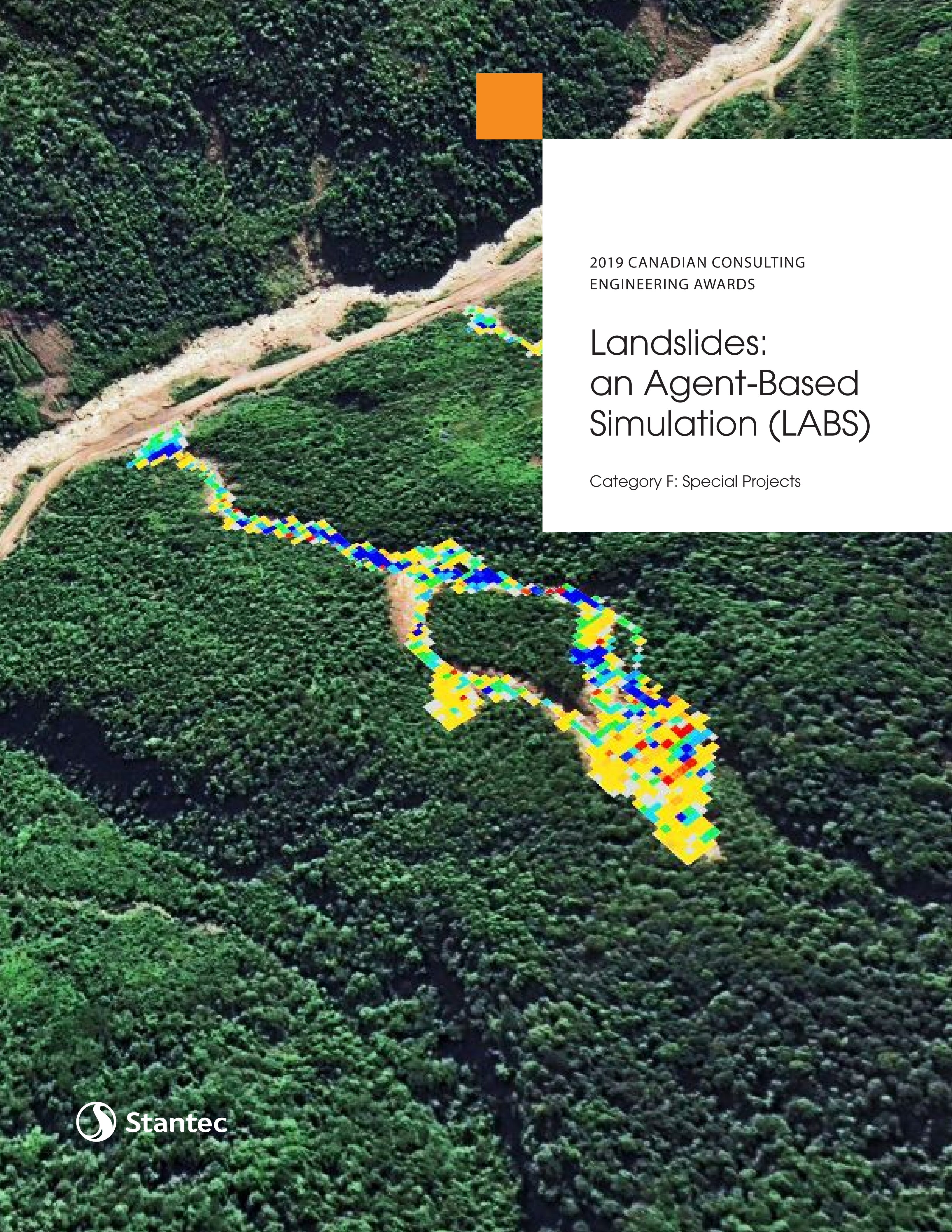
