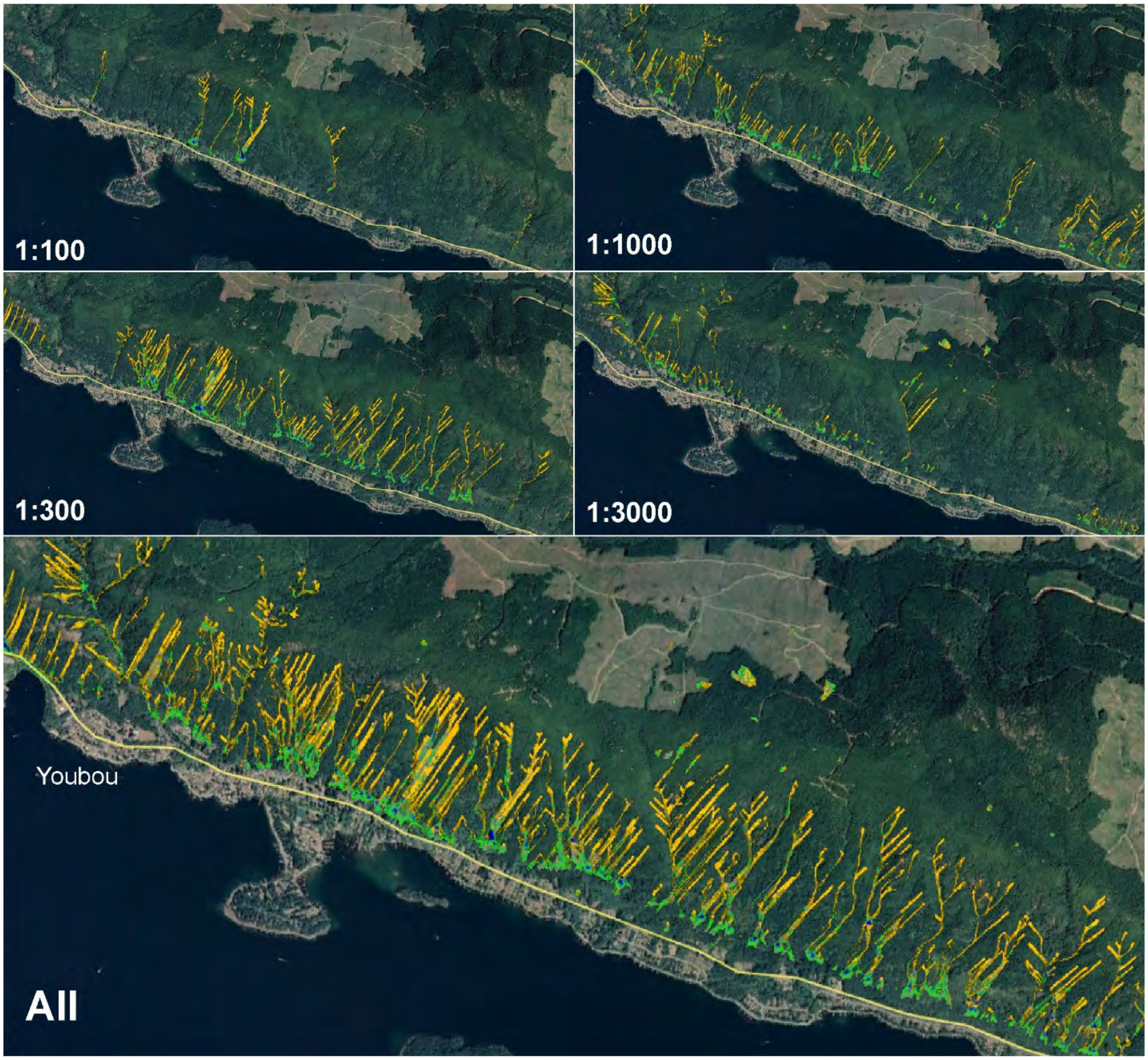

Figure 4-6. Model landslide runs on the North Shore of Cowichan Lake. Return period numbers refer to the Encounter Probability of terrain polygons within which landslides were initiated. Yellow zones are largely scour and green and blue zones are largely deposition. Background imagery from Google Earth.

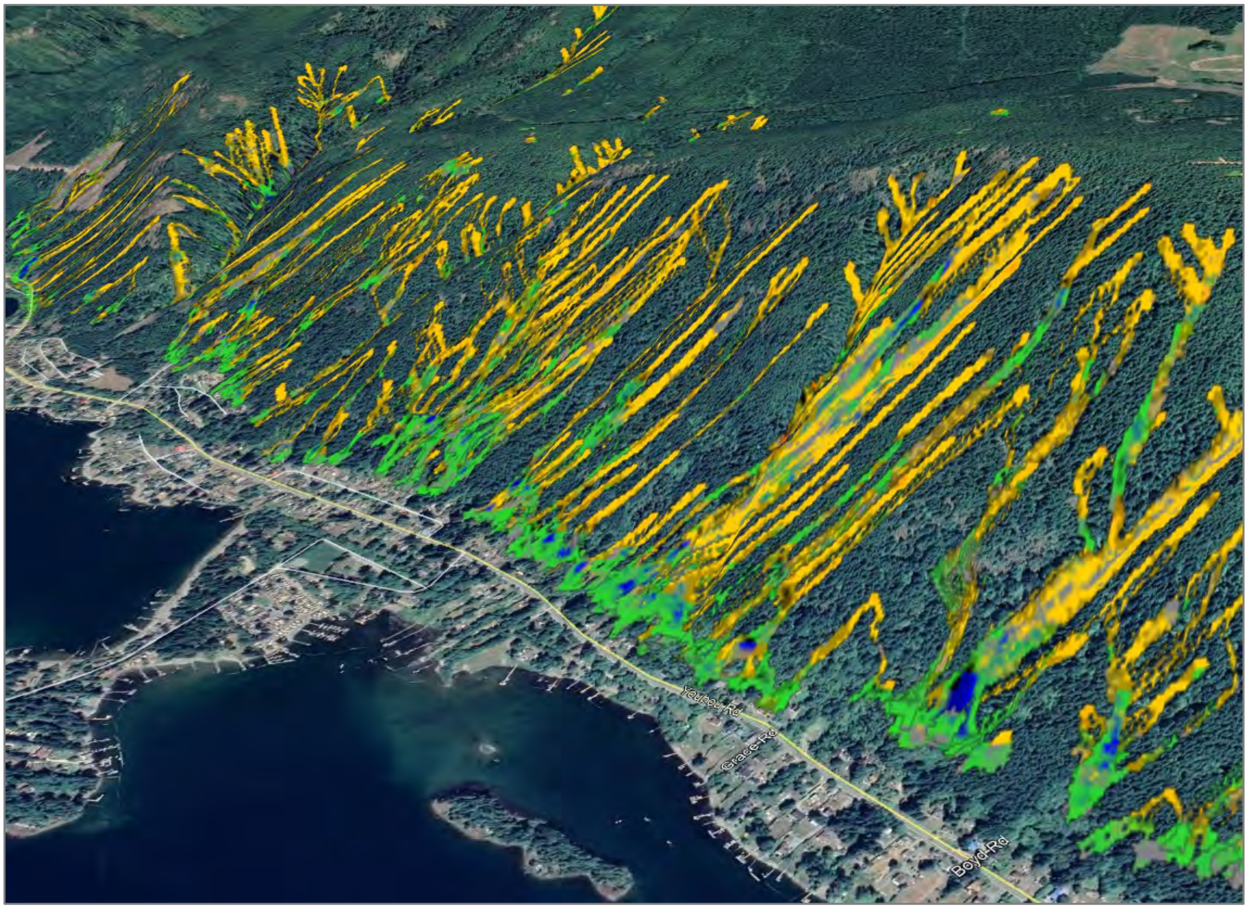

Figure 4-7. Oblique view of Youbou and the houses along the North Shore of Cowichan Lake with modeled landslides. Each landslide path represents the cumulative footprint of 50 model runs.

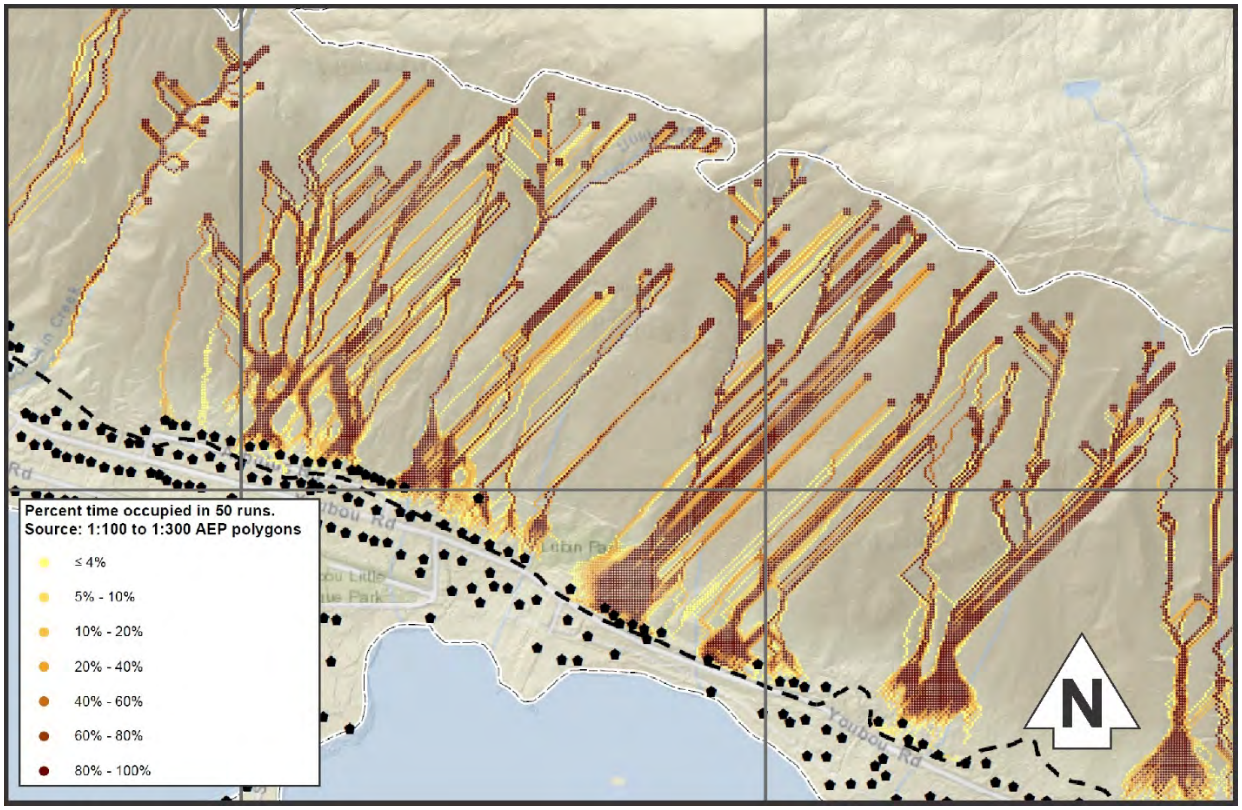

Figure 4-8. Landslide runout map detail showing properties and modeled landslide runout in Youbou. Map shows the percentage of the time landslides from 1:100 and 1:300 Annual Encounter Probability polygons (Palmer, 2018) occupied a position on the landscape. Details are in Appendix B.

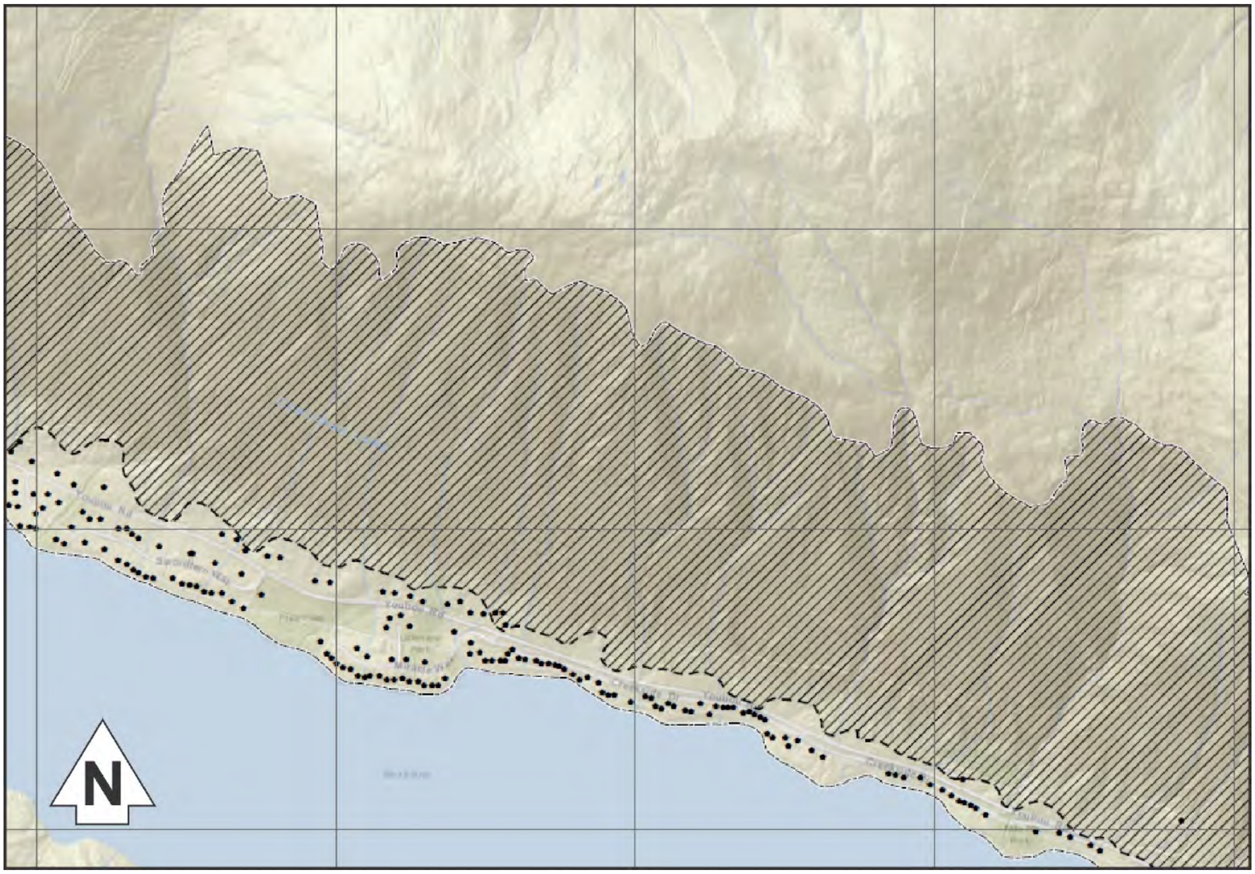

Figure 4-9. The distal limit of modeled runout for a portion of the North Shore of Cowichan Lake. Details are in Appendix C.

4.3 DAMAGE

The probability of damage due to debris flows and debris avalanches has been discussed by several authors and can be modeled empirically (Jakob, Stein, & Ulmi, 2012; Papathoma-Kohle, Keiler, Totschnig, & Glade, 2012), analytically (Corominas, et al., 2014; Mavrouli, et al., 2014), or using engineering judgement (Winter, et al., 2014). Ciurean et al. (2017) developed an analytical method that required only depth, and compared favorably to both empirical and analytical methods previously developed. That method is followed here.

To estimate the potential impact of debris flows or debris avalanches that were modeled to reach buildings, a damage class was assigned to each polygon based on estimated landslide depth (from LABS). The damage classes are described in Table 4-1 and potential degree of loss is shown in Figure 4-10 for different classes of buildings.

An example detail of the damage map is shown for the town of Youbou in Figure 4-7, and the full map is provided in

Table 4-1. Assigned Debris Flow Damage Classes (Vulnerability)

Damage Class	Description
0	Scour and transportation zones. Buildings assumed not present. Damage class 0 is blue on the Damage maps in Appendix B
1	Debris flow runout depth < 0.5 m
2	Debris flow depth generally between 0.5 and 1.5 m
3	Debris flow depth generally between 1.5 and 2.5 m
4	Debris flow depth generally > 2.5 m

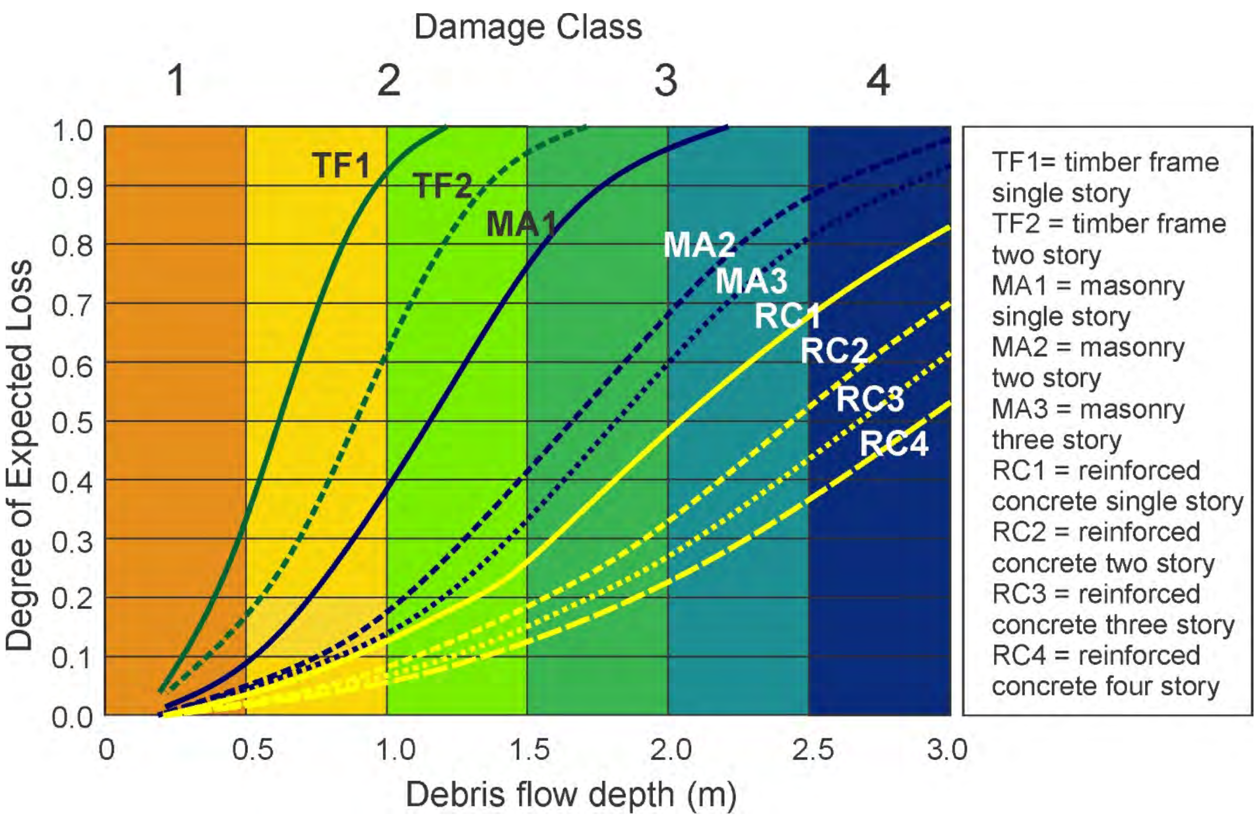

Figure 4-10. Vulnerability identified by degree of expected loss for constructed buildings by debris flow depth (Ciurean, et al., 2017). Colors match Damage Maps in Appendix D.

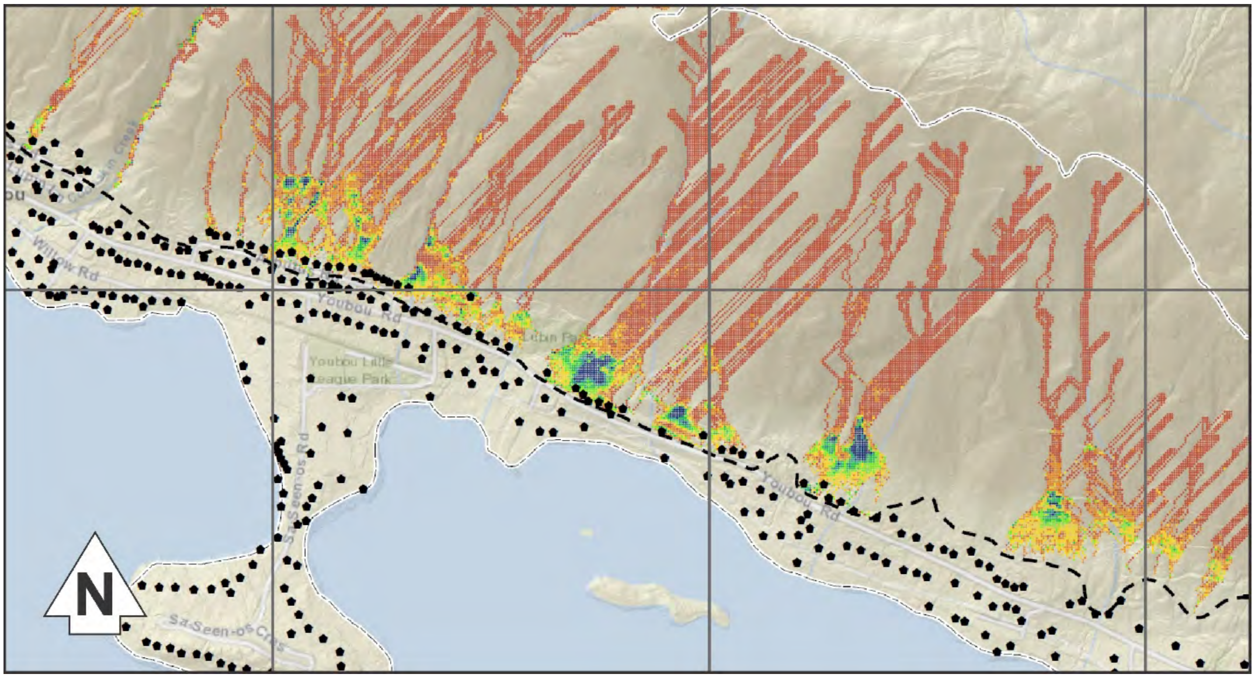

Figure 4-11. Landslide damage map detail showing properties and modeled landslide runout in Youbou. Damage classes are assigned by color per Figure 4-10. Details in Appendix D.

4.4 FLOOD HAZARDS

Debris floods can mobilize large quantities of sediment and often occur concurrently with debris flows, driven by large storms. Similarly, landslide dam outburst floods can occur when a channel is temporarily blocked and overflow or collapse results in the sudden release of water and debris. Debris floods and landslide dam outburst floods both have the potential to transport large volumes of sediment to more distal locations on the fans. Though generally less damaging than debris flows, debris floods may be 2-3 times the peak discharge of the comparable clear water flood (Hungr & Picarelli, 2014).

The Damage Class maps in Appendix D can be used to determine which channels are likely to become clogged with debris. Youbou Creek, Coonskin Creek, Swordfern Creek, 77-Mile Creek, and Meade Creek, are all repositories for landslides that occur in their watersheds. Based on the Exceedance Probability maps in Appendix A, Meade Creek landslides will accumulate less frequently.

Periodic inspection of the channels will help inform their condition.

4.5 FUTURE CHANGES

Ebbwater and Palmer (2019) referenced an assumed order of magnitude increase in the Hazard component of the risk equation due to future land use change and/or climate change. Both could indeed increase landslide frequencies in the watershed, however, neither are likely to result in landslide frequencies in excess of what was modelled in this study.

With respect to climate change, modeled results should be resistant to expected future changes.

5.0 CONCLUSIONS

Landslide runout software, LABS, was employed on the North Shore of Cowichan Lake to better refine the hazard model (Palmer, 2018) and the geohazard risk assessment (Ebbwater and Palmer, 2019) per the recommendations made by both. Indeed, this report meets the top two section 10.5 (refinement of technical assessment) objectives in the risk assessment, and to some extent, the 10.1 objective (address the extreme risk to life) in doing so.

In order to better discretize potential impacts from landslide runout, 68,200 landslides from 1,364 separate initiation locations, were initiated on the slopes above the North Shore.

With some exceptions, the cumulative footprint of modeled landslides did not reach most residential homes on the paraglacial fans.

The exceptions are easily identified on the maps provided in the Appendices B through D.

With over 68,000 landslide runs, the probability that a modeled debris flow will exceed the distal limit indicated on the maps is less than 0.000015.

Properties above (north) of the distal limit of modeled runout can use the estimated Annual Encounter Probability and Damage Curves to inform subsequent investigation.

Despite the aforementioned, houses on the North Shore may be subject hazards that were not modeled here, such as rock fall hazards within the rock fall shadow, and debris flood and channelized debris flow hazards adjacent to steep creeks.

While debris floods were not assessed in this report, the potential for debris floods could be inferred from the results herein, and the morphometric classification provided in the Lake Cowichan and Youbou Slope Hazard Assessment (Palmer, 2018).

The model is not sensitive to projected climate change.

The model results are not intended to replace ground evidence of landslide hazards but are intended to provide a more comprehensive understanding of processes and credible outcomes.

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Appendix A TERMS AND CONDITIONS

USE OF THIS REPORT: This report has been prepared for the sole benefit of the Client or its agent and may not be used by any third party without the express written consent of Stantec and the Client. Any use which a third party makes of this report is the responsibility of such third party.

BASIS OF THE REPORT: The information, opinions, and/or recommendations made in this report are in accordance with Stantec's present understanding of the project as described by the Client. The applicability of these is restricted to the site conditions encountered at the time of the investigation or study. If the proposed project differs or is modified from what is described in this report or if the site conditions are altered, this report is no longer valid unless Stantec is requested by the Client to review and revise the report to reflect the differing or modified project specifics and/or the altered site conditions.

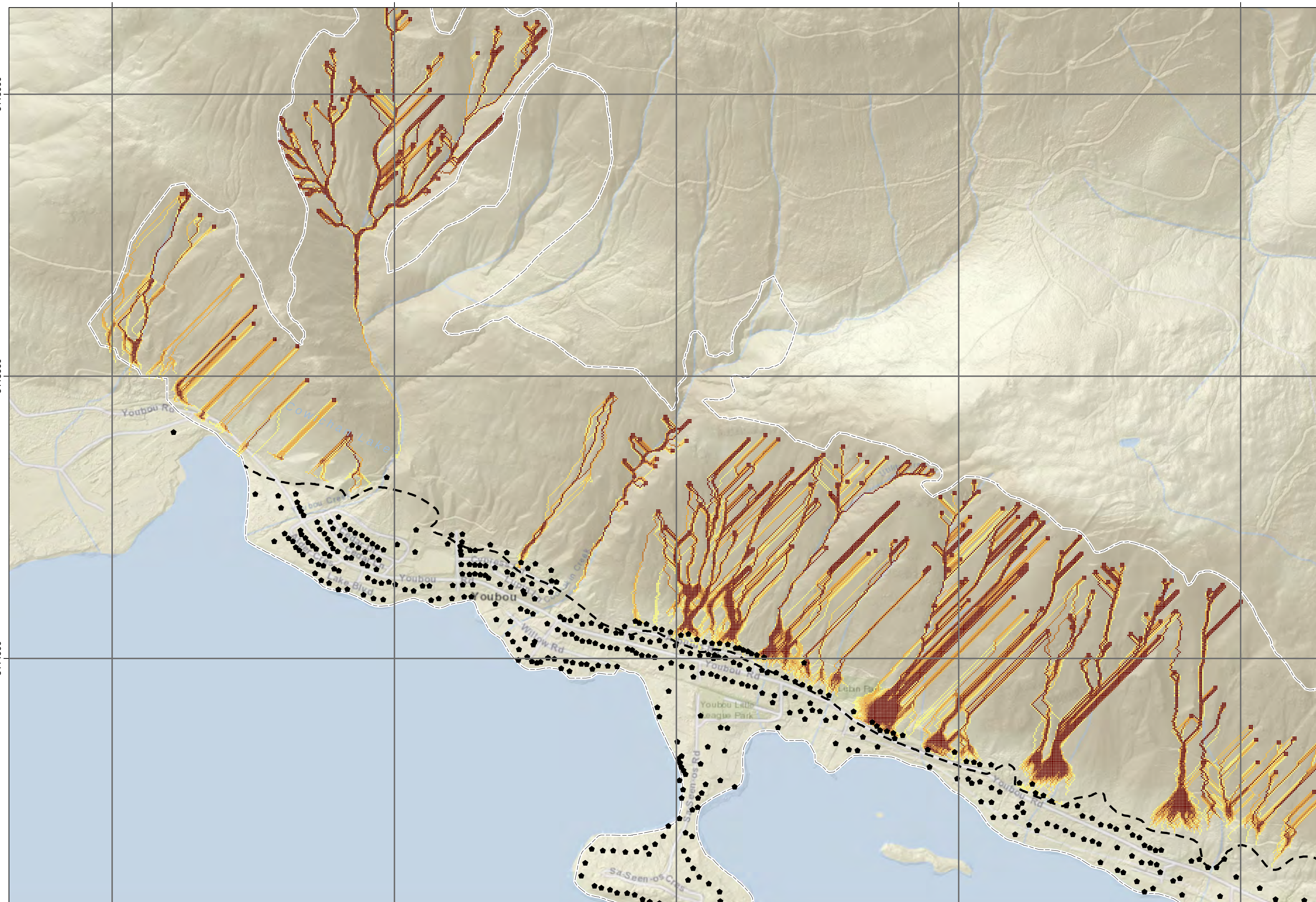
STANDARD OF CARE: Preparation of this report, and all associated work, was carried out in accordance with the normally accepted standard of care in the state or province of execution for the specific professional service provided to the Client. No other warranty is made.

INTERPRETATION OF SITE CONDITIONS: Soil, rock, or other material descriptions, and statements regarding their condition, made in this report are based on site conditions encountered by Stantec at the time of the work at field observation locations (i.e., specific sites, areas or traverses) and through interpretation of both digital air photos and LiDAR data. Classifications and statements of condition have been made in accordance with normally accepted practices which are judgmental in nature; no specific description should be considered exact, but rather reflective of the anticipated behaviour of materials or geomorphic processes. Extrapolation of in-situ conditions can only be made to some limited extent beyond the field observation locations. The extent depends on variability of the soil, surficial materials, bedrock, soil moisture and groundwater conditions as influenced by geological processes, construction activity, and land use.

VARYING OR UNEXPECTED CONDITIONS: Should any site or subsurface conditions be encountered that are different from those described in this report, Stantec must be notified immediately to assess if the varying or unexpected conditions are substantial and if reassessments of the report conclusions or recommendations are required. Stantec will not be responsible to any party for damages incurred as a result of failing to notify Stantec that differing site or sub-surface conditions are present upon becoming aware of such conditions.

PLANNING, DESIGN, OR CONSTRUCTION: Development or design plans and specifications should be reviewed by Stantec, sufficiently ahead of initiating the next project stage (property acquisition, tender, construction, etc.), to confirm that this report completely addresses the elaborated project specifics and that the contents of this report have been properly interpreted. Specialty quality assurance services (field observations and testing) during construction are a necessary part of the evaluation of sub-subsurface conditions and site preparation works. Site work relating to the recommendations included in this report should only be carried out in the presence of a qualified geotechnical engineer or geoscientist; Stantec cannot be responsible for site work carried out without being present.

Appendix B DEBRIS FLOW ENCOUNTER PROBABILITY FROM LANDSLIDES



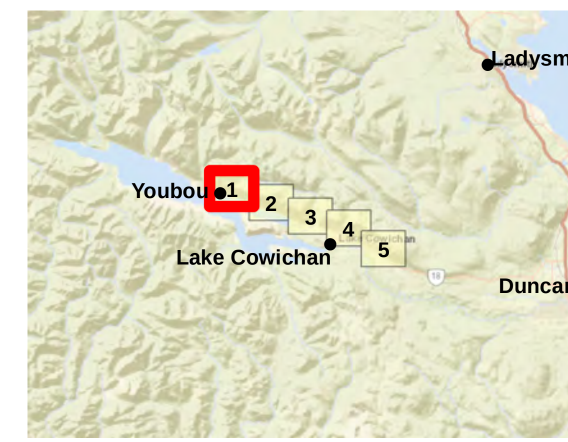
LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:100 and 1:300 AEP polygons

- ≤ 4%
- 5% - 10%
- 10% - 20%
- 20% - 40%
- 40% - 60%
- 60% - 80%
- 80% - 100%

Note: Model landslides initiated based on polygons mapped by Palmer (2018).
Building data provided by the Cowichan Valley Regional District



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Meters

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CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM	CHECKED: RG	PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:100 and 1:300 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

Palmer Stantec

The models used in this work incorporate peer-reviewed techniques to predict dynamic behavior in the physical world. There may be elements that are not known or available to Stantec that can affect predictions including local physical conditions that are not resolvable at the model scale, or inputs and interactions that arise dynamically through behavior that are not included in model dynamics.

- Stantec runs, where practical, multiple predictive simulations to identify credible outcomes. These probabilistic models do not mean that any particular outcome will occur in any real-world event, nor do they mean that unpredicted outcomes will not occur. The predicted outcomes are Stantec's best effort to identify the locations and magnitudes of the most credible events. Interpretation of these predictions require an understanding of these uncertainties, high level of subject matter expertise, and good professional judgment.
- Local topography smaller than the DEM resolution or not captured by the DEM (due to DEM quality or the difference between ground conditions when the DEM was captured and existing ground conditions) may affect the path selection or landslide behavior in a manner not resolvable by LABS.
- Landslide behavior including inundation, runout, scour, deposition, spread, and path selection, may vary from modeled behavior for several reasons including: stochastic variability in the landsliding process (natural or modeled), controlling factors that defy parameterization within the model, generalizations used to make the model practical and applicable across large areas.
- LABS simplifies extremely complex behavior to provide reasonable predictions of outcomes. Should there be a perceived difference between modeled results, and on-the-ground evidence, the ground-based evidence should take priority. LABS does not relieve professionals from using their experience, training and education to make good judgments when assessing actual ground conditions, but provides additional understanding of processes, and credible outcomes.

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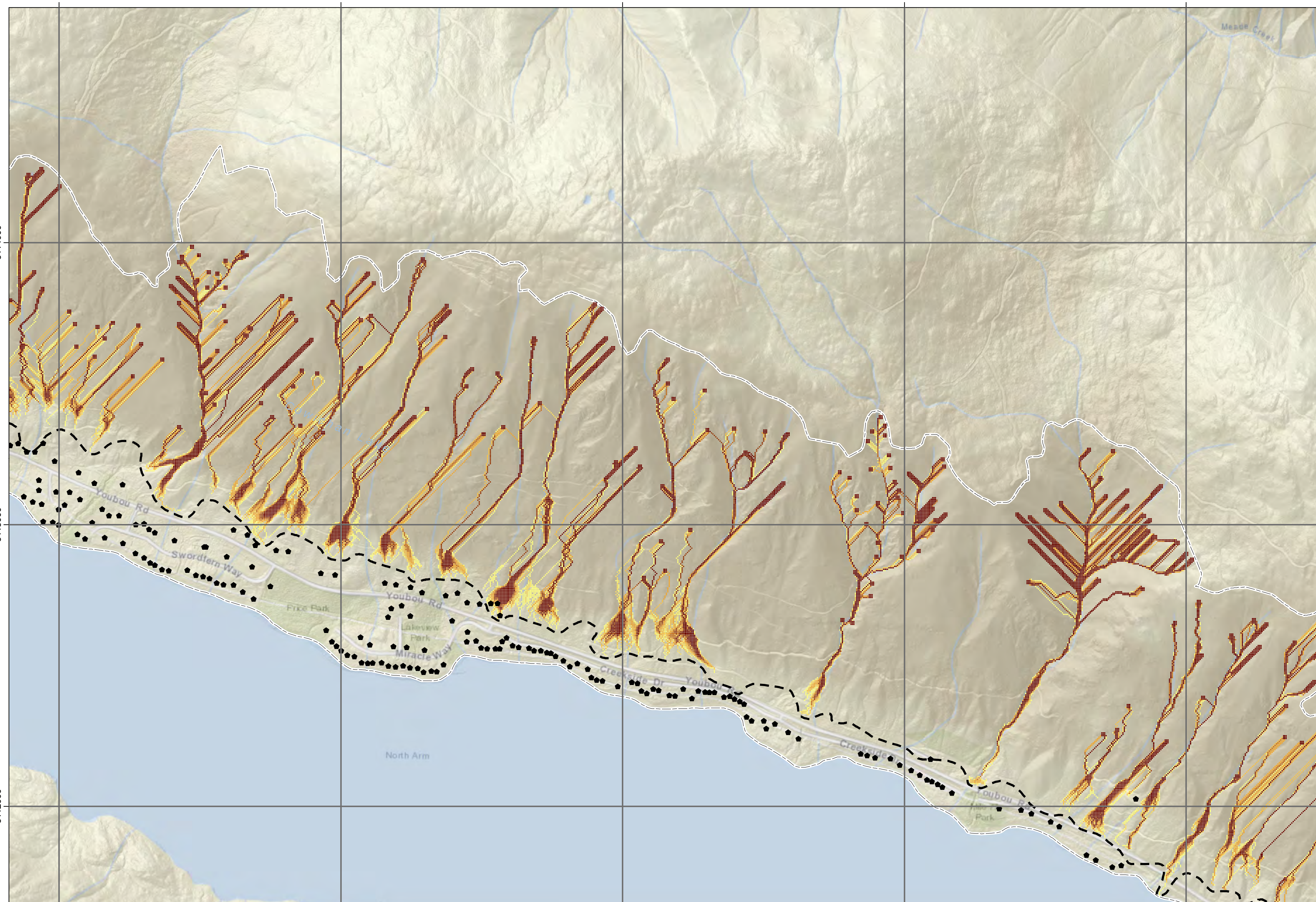

LEGEND:

- Building
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- Study Area

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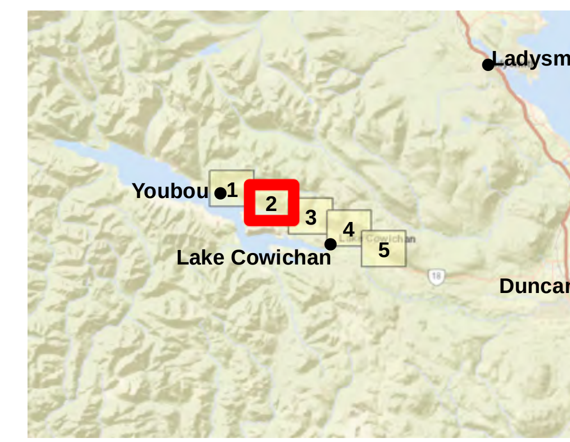