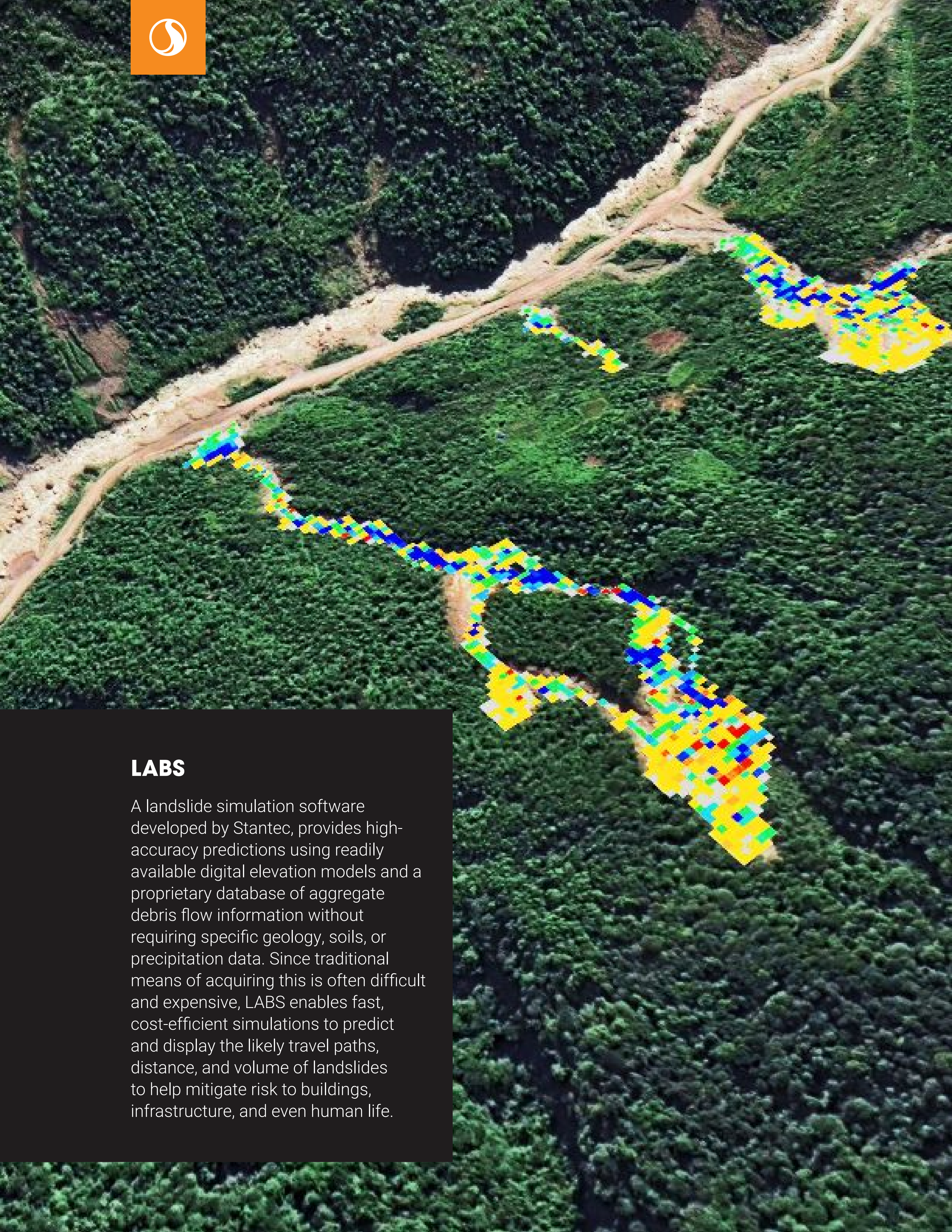