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CLIENT: Cowichan Valley Regional District

PROJECT: CVRD Rock Slide and Flood Assessment

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Debris Flow Encounter Probability from Landslides Initiated in 1:100 and 1:300 AEP polygons

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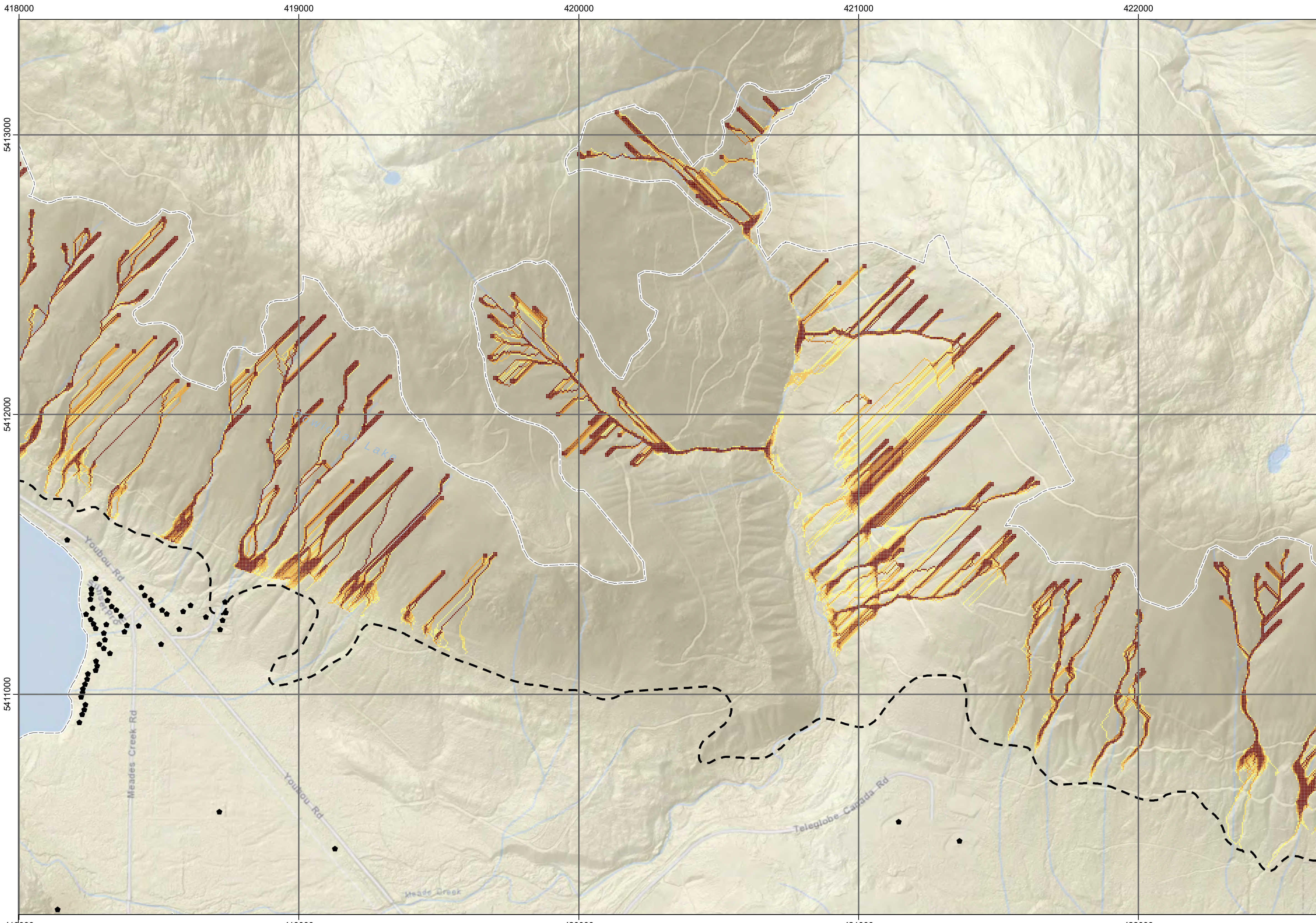

LEGEND:

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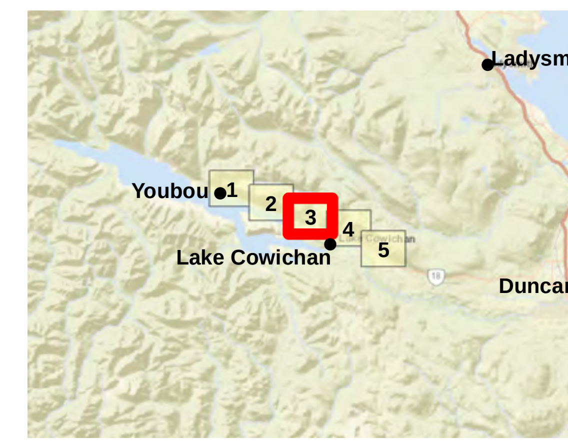

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PROJECT:
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DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:100 and 1:300 AEP polygons

Date: Jan 13, 2021
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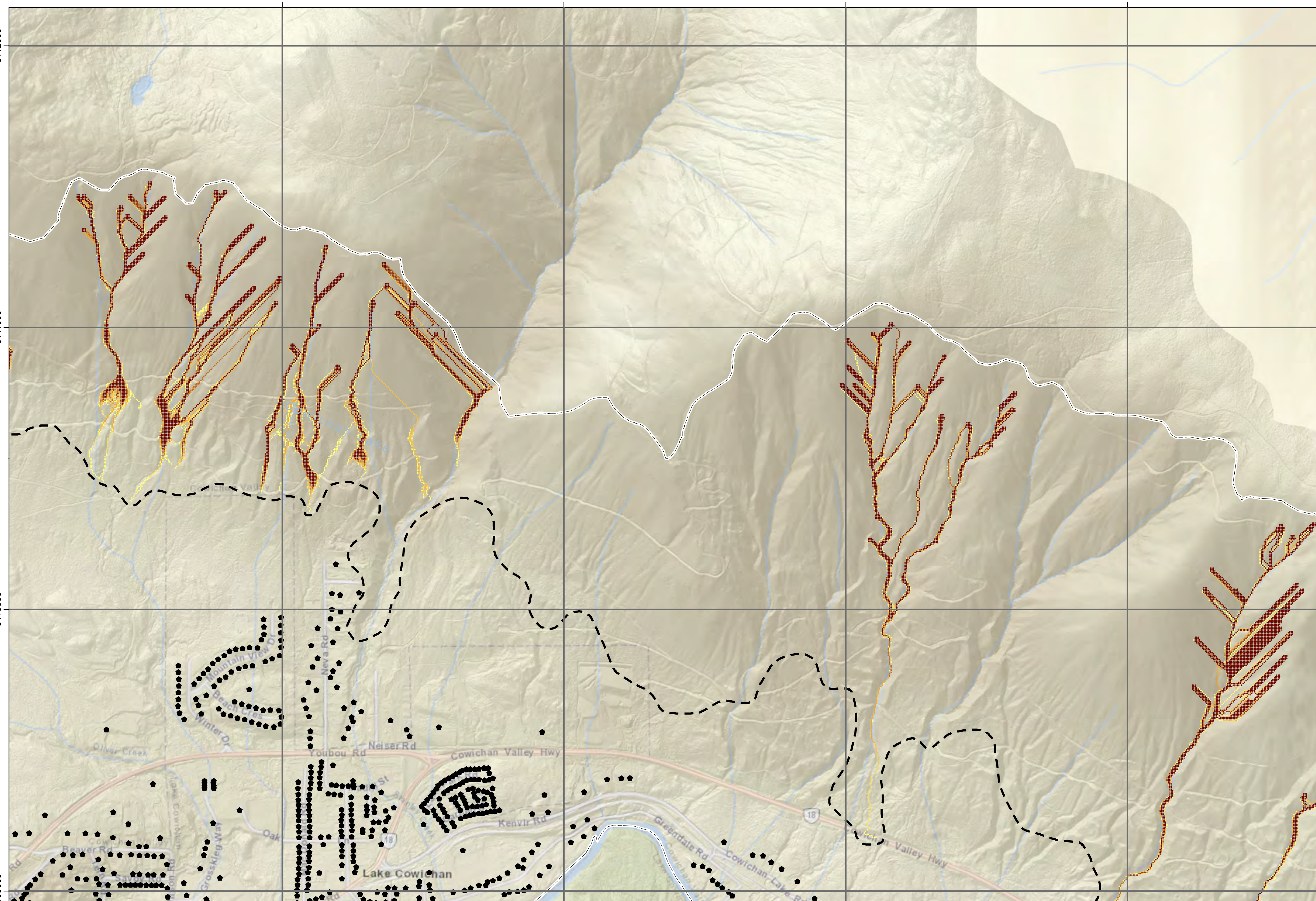

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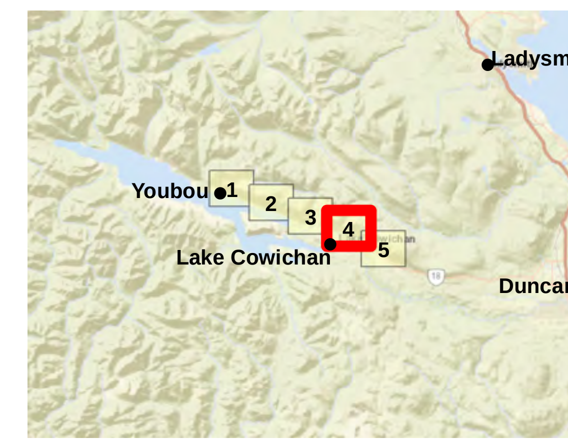

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CLIENT:
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Debris Flow Encounter Probability from Landslides Initiated in 1:100 and 1:300 AEP polygons

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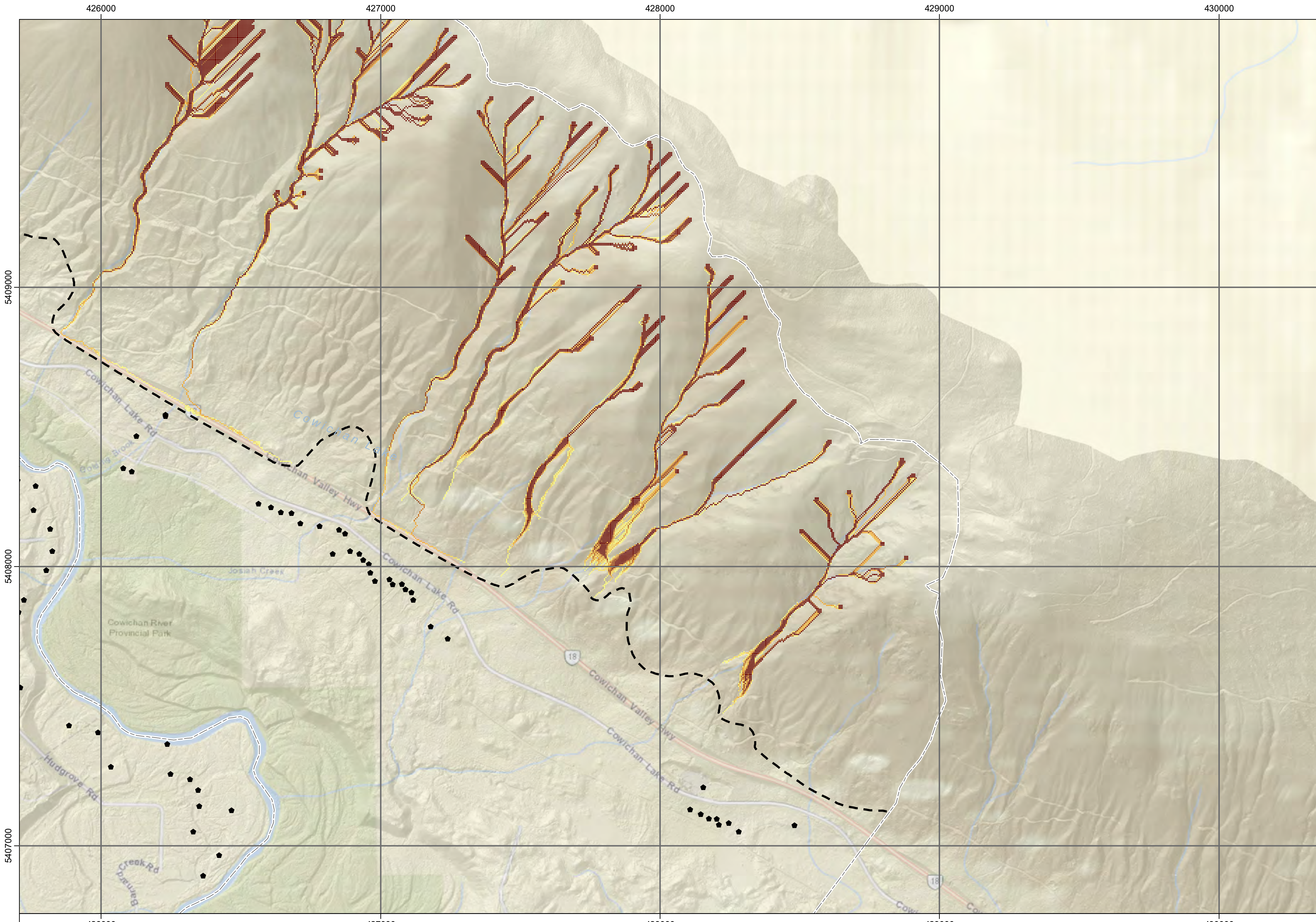

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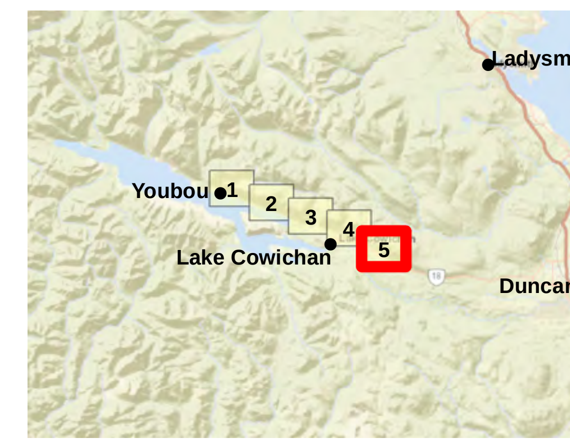

KILOMETRE SCALE:

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Meters

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CLIENT:
Cowichan Valley Regional District

PROJECT:
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DRAWN: CM | CHECKED: RG | PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:100 and 1:300 AEP polygons

Date: Jan 13, 2021
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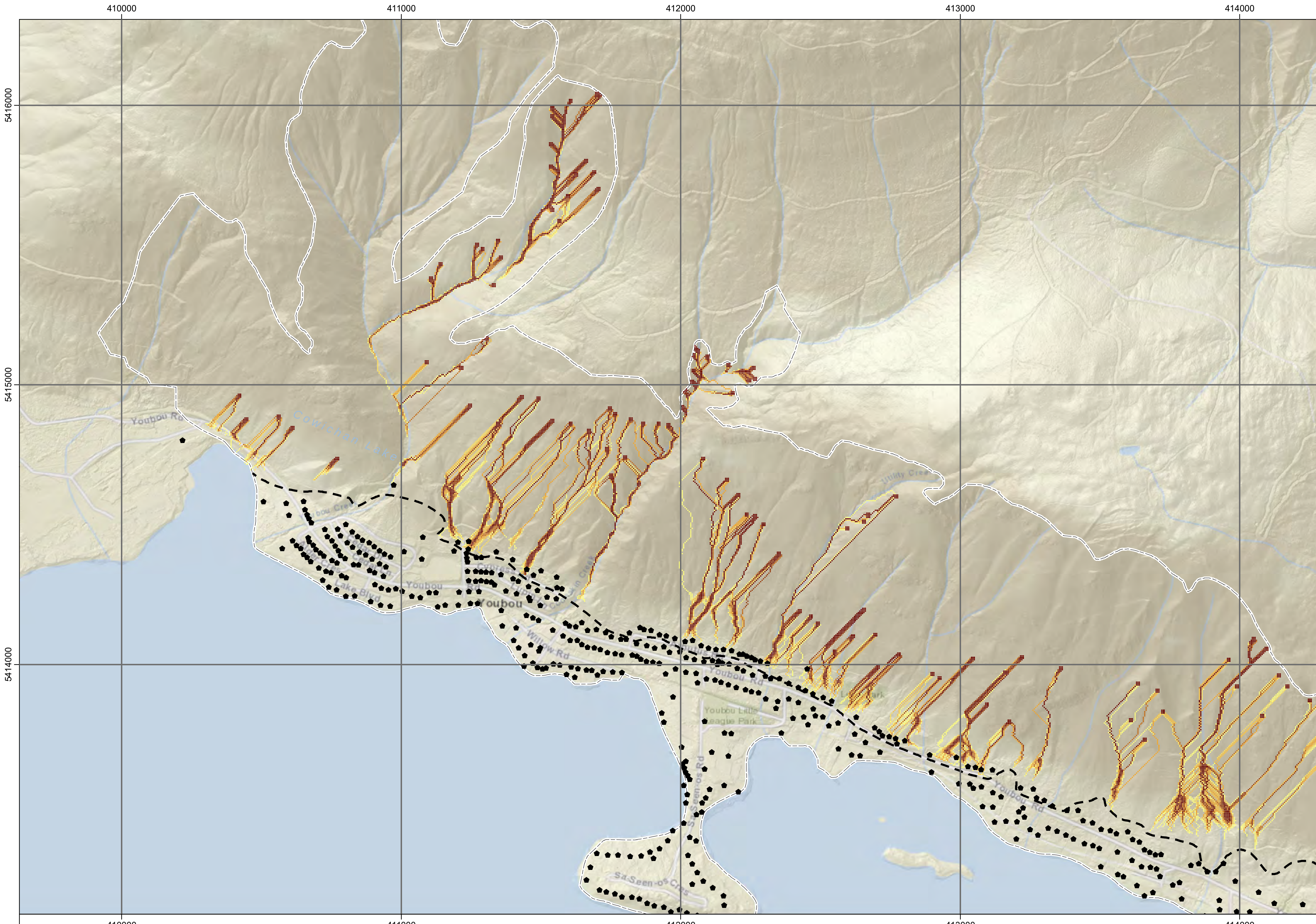
Document Path: G:\Shared drives\Projects 2019\19049 - CVRD\1904901 - Rockslide - Flood Assessment\Mapping\MXD\1904901_LABS_PercentTime.mxd



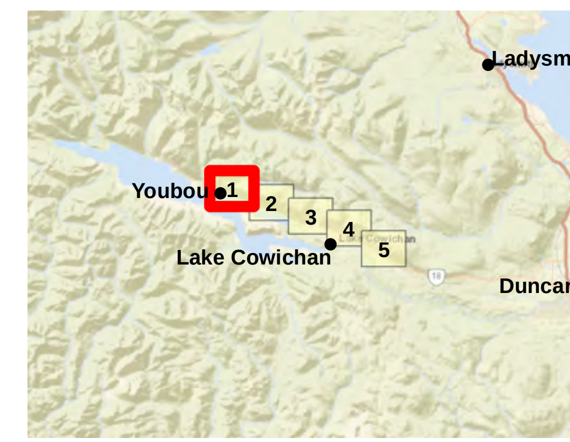
LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:1,000 AEP polygons

- ≤ 4%
- 5% - 10%
- 10% - 20%
- 20% - 40%
- 40% - 60%
- 60% - 80%
- 80% - 100%

Note: Model landslides initiated based on polygons mapped by Palmer (2018).
Building data provided by the Cowichan Valley Regional District



KILOMETRE SCALE:

0 500 1,000
Meters

N

UTM NAD83 Zone 10 1:15,000

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:1,000 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

1 of 5

Palmer Stantec

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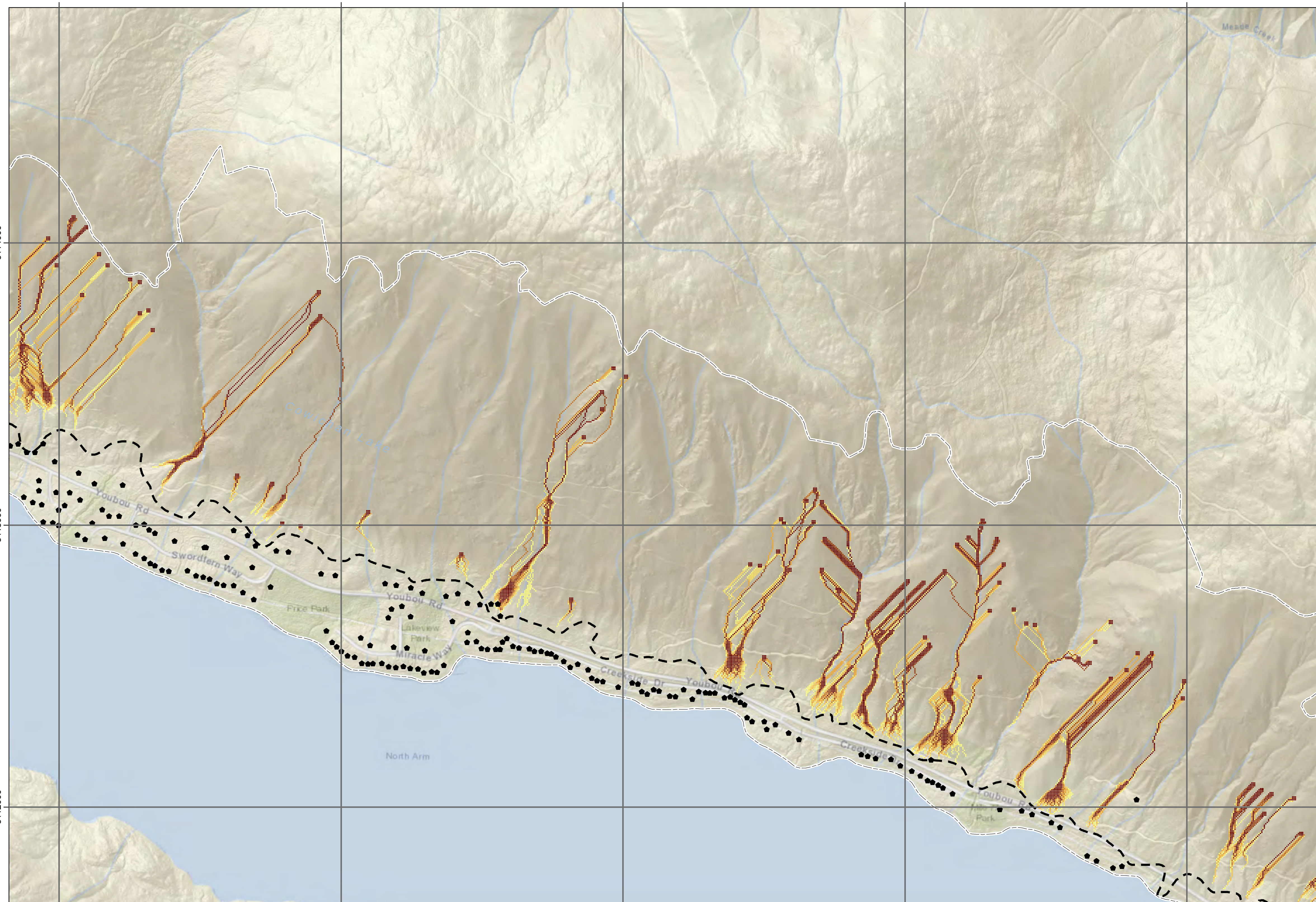

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:1,000 AEP polygons

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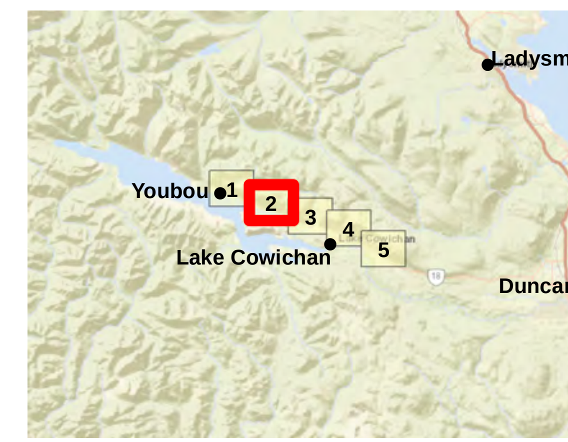

KILOMETRE SCALE:

0 500 1,000
Meters

UTM NAD83 Zone 10 1:15,000

N

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN:	CM	CHECKED:	RG	PRINT SIZE:	Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:1,000 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

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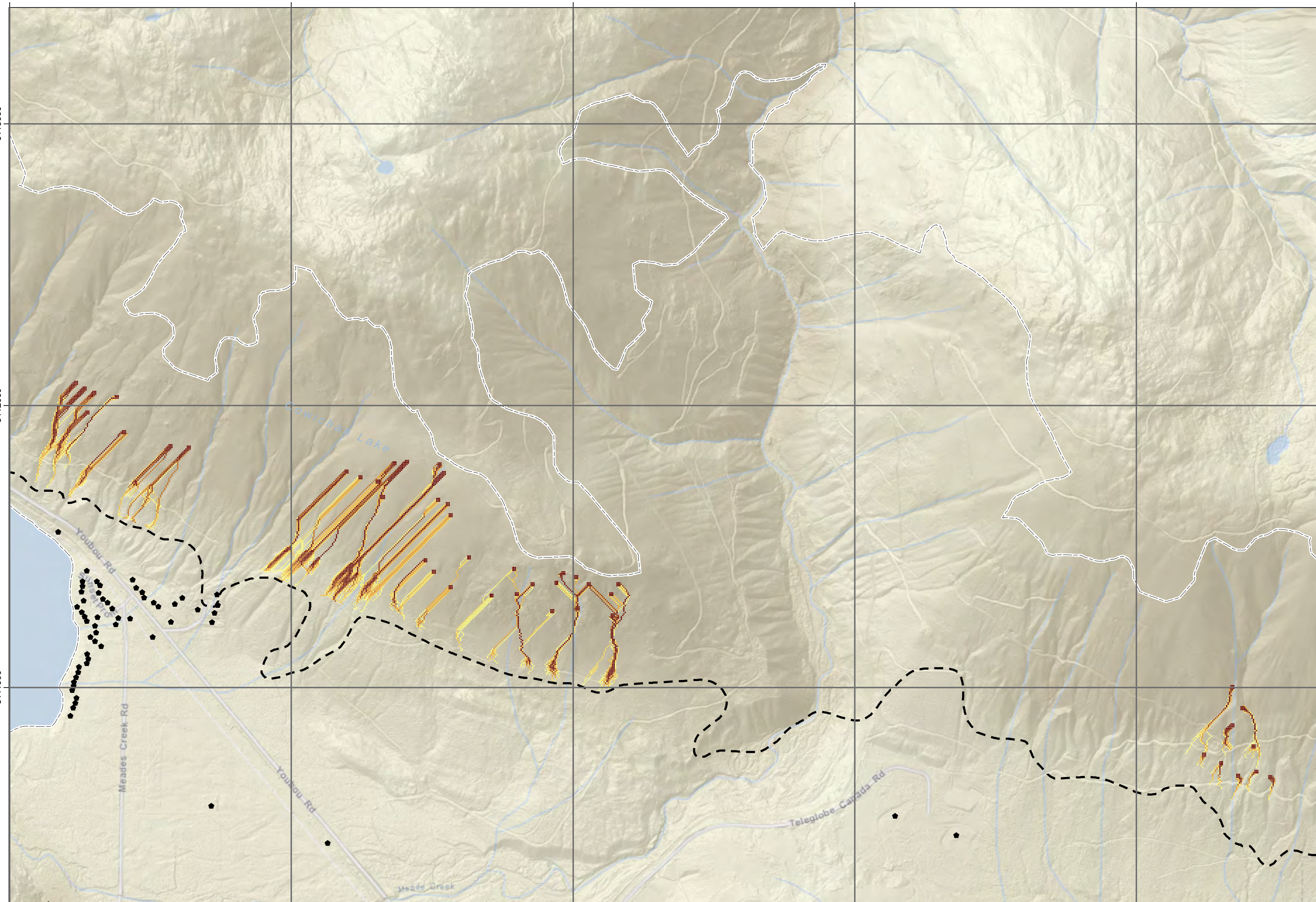

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:1,000 AEP polygons

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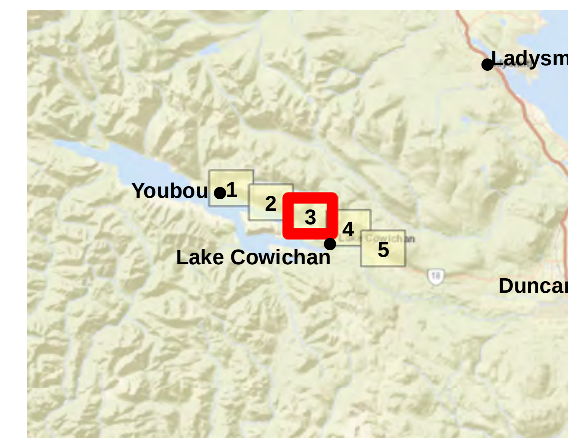

KILOMETRE SCALE:
0 500 1,000
Meters
UTM NAD83 Zone 10
1:15,000
N

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM | CHECKED: RG | PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:1,000 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

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Palmer Stantec

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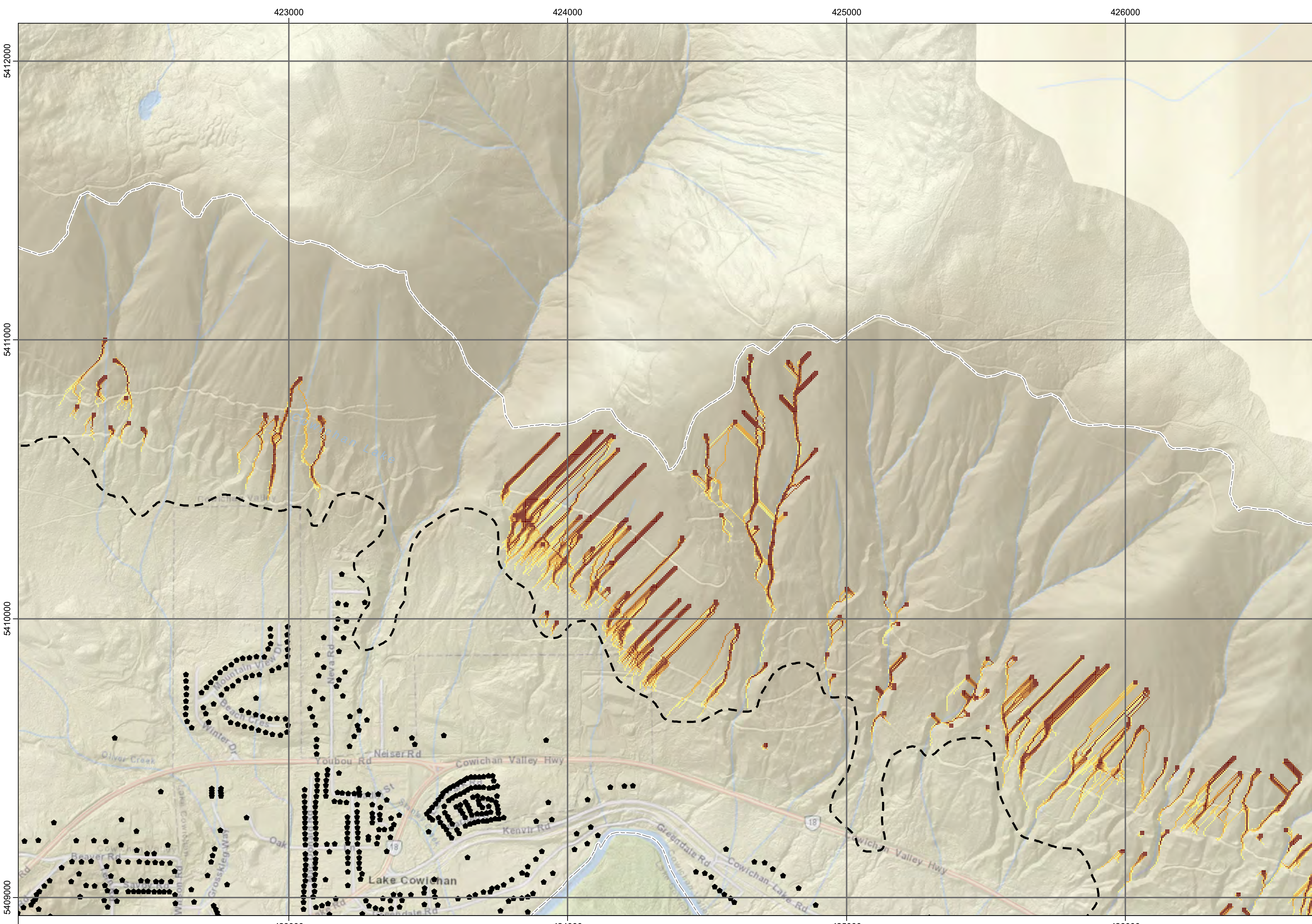

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:1,000 AEP polygons

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- 5% - 10%
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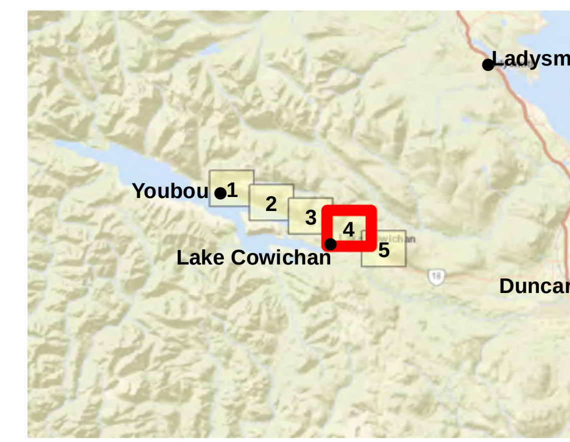

KILOMETRE SCALE:
0 500 1,000
Meters
UTM NAD83 Zone 10
1:15,000

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM	CHECKED: RG	PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:1,000 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

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Palmer
Stantec

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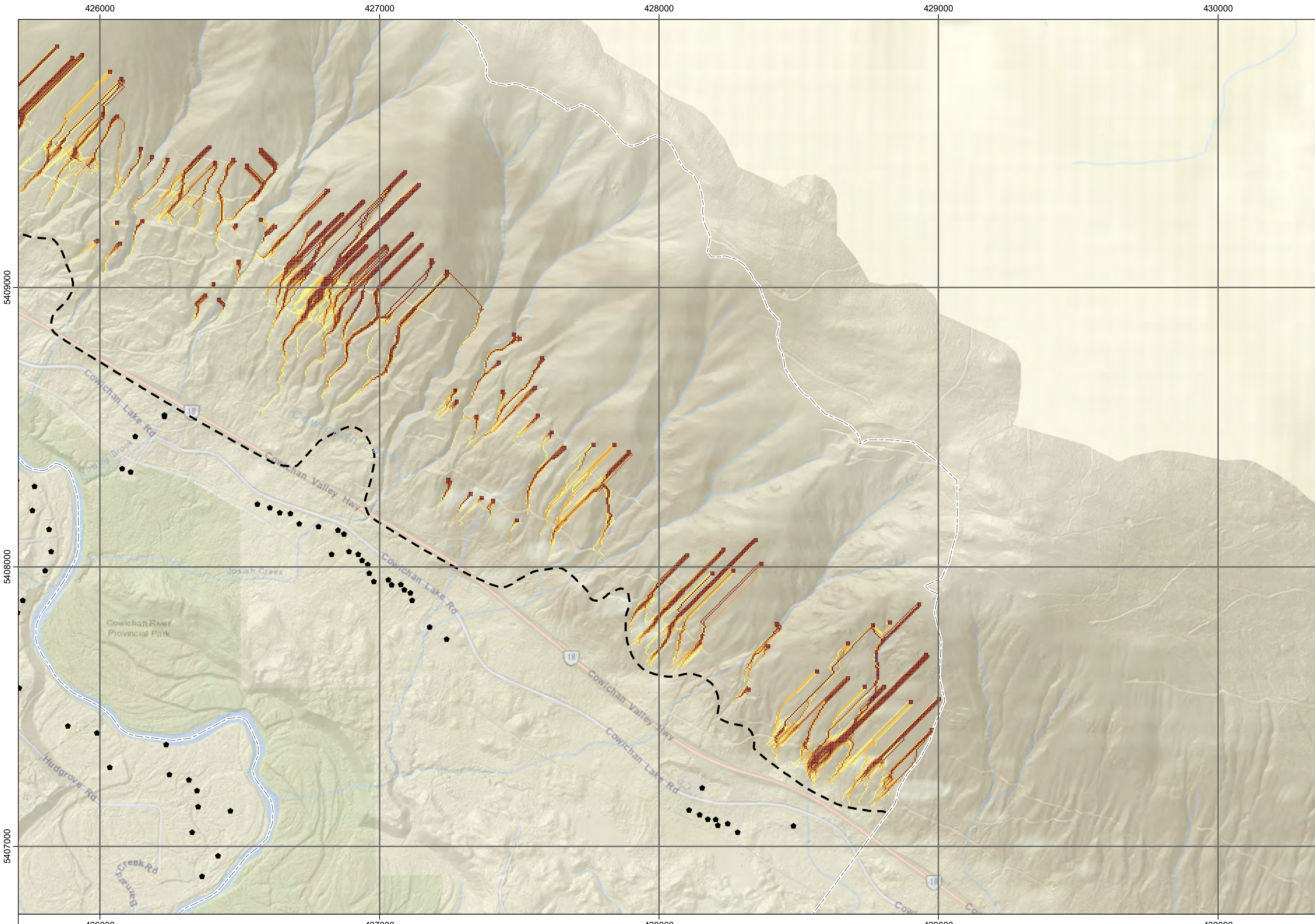