2019 CANADIAN CONSULTING
ENGINEERING AWARDS

Landslides: an Agent-Based Simulation (LABS)

Category F: Special Projects

Stantec



LABS

A landslide simulation software developed by Stantec, provides high-accuracy predictions using readily available digital elevation models and a proprietary database of aggregate debris flow information without requiring specific geology, soils, or precipitation data. Since traditional means of acquiring this is often difficult and expensive, LABS enables fast, cost-efficient simulations to predict and display the likely travel paths, distance, and volume of landslides to help mitigate risk to buildings, infrastructure, and even human life.

Project Highlights

Q.1 INNOVATION

Movements of the earth's surface and substrate – commonly referred to as landslides – can have potentially devastating impacts on the landscape, built infrastructure, and even human life. A clearer understanding of the magnitude and frequency of landslides is critical to adequately develop means to mitigate their effects.

Stantec was approached by a tropical mountain town frequently impacted by debris floods and debris flows (to respect the client's request to remain anonymous, we will refer to them as "X-Town"). Hundreds of open slope debris flows occur almost annually (Figure 1), charging the two major streams that flow through X-Town with sediment. Consequently, and all too often, periodic debris floods impact infrastructure and threaten lives, such as the two deaths and the destruction of a $60 M power station in the fall of 2017. Stantec was asked to look at mitigation efforts in the town, determine the likelihood of success, and advise on potential improvements that could be made to the existing design.

While several landslide models exist, they are not intended to be used to predict runout for hundreds of open slope debris flows and typically require calibration to known or existing events or entry of sediment assumptions to be used predictively.

Guthrie et al., (2008) created a program wherein the aggregate behavior of shallow debris flows was modeled using an agent-based cellular automata approach. The approach was promising in that minimal inputs were required, it effectively reproduced the magnitude and frequency characteristics of landslides, and it exhibited realistic flow patterns. To our knowledge, there is no other model available that does this.

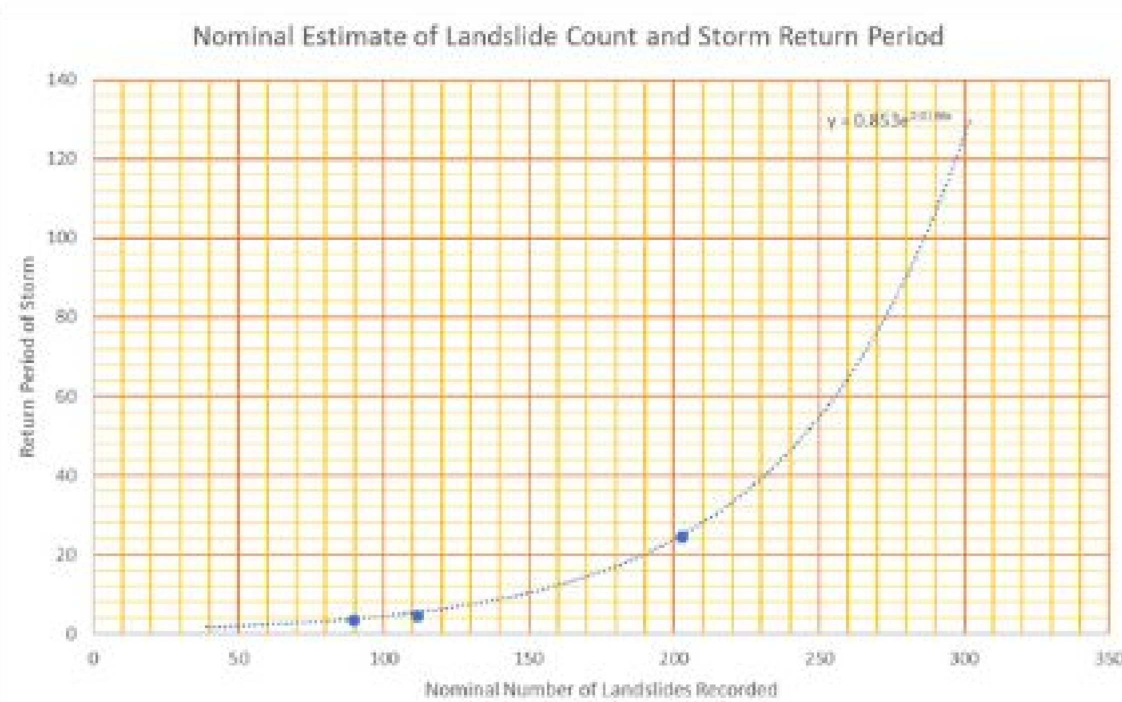


Figure 1. Landslide count compared to the return period of storms (in years) affecting the watershed surrounding X-Town.