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:1,000 AEP polygons

- ≤ 4%
- 5% - 10%
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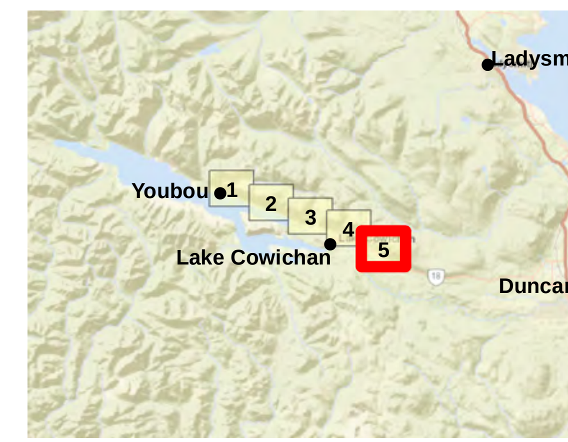

KILOMETRE SCALE:

0 500 1,000
Meters

N

UTM NAD83 Zone 10 1:15,000

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:1,000 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

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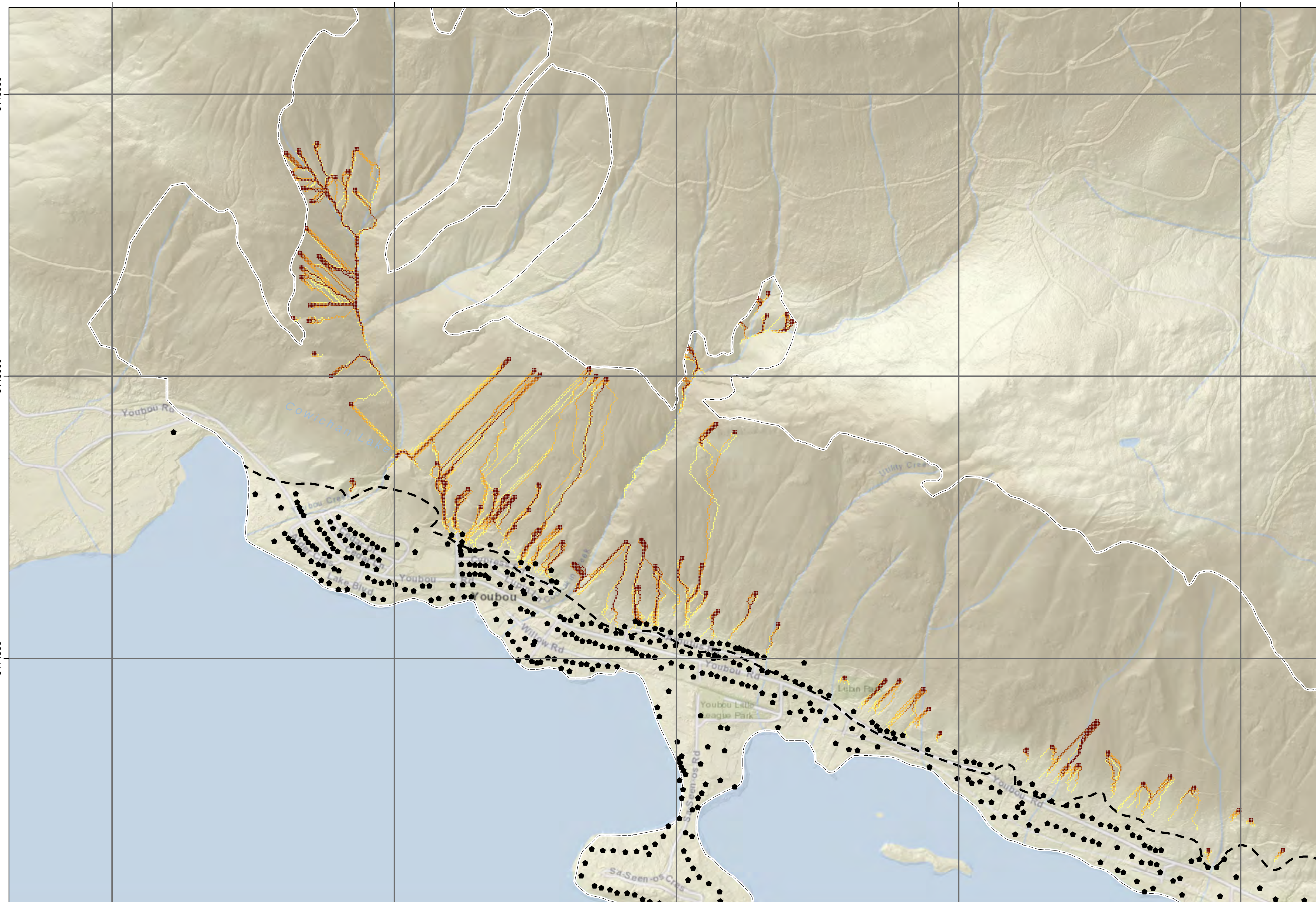

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:3,000 AEP polygons

- ≤ 4%
- 5% - 10%
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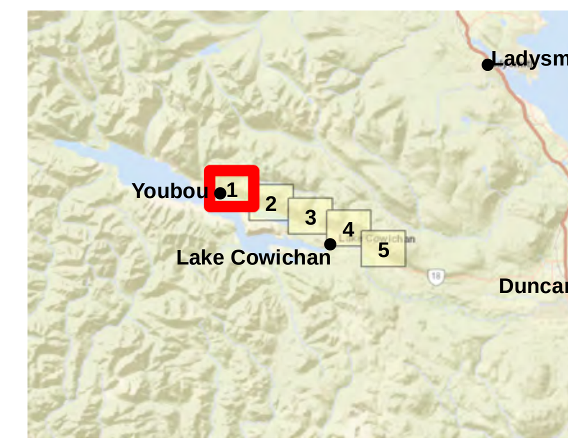

KILOMETRE SCALE:

0 500 1,000
Meters

UTM NAD83 Zone 10 1:15,000

N

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN:	CM	CHECKED:	RG	PRINT SIZE:	Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:3,000 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

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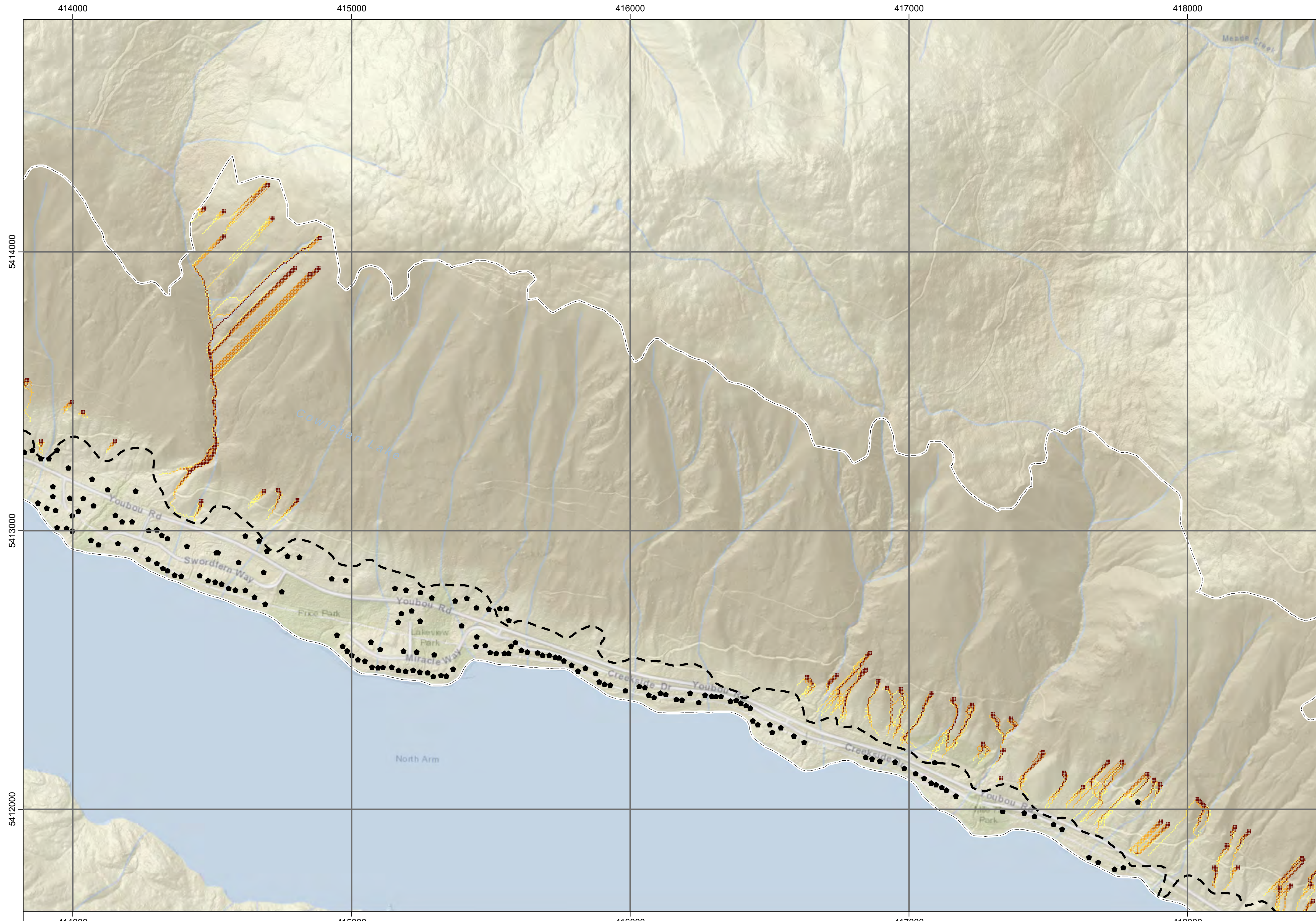

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:3,000 AEP polygons

- ≤ 4%
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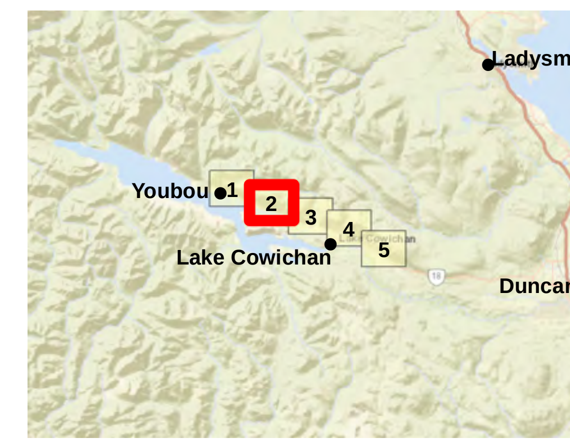

KILOMETRE SCALE:

0 500 1,000

Meters

UTM NAD83 Zone 10

1:15,000

N

CLIENT:

Cowichan Valley Regional District

PROJECT:

CVRD Rock Slide and Flood Assessment

DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:3,000 AEP polygons

Date: Jan 13, 2021
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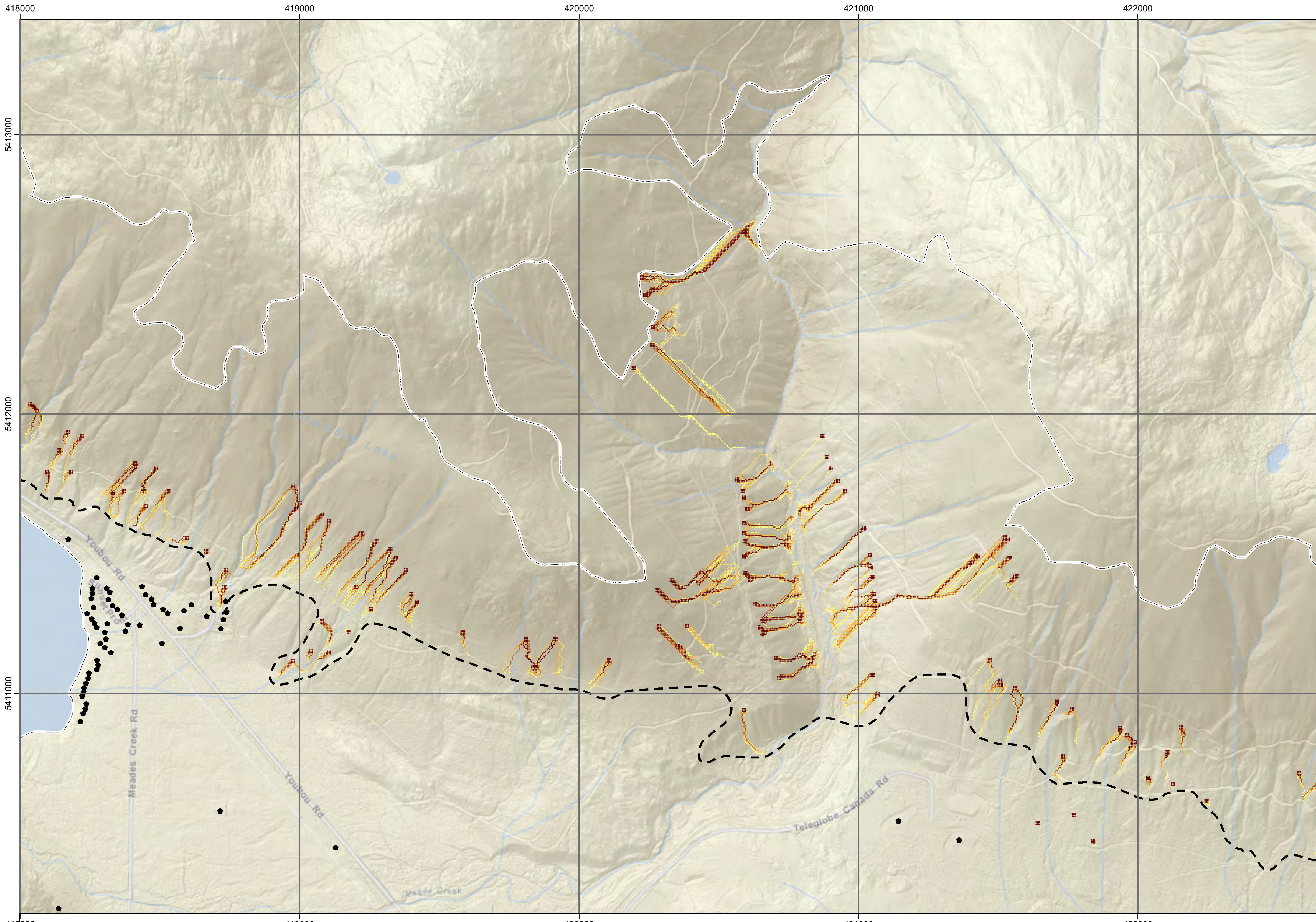

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:3,000 AEP polygons

- ≤ 4%
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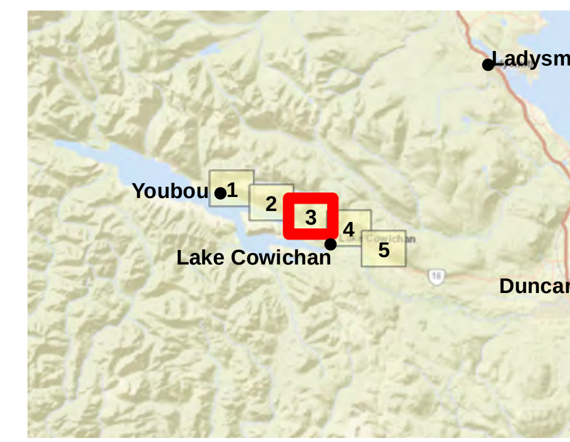

KILOMETRE SCALE:

0 500 1,000
Meters

N

UTM NAD83 Zone 10 1:15,000

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:3,000 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

3 of 5

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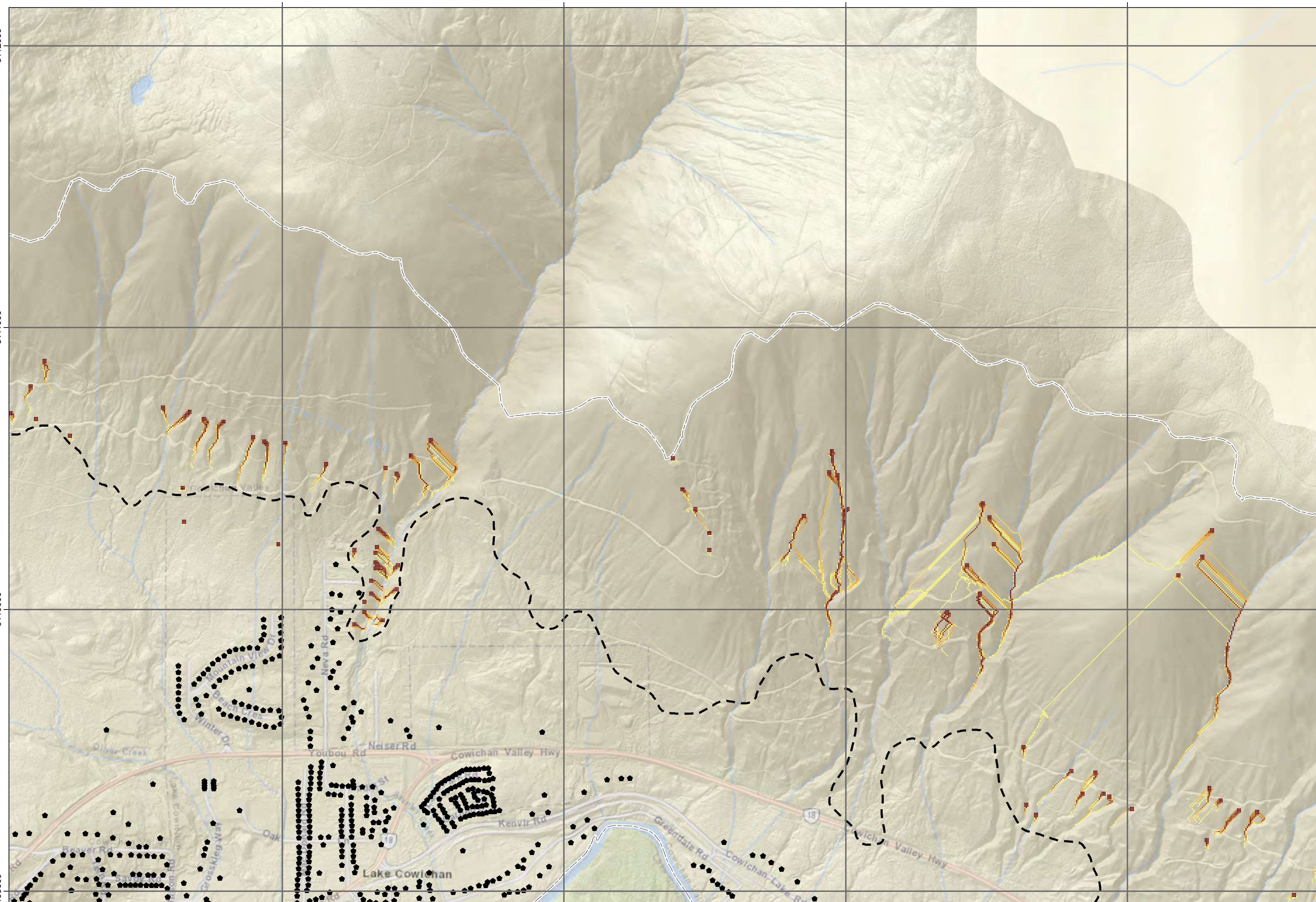

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:3,000 AEP polygons

- ≤ 4%
- 5% - 10%
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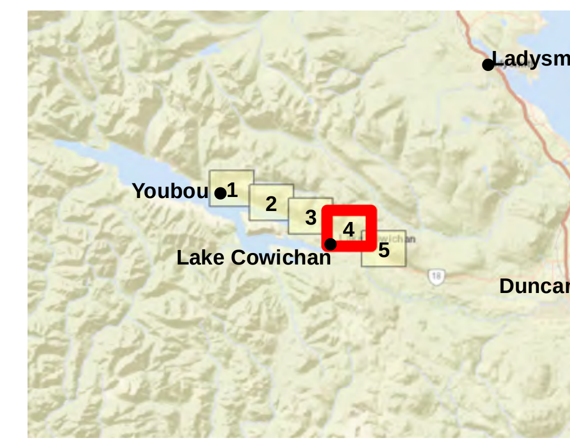

KILOMETRE SCALE:

0 500 1,000
Meters

UTM NAD83 Zone 10 1:15,000

N

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM	CHECKED: RG	PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:3,000 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

4 of 5

Palmer Stantec

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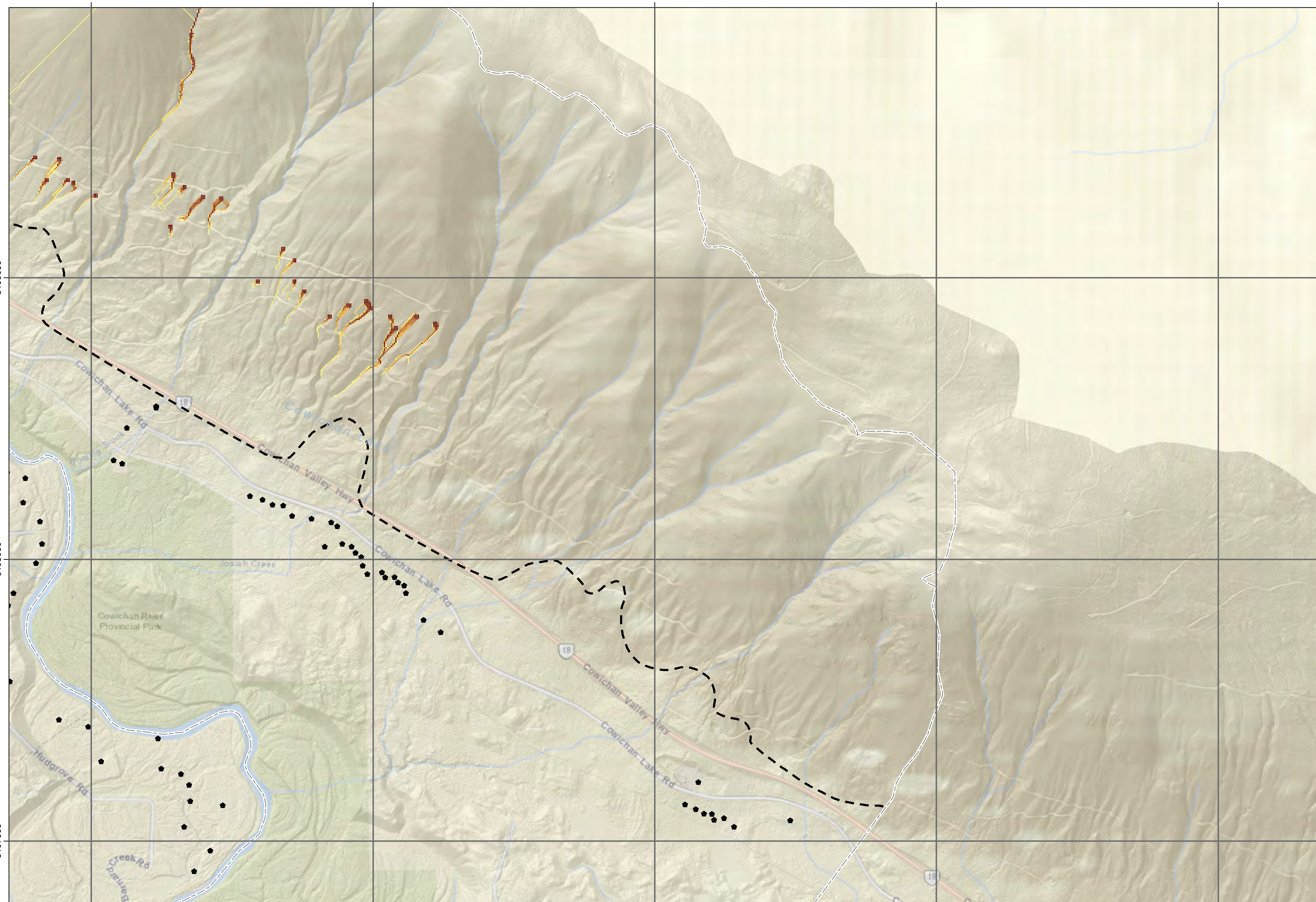
Document Path: G:\Shared drives\Projects 2019\19049 - CVRD\1904901 - Flood Assessment\Mapping\MXD\1904901 - Rockslide - 1904901_LABS_PercentTime.mxd



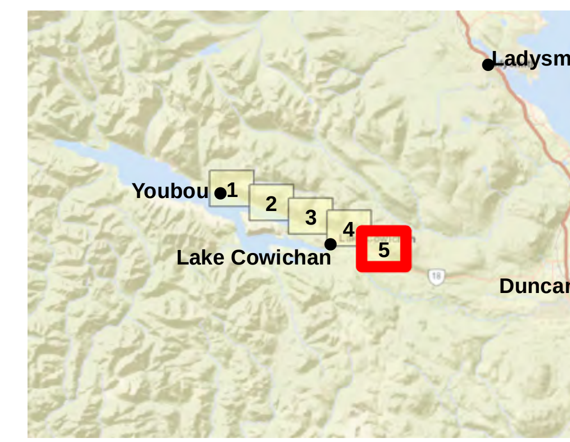
LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Percent time occupied in 50 runs.
Source: 1:3,000 AEP polygons

- ≤ 4%
- 5% - 10%
- 10% - 20%
- 20% - 40%
- 40% - 60%
- 60% - 80%
- 80% - 100%

Note: Model landslides initiated based on polygons mapped by Palmer (2018).
Building data provided by the Cowichan Valley Regional District



KILOMETRE SCALE:

0 500 1,000
Meters

N

UTM NAD83 Zone 10 1:15,000

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM | CHECKED: RG | PRINT SIZE: Tabloid (11" x 17")

Debris Flow Encounter Probability from Landslides Initiated in 1:3,000 AEP polygons

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

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Palmer™ Stantec

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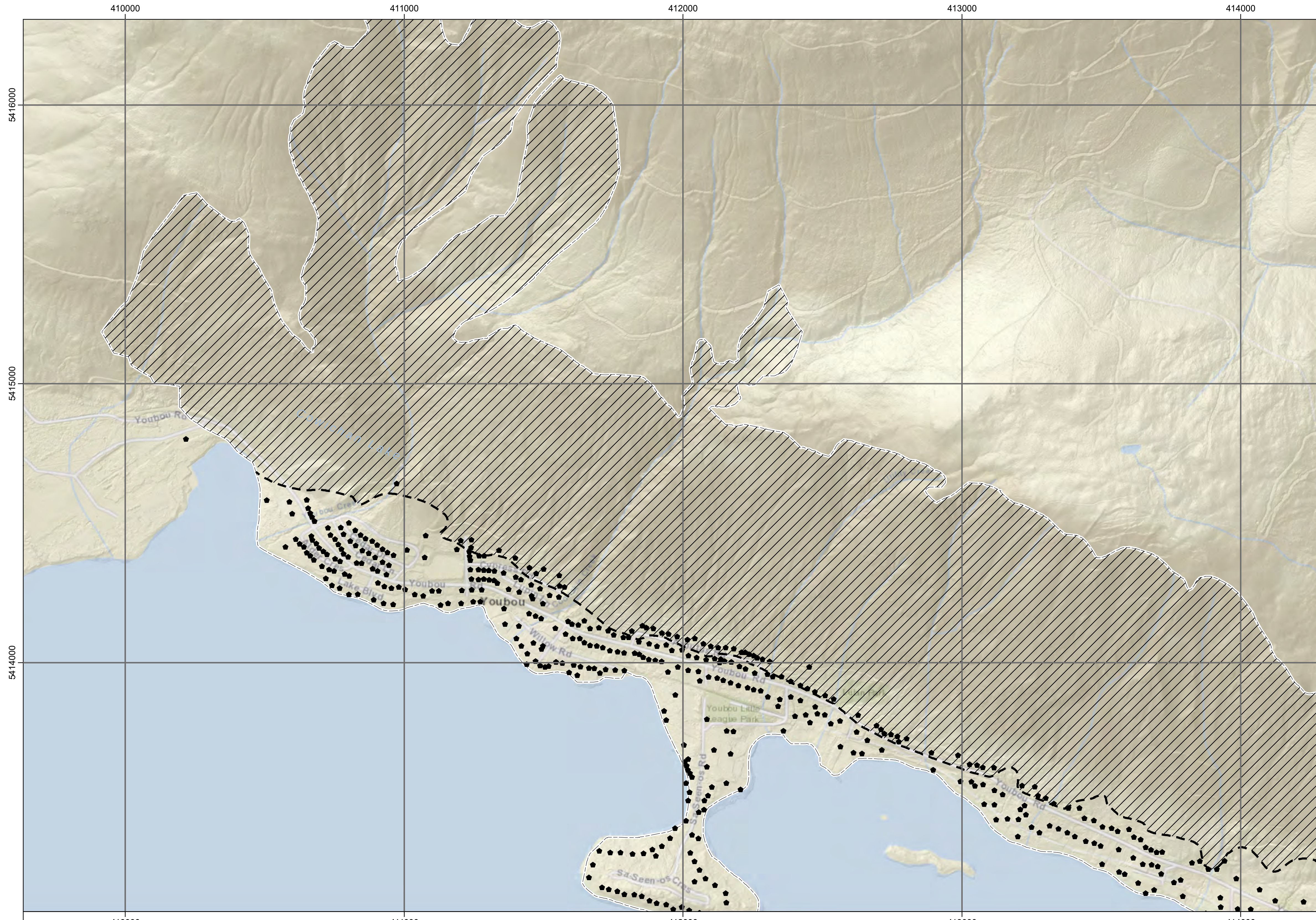
Document Path: G:\Shared drives\Projects 2019\19049 - CVRD\1904901 - Rockslide - Flood Assessment\Mapping\MXD\1904901_LABS_PercentTime.mxd

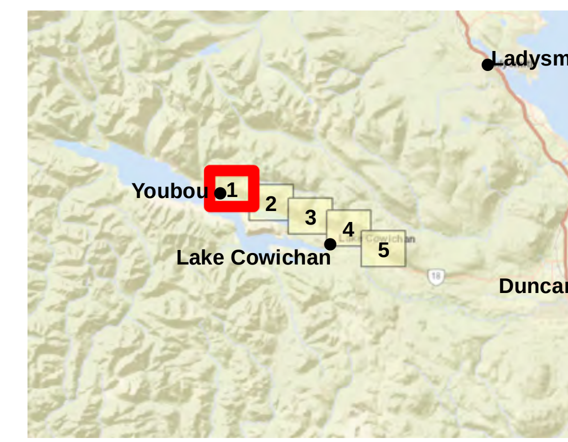
Appendix C LIMIT OF MODELED DEBRIS FLOWS USING LABS



LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study

Note: Model landslides initiated based on polygons mapped by Palmer (2018).
Building data provided by the Cowichan Valley Regional District



KILOMETRE SCALE:

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Meters

UTM NAD83 Zone 10 1:15,000

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CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM	CHECKED: RG	PRINT SIZE: Tabloid (11" x 17")

Limit of modeled debris flows using LABS

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

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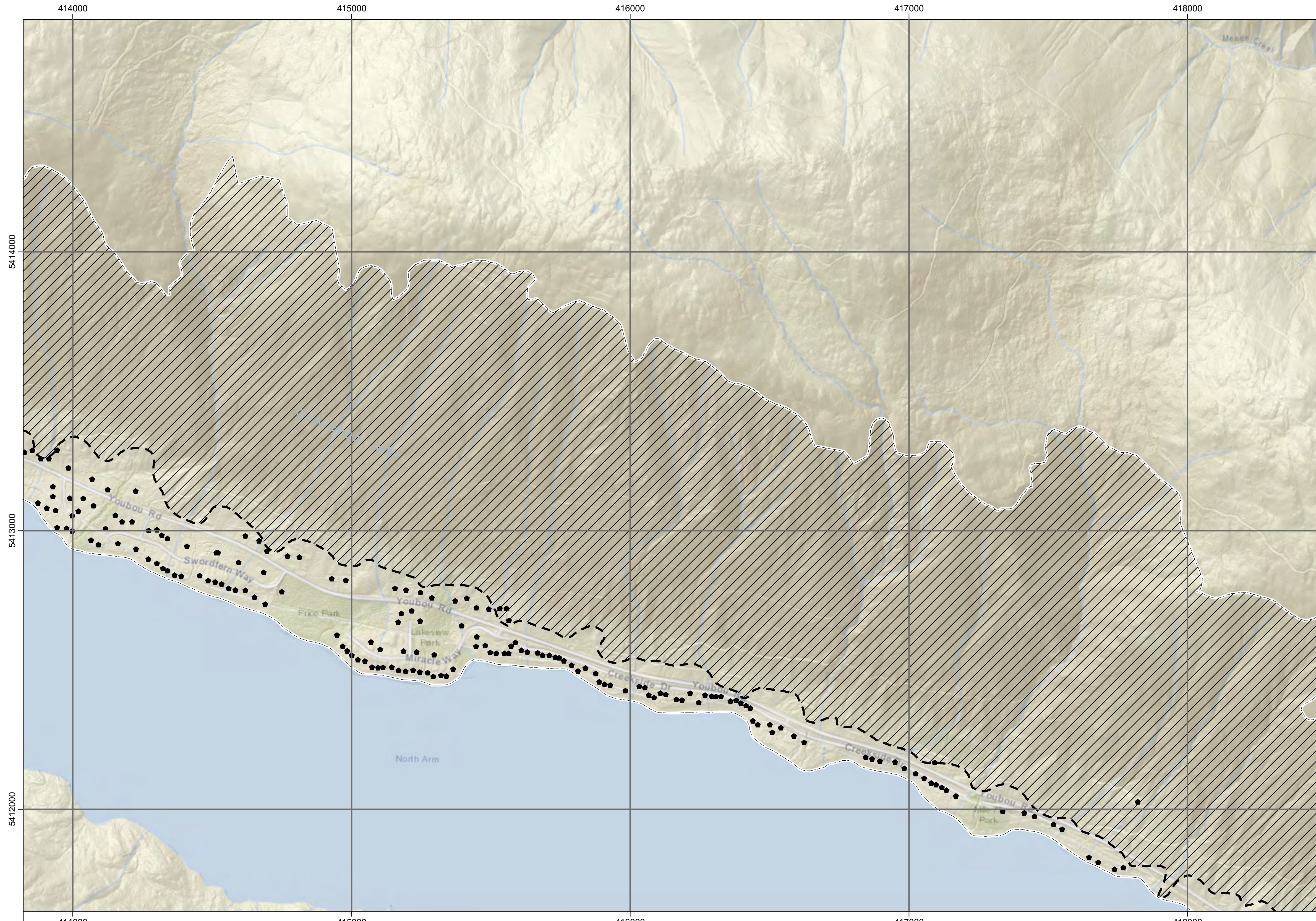
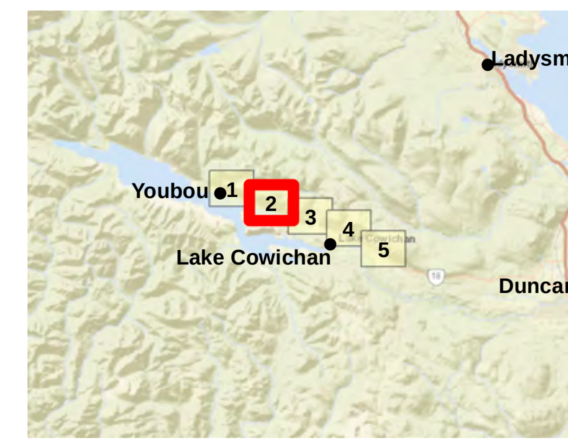


LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study

Note: Model landslides initiated based on polygons mapped by Palmer (2018).
Building data provided by the Cowichan Valley Regional District



KILOMETRE SCALE:

0 500 1,000
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UTM NAD83 Zone 10 1:15,000

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CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM	CHECKED: RG	PRINT SIZE: Tabloid (11" x 17")

Limit of modeled debris flows using LABS

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

2 of 5

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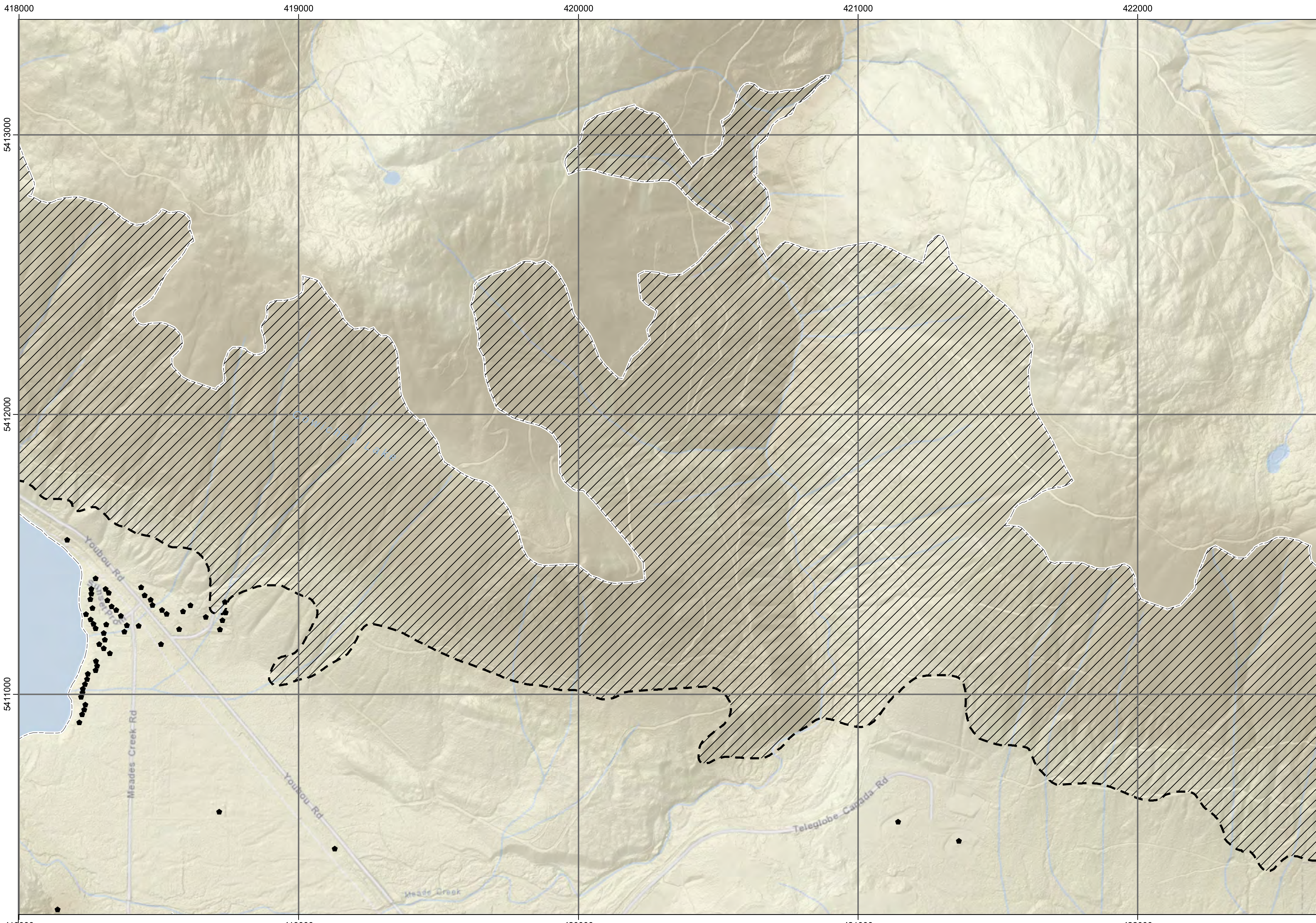
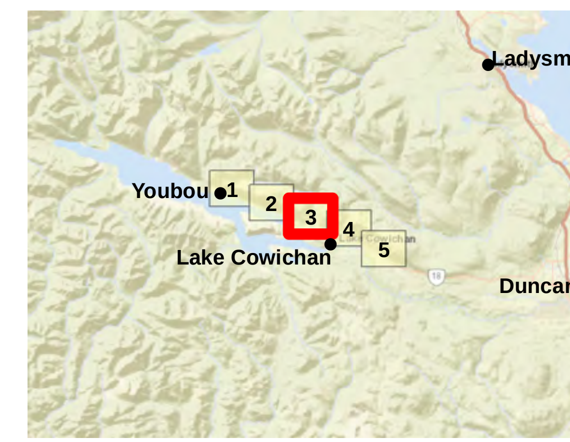


LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study

Note: Model landslides initiated based on polygons mapped by Palmer (2018).
Building data provided by the Cowichan Valley Regional District



KILOMETRE SCALE:

0 500 1,000
Meters

UTM NAD83 Zone 10 1:15,000

N

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

Limit of modeled debris flows using LABS

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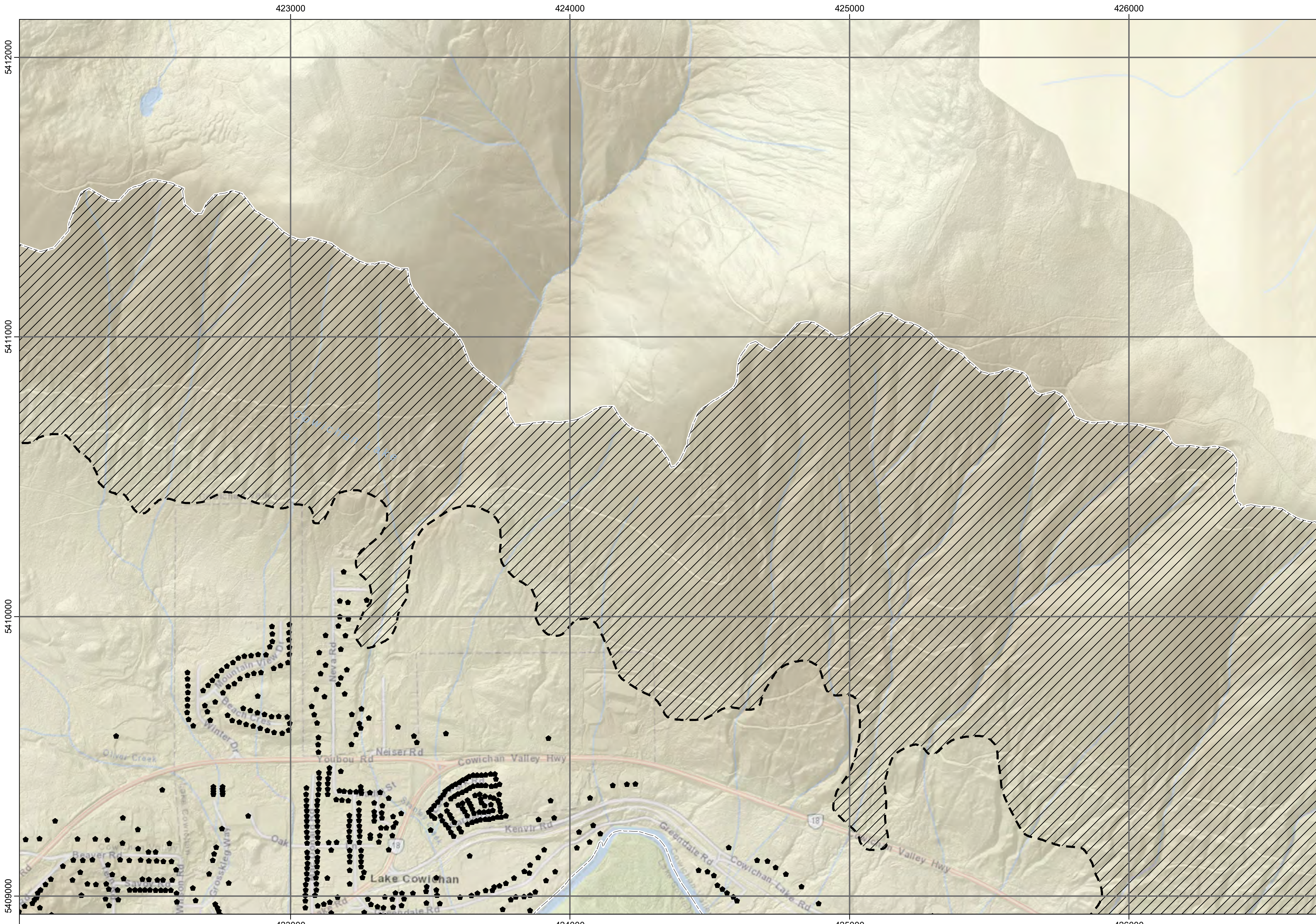

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study

Note: Model landslides initiated based on polygons mapped by Palmer (2018).
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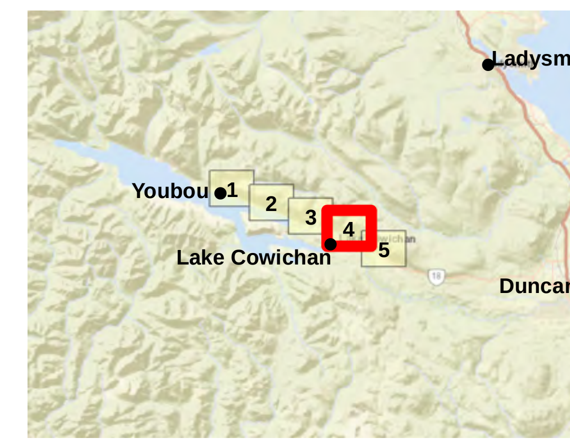

KILOMETRE SCALE:

0 500 1,000
Meters

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UTM NAD83 Zone 10 1:15,000

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN:	CM	CHECKED:	RG	PRINT SIZE:	Tabloid (11" x 17")

Limit of modeled debris flows using LABS

Date: Jan 13, 2021
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Revision: 2

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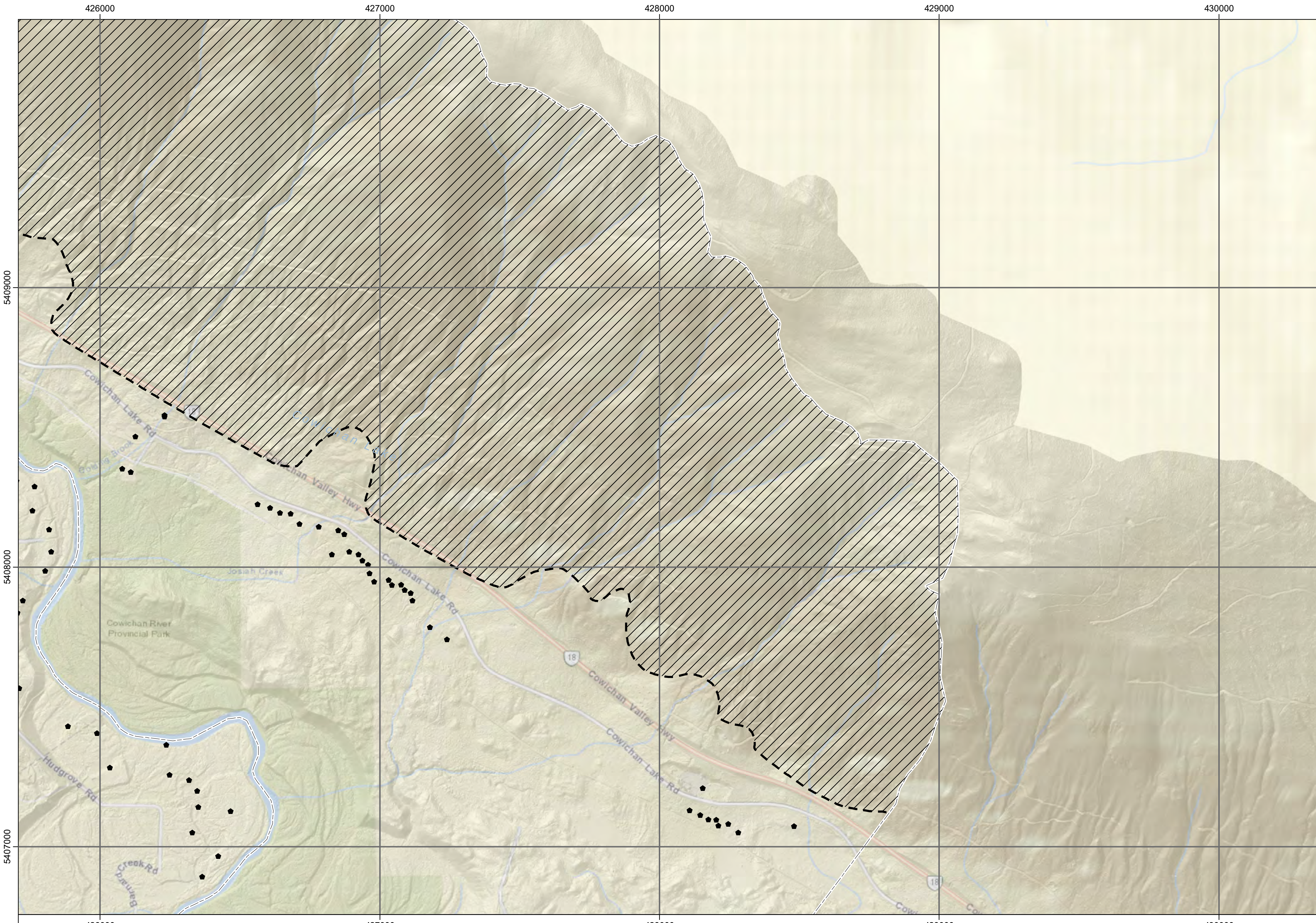

LEGEND:

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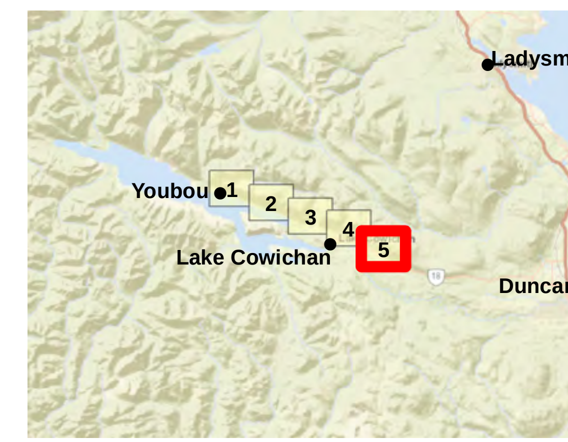

KILOMETRE SCALE:

0 500 1,000
Meters

N

UTM NAD83 Zone 10 1:15,000

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM	CHECKED: RG	PRINT SIZE: Tabloid (11" x 17")

Limit of modeled debris flows using LABS

Date: Jan 13, 2021
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Revision: 2

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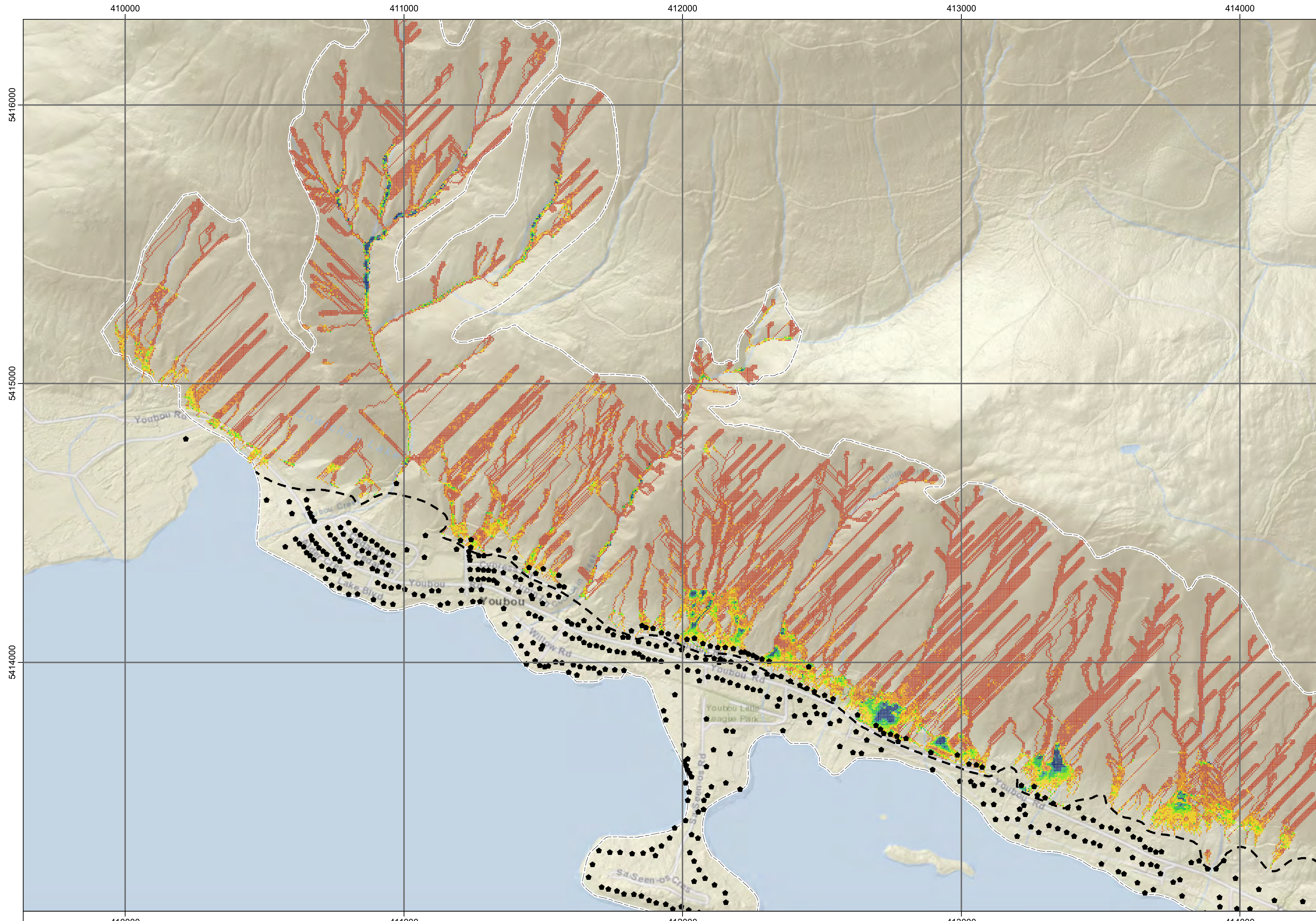
Appendix D LABS DEBRIS FLOW DAMAGE CLASSES



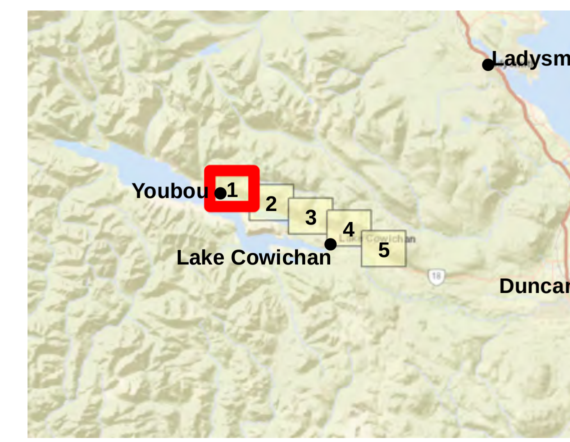
LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Damage Class

- Scour and Transportation
- 0 - 0.5 m Deposition
- > 0.5 m - 1.0 m Deposition
- > 1.0 m - 1.5 m Deposition
- > 1.5 m - 2 m Deposition
- > 2 m - 2.5 m Deposition
- > 2.5 m Deposition

Note: Model landslides initiated based on polygons mapped by Palmer (2018).
Building data provided by the Cowichan Valley Regional District



KILOMETRE SCALE:

0 500 1,000
Meters

UTM NAD83 Zone 10 1:15,000

N

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

LABS Debris Flow Damage Classes

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

Palmer™ Stantec

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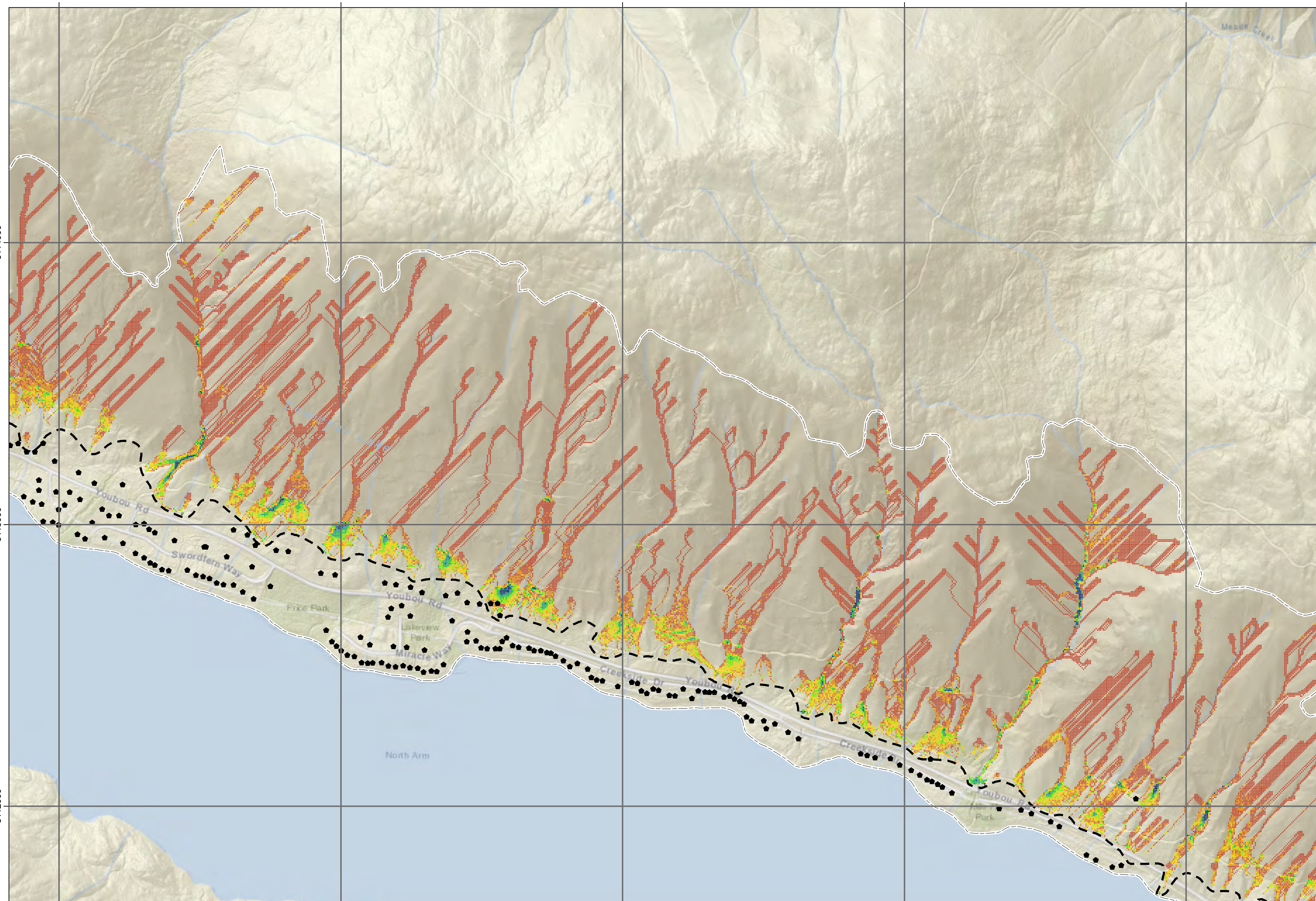