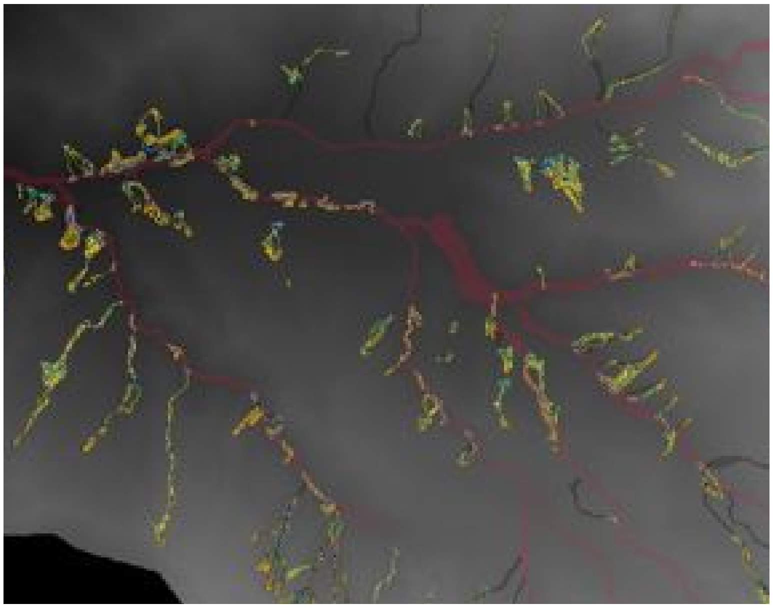


Figure 2. LABS modeled landslides (in color) compared to existing mapped landslides (in grey) in the watershed. Colors relate to amount of scour or deposition.

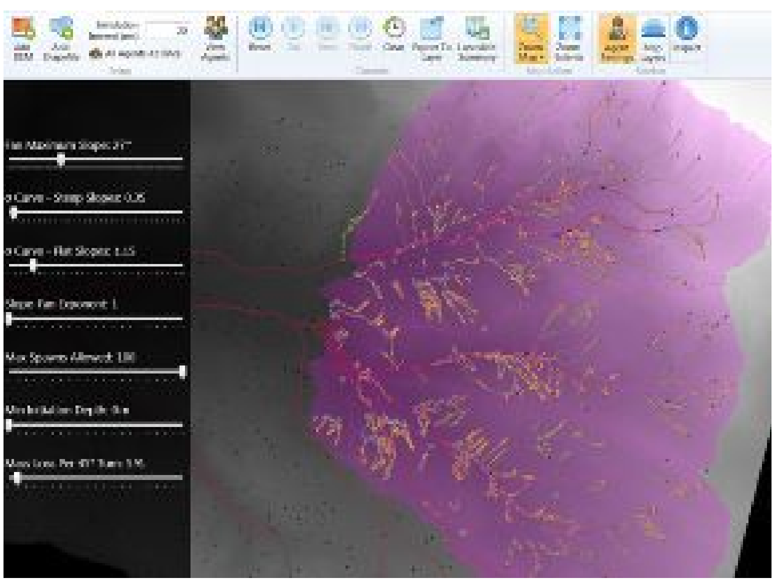


Figure 3. Landslides predicted from scenario-based criteria. Black dots are random points stratified within susceptibility zones and represent initiation points. Volumes were written to the debris flood polygons, shown in red. The pink area is highlighting the key area of interest within the watershed.

With this project, based on the principles adopted from Guthrie et al. (2008), Stantec developed an agent-based software simulation called Landslides: an Agent-Based Simulation ("LABS") which predicts landslide area, volume, and runout of shallow debris flows from anywhere in a watershed. LABS determines erosion and deposition along the landslide path and can write the change to a digital elevation model or export the values to shapefiles. Simulations can be overlaid onto existing landslides for finer calibration (Figure 2) and new simulations run from scenario-based locations, either random or user defined (Figure 3).

Using LABS, Stantec was able to demonstrate where landslides would travel based upon random initiation points stratified by an existing susceptibility map and estimate the volumetric contribution to stream bulking for several return periods of storms. FLO2D (existing software) used the bulking data to route the sediment through the streams as debris floods under each scenario.

In addition to providing input to shapefile polygons (used for FLO2D), LABS provides a dramatic visualization of landslides occurring in virtual-time from any point in the watershed. This helps us to better understand the potential impacts to infrastructure built onto the slopes and assess mitigation options.

Stantec was able to combine aggregate statistics, empirical evidence, and expert judgement into an agent-based model to create a genuinely predictive, probabilistic landslide model that can inform communities and help reduce risk with limited inputs. Because the embedded rules model aggregate behavior observable across a wide range of flow-type landslides, detailed soils, geology, or precipitation data is not specifically required, making the tool useful in areas where that data is difficult to gather.

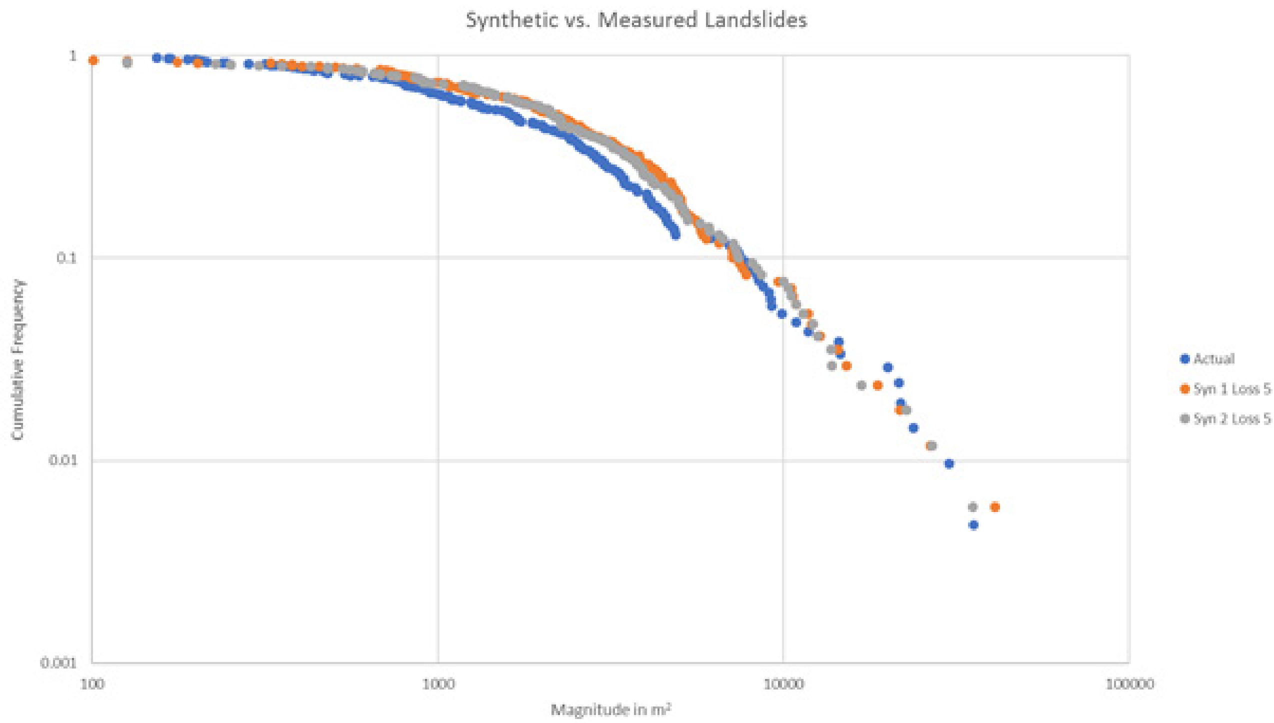


Figure 4. Cumulative magnitude-frequency curves for mapped and modeled landslides in X-Town.

Despite the foregoing, LABS does provide user-configurable variables that can be adjusted for sites where soils, geology, and precipitation data is available. Modeled flows can easily be compared visually against mapped behavior, or, since all LABS landslides can be exported to Microsoft Excel, through more thorough magnitude-frequency analysis, such as those shown in Figure 4.

LABS was built in C# and XAML as a standalone program to provide users with both analytic and visualization capability. It is designed so users can see the entire path of the predicted debris flow and stop and start the simulation at any stage to examine the behavior more closely. Agent characteristics and parameters can be customized to run various what-if scenarios and once optimized, run multiple times to determine the likely inner and outer bounds of the identified event (the results will vary slightly in each run).

Stantec believes that this program has the potential to provide critical information to many communities affected by open slope debris flows.

Q.2 COMPLEXITY

There were numerous challenges that contributed to the high degree of difficulty developing this model. The first was to take a significant database of aggregate debris-flow data and be able to define a set of rules that could be deployed by an agent-based application (where every single pixel is a subroutine within the broader program) to define how each agent would interact with each other agent and predict the aggregate behaviors.