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Damage Class

- Scour and Transportation
- 0 - 0.5 m Deposition
- > 0.5 m - 1.0 m Deposition
- > 1.0 m - 1.5 m Deposition
- > 1.5 m - 2 m Deposition
- > 2 m - 2.5 m Deposition
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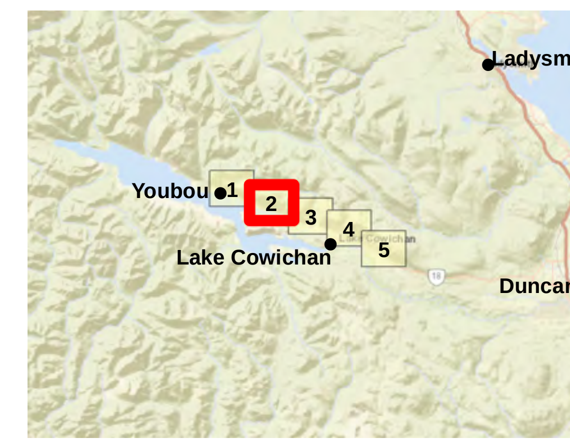

KILOMETRE SCALE:

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Meters

UTM NAD83 Zone 10 1:15,000

N

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

LABS Debris Flow Damage Classes

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

2 of 5

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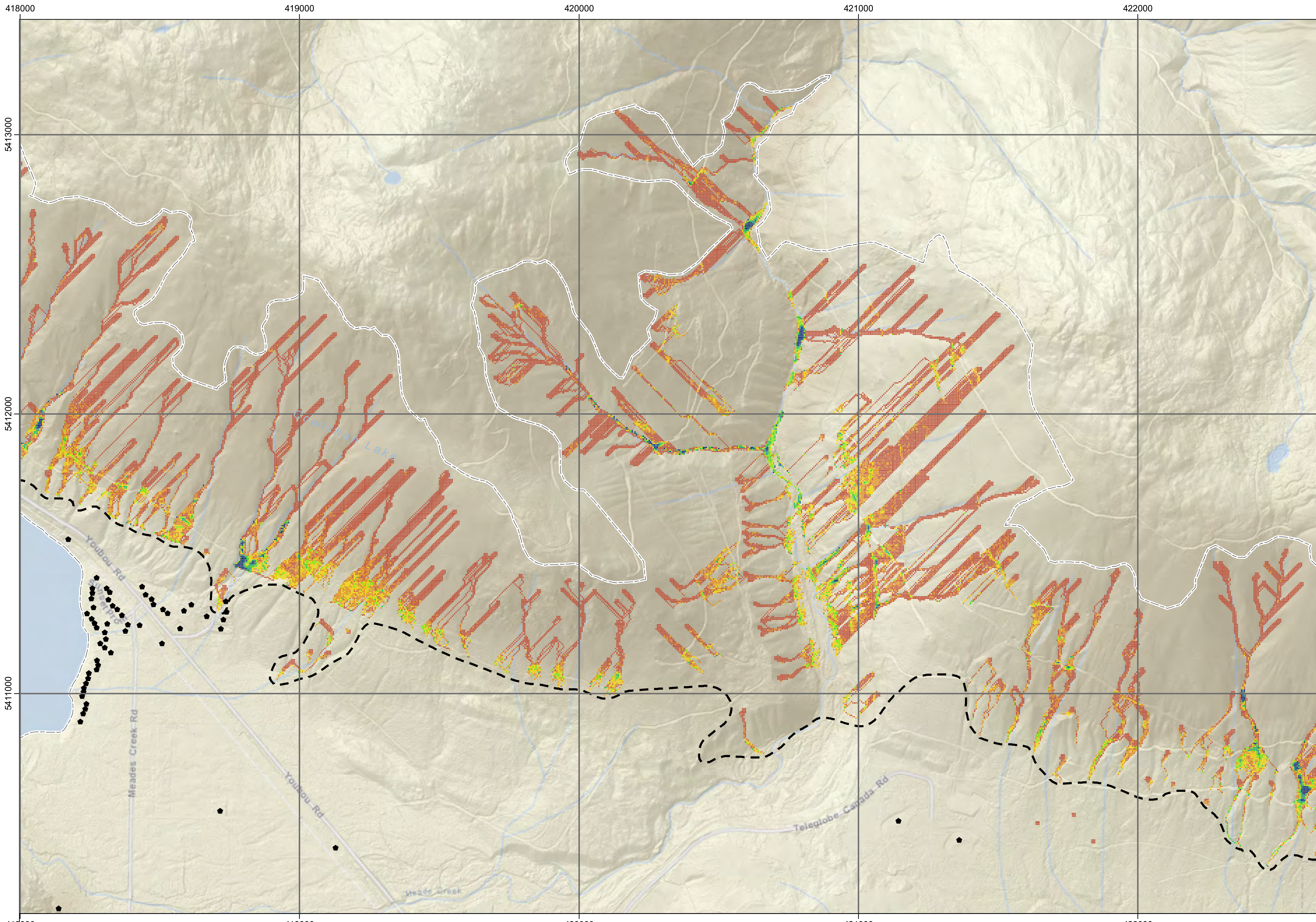

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Damage Class

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- > 0.5 m - 1.0 m Deposition
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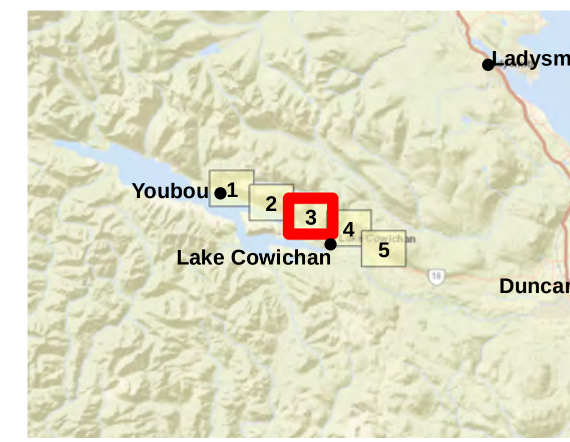

KILOMETRE SCALE: 0 500 1,000 Meters

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UTM NAD83 Zone 10 1:15,000

CLIENT: Cowichan Valley Regional District

PROJECT: CVRD Rock Slide and Flood Assessment

DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

LABS Debris Flow Damage Classes

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

3 of 5

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- Landslide behavior including inundation, runout, scour, deposition, spread, and path selection, may vary from modeled behavior for several reasons including: stochastic variability in the landsliding process (natural or modeled), controlling factors that defy parameterization within the model, generalizations used to make the model practical and applicable across large areas.
- LABS simplifies extremely complex behavior to provide reasonable predictions of outcomes. Should there be a perceived difference between modeled results, and on-the-ground evidence, the ground-based evidence should take priority. LABS does not relieve professionals from using their experience, training and education to make good judgments when assessing actual ground conditions, but provides additional understanding of processes, and credible outcomes.

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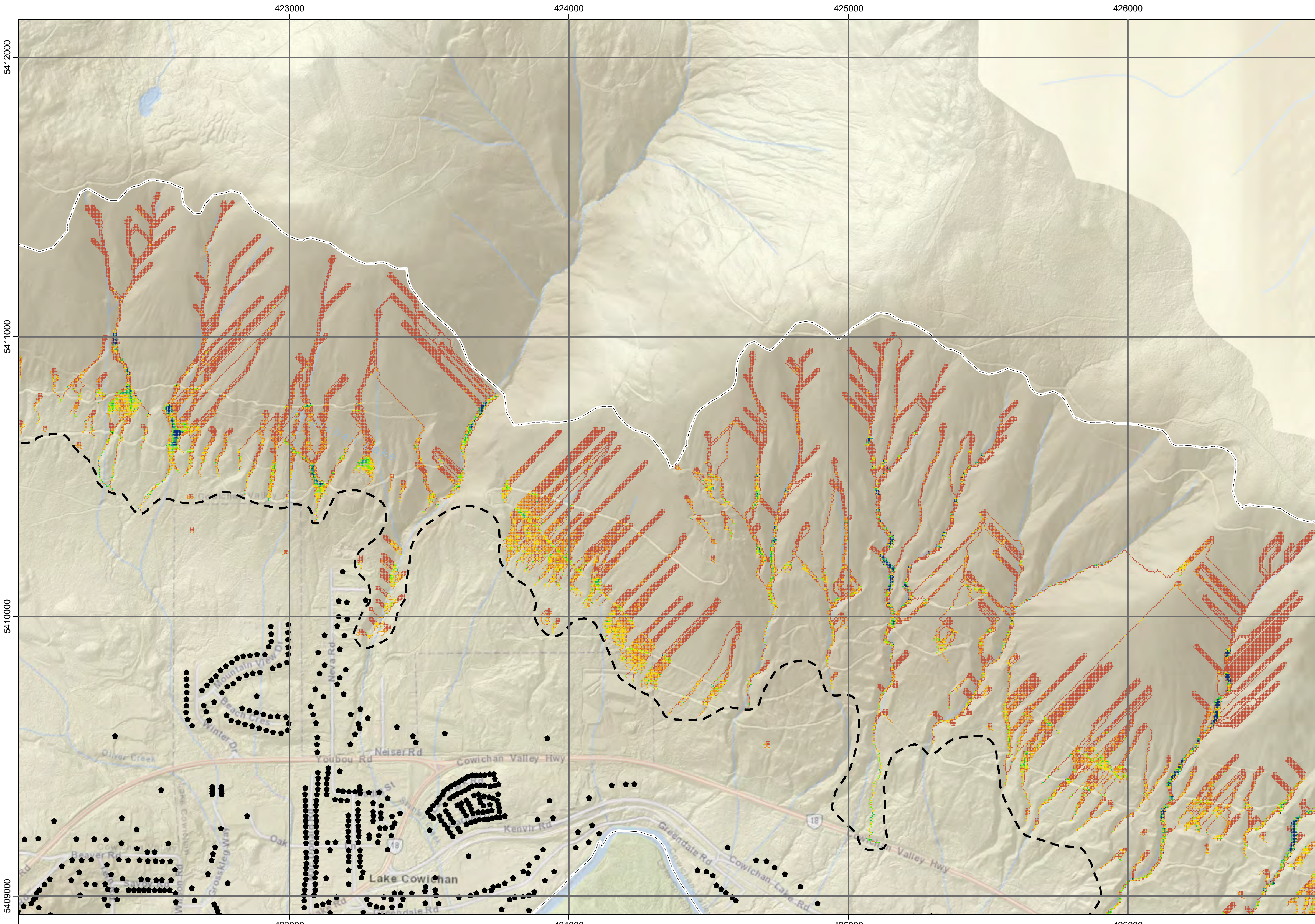


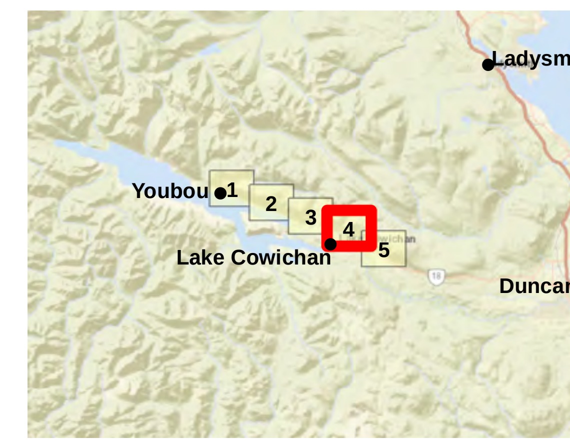
LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
- Study Area

Damage Class

- Scour and Transportation
- 0 - 0.5 m Deposition
- > 0.5 m - 1.0 m Deposition
- > 1.0 m - 1.5 m Deposition
- > 1.5 m - 2 m Deposition
- > 2 m - 2.5 m Deposition
- > 2.5 m Deposition

Note: Model landslides initiated based on polygons mapped by Palmer (2018).
Building data provided by the Cowichan Valley Regional District



KILOMETRE SCALE:

0 500 1,000

Meters

UTM NAD83 Zone 10 1:15,000

N

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM CHECKED: RG PRINT SIZE: Tabloid (11" x 17")

LABS Debris Flow Damage Classes

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

Palmer. Stantec

The models used in this work incorporate peer-reviewed techniques to predict dynamic behavior in the physical world. There may be elements that are not known or available to Stantec that can affect predictions including local physical conditions that are not resolvable at the model scale, or inputs and interactions that arise dynamically through behavior that are not included in model dynamics.

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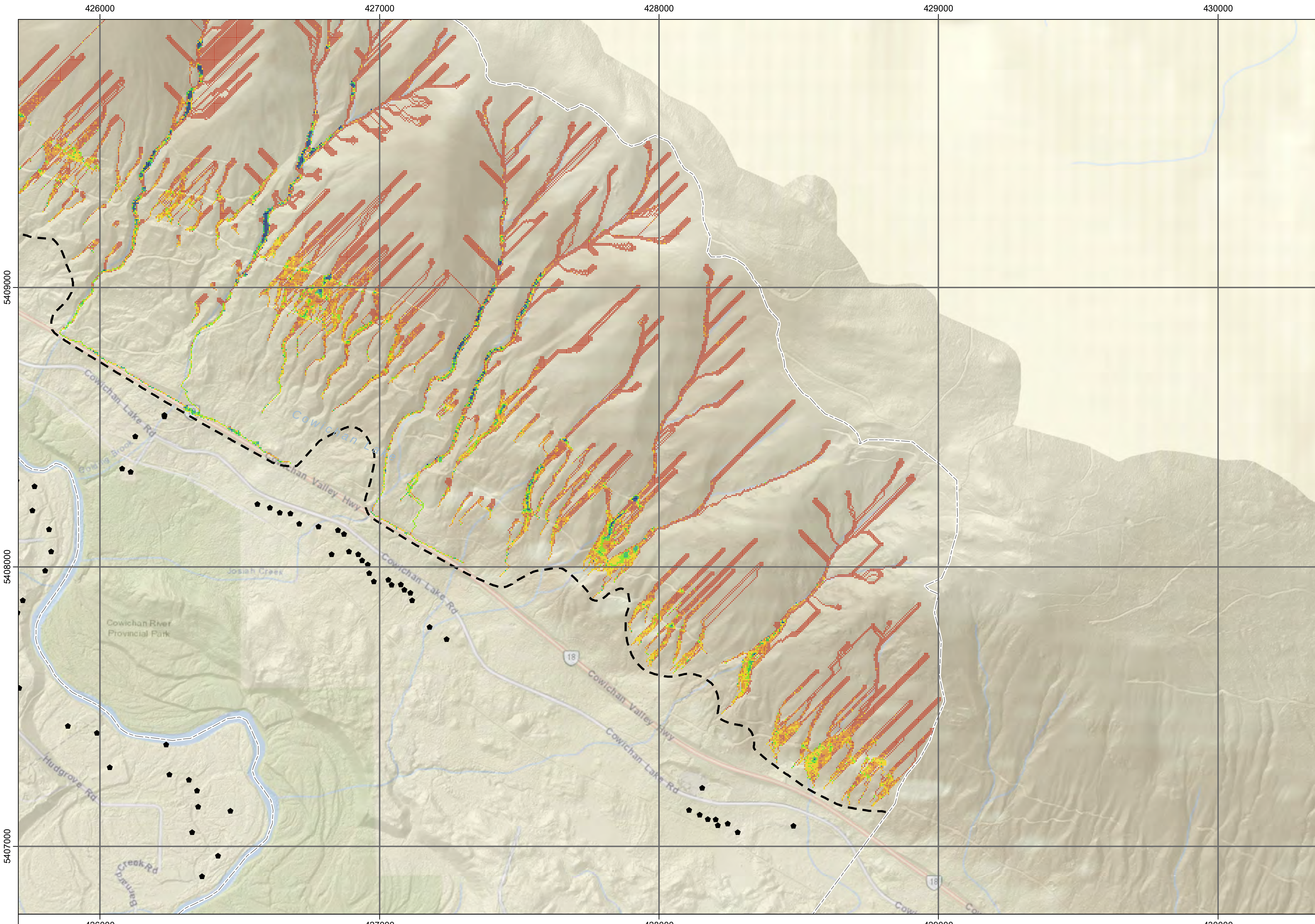

LEGEND:

- Building
- Maximum runout limit of modeled debris flows using LABS independent of return period
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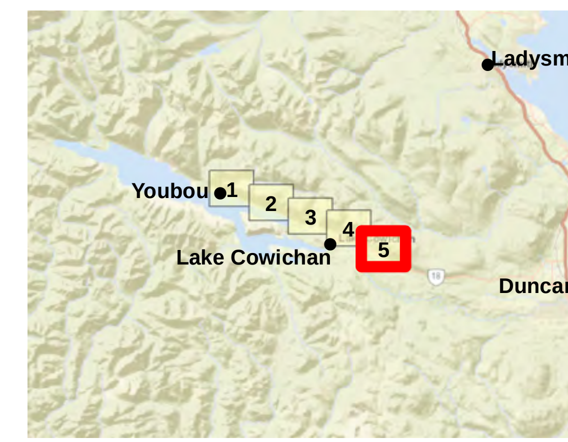

KILOMETRE SCALE:

0 500 1,000
Meters

UTM NAD83 Zone 10 1:15,000

N

CLIENT:
Cowichan Valley Regional District

PROJECT:
CVRD Rock Slide and Flood Assessment

DRAWN: CM | CHECKED: RG | PRINT SIZE: Tabloid (11" x 17")

LABS Debris Flow Damage Classes

Date: Jan 13, 2021
Project No. 1904901
Revision: 2

5 of 5

Palmer™ Stantec

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