The second was to build this model as a standalone application that would allow it to easily be distributed or shared and would contain a fully interactive map interface capable of displaying, managing, and animating vector and raster layers. This means users of the application would be able to visually see the likely travel paths, scour, and deposition of potential landslides, and be able to start and stop the model at any stage to examine the behavior more closely.

The final challenge was determining, amongst a large and complex set of rules, which were the most sensitive and would have the greatest impact on the overall accuracy of the model. The team needed to resist the temptation to undertake an in-depth examination of every single rule, which would have been time-prohibitive. The team built a tool directly into the application that allowed them to pause and debug the program to conduct a Pareto-type analysis to identify the sets of rules needing the most fine-tuning to focus their efforts.

In reflecting upon this project, the team frequently commented that it was the passion and commitment of each other that truly brought this model to fruition. Rick Guthrie mentioned "there were numerous occasions when I was up at 2 am working on this model. I would look at my Skype window and see that Andrew [Befus] was also online. We would end up talking with one another, find out the other was also working on the model, and we'd start brainstorming and refining the application right there."

The team also had a unique combination of skillsets. Rick Guthrie has 24 years of specialized experience in understanding and trying to predict landslide behaviour. Through this experience, we had access to a significant database of aggregate debris-flow behaviour through which the model could be built from and tested against. Andrew Befus, in addition to having more than a decade of experience in software development, also has a background in geology and geomorphology. This meant Andrew had a deeper understanding of the predictive model and how to codify it. It also meant Rick and Andrew were able to communicate in terms more easily understood by the other as they worked to troubleshoot and refine the model.

Q.3 SOCIAL AND/OR ECONOMIC BENEFITS

With the continual growth in global population and corresponding need for resource production, we see an ever-increasing amount of buildings and infrastructure being constructed in increasingly remote and hazardous locations. The risks to these projects are further compounded by the rise in extreme weather events influenced through global-warming.

The ability for us to run fast and cost-efficient simulations in these high-risk areas, both on the landslide events themselves, as well as the effect of various mitigating activities, can dramatically reduce the risk to human safety and billions of dollars of built infrastructure.

As scientists and engineers, it is exciting to not just be a part of a single project that makes a real impact on society, but to also move the entire science forward and develop a tool that can be used repeatedly with the potential to help numerous clients across many communities.

Q.4 ENVIRONMENTAL BENEFITS

Multiple simulations can be run without the additional environmental impacts of travel to and from remote sites, as well as the footprint and disturbance of more traditional monitoring and sampling activities. And since many geohazard risks are found in more dangerous and difficult-to-access terrain, there is reduced risk to human safety by using this model.

Use of this model can also reduce the impacts to lives and infrastructure situated in, or being planned near, high-hazard areas by increasing expert knowledge about the likely travel paths, distance, and volume of landslides in those areas. It also provides a visualization tool to communicate that information more easily.

The simulation scenarios produced by LABS can also help guide strategies for long-term management of riparian areas, for example the timing and amount of land disturbance for construction projects or the rate of deforestation and planting of replacement seedlings.

Q.5 MEETING CLIENT'S NEEDS

To help provide the best solution to a community beset by landslides, Stantec developed and applied a world-class landslide model to provide critical inputs about sediment loading under a variety of scenarios (return events).

In doing so, we built a model that also allows communities to visualize the threat to elements at risk from flow-type landslides anywhere in their watershed and allows experts to work with the analytical results. It does so by using data that is widely available (digital elevation models) and calibrating, where needed, against mapped landslides. Simulations are run in virtual-time, meaning the model progresses through time steps that can be observed, paused, and restarted by the viewer. By quickly running several potential simulations, clients can assess the likely risks to their proposed or existing infrastructure and determine the best project siting and design factors that fit within their risk bounds.

This model was part of a larger project and provided key data inputs to the understanding of hazards from debris floods that could impact X-Town. In the absence of the model, debris inputs would be estimated using traditional methods, including mapping and field visits. However, the inaccessibility of most of the watershed meant that LABS played an important role in the accuracy of the findings.

As a result, LABS has the potential to provide, in addition to the critical results already provided for X-Town, an expert tool for landslide impacted communities in different regions around the world.