Chapter 37
Saguenay Risk Management

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Abstract The city of Saguenay, in the province of Quebec, is located in an area with a hilly topography and where sensitive marine clays are predominant. The slopes throughout the city are either former riverbanks or scarps of old large retrogressive landslides and their height can vary from a few meters to dozens of meters. Although the toe of these slopes is no longer subject to erosion, they can still be affected by shallow landslides. The spreading debris of such landslides is a threat to buildings located at the toe of slopes and thus a significant hazard for the safety of residents. This article presents the approach developed jointly by the Government of Quebec and the city of Saguenay to manage the risks associated with this hazard. Following the mapping of landslide prone areas, risk analyses allowed to bring out areas most exposed to shallow landslides. An annual inspection program was implemented in 2007 by the city of Saguenay and allowed on numerous occasions to detect early signs of landslides and take preventive action, in the form of stabilization work. This program has considerably reduced the risk to the population.

37.1 Introduction

In the early 2000s, the Government of Quebec reviewed its approach to risk management (Ministère de la Sécurité publique 2008; Potvin et al. 2014) after major disasters in the late 1990s (torrential rain in Saguenay–Lac-Saint-Jean and ice storm in Southern Quebec). The Government of Quebec recognized that landslides

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(particularly those occurring in sensitive clayey soils) pose a threat that must be considered a priority.

Different measures can be implemented to assist the municipal or government authorities to improve risk management in their territory, and thus reduce the risk level for the population and infrastructure (Demers et al. 2008; Thibault et al. 2008).

This article describes the problem of shallow landslides, the semi-quantitative analysis method and the treatment of the shallow landslide risk developed jointly by the Government of Quebec and the city of Saguenay. This historical case concern the La Baie borough located in the East part of the city.

37.2   Problems Related to Shallow Landslides

In Quebec Province, most landslides in clayey soils occur on the banks of watercourses where the toe is subjected to erosion. However, shallow landslides also occur along slopes without erosion. These slopes are the remains of old marine terraces or scarps of large retrogressive landslide scars (Fig. 37.1).

Hundreds of shallow landslides occur in Quebec per year. They can happen in all types of soil but are most common in clay. Shallow landslides are caused by saturation of the soil during heavy rains or spring snowmelt. This type of landslide is generally characterized by a shallow failure surface, usually less than 1.5 m deep. They occur essentially in the slope and rarely reach the crest. However, the debris may extend to the toe of the slope, sometimes over long distances. Although these landslides seem innocuous because they are relatively small, they can cause major damage to buildings located at the toe (Fig. 37.2) and, if there are people exposed even casualties.

Fig. 37.1 Typical example of a slopes without erosion formed by the scarp of a large retrogressive landslide scar

Fig. 37.2 Example of the consequences of a shallow landslide. The debris slammed into the house located at the toe of the slope

Many shallow landslides occur during extreme weather events. This was the case during the heavy rainstorm of July 19th and 20th, 1996, in the Saguenay – Lac-St-Jean area, where over 250 mm of rain fell within 36 h, causing more than 1,000 landslides (Demers et al. 1999). One of the landslides caused the death of two young children in Saguenay (Bouchard et al. 2008). In April 2005, in the Charlevoix region, heavy rains combined with snowmelt triggered about 50 landslides, forcing the evacuation of many residences (Locat et al. 2008). In June 2011, 260 mm of rain fell in the Outaouais region in western Quebec within 48 h, threatening over 50 homes. In view of the anticipated climate changes, extreme weather events should become more numerous, thus increasing the occurrence of landslides. Shallow landslides occur not only during extreme weather events but also during more regular and less significant events.

La Baie borough in the city of Saguenay is particularly exposed to this type of landslide. The very variable terrain and the large spread of clayey soils make this area prone to the development of shallow landslides.

37.3   Risk Analysis

Mapping of areas prone to landslides is the main step in risk identification. For the La Baie borough, it revealed that a large number of buildings at the toe of the slopes could be hit by shallow landslide debris. Due to the concerns expressed byt the municipal authorities, a risk analysis was performed.

For each building located in the restricted zone at the toe of a slope, the risk (R) is calculated by considering the following equation.

$$R = P_{site} \times C_{site}$$

Where

P$_{site}$: Probability of landslide occurrence for a site
C$_{site}$: Consequences for a site

The risk is assessed on the basis of the probability and the consequences associated with such an event in terms of the loss of lives for a given site. The value of the risk is not absolute; it serves to compare sites with each other. In a first stage, a general risk analysis is performed, which considers the predisposing factors of a slope (slope angle, height, etc.). This stage of the analysis is automated and uses geographic information systems. The buildings with a very high risk level are the object of a more specific analysis where the worsening and revealing factors, identified during site inspections, are then considered.

37.3.1   General Risk Analysis

At this stage, the probability that a shallow landslide will occur at a given site (P$_{site}$) is determined according to the slope angle and the height of the slope

$$P_{Site} = P_i \times K_h \times K_{ci}$$

Where

P$_i$: Probability of occurrence for slope class "i"
K$_h$: Weighting factor associated with the height of the slope
K$_{ci}$: Correction factor for each slope class

Clay slopes are divided into six classes according to the strongest slope section constituting them. Probability P$_i$ is determined for each of these six classes (Levasseur 2003).

$$P_i = \frac{N_{gi}}{N_i}$$

Where

N$_{gi}$: Average number of landslides that occur each year in slope class "i"
N$_i$: Number of potential sites where a shallow landslide can occur for slope class "i"

N$_{gi}$ is valued based on a non-exhaustive inventory produced from air photos that cover a period of nearly 50 years. The number of potential slope class "i" sites (N_i) is determined for each slope class, considering that the average width of a landslide is 10 m.

$$N_i = \frac{L_i}{L_g}$$

Table 37.1 Weighting
factors associated with slope
height

Height (in meters)	Weighting
5–10	0.8
10–15	1.0
15–25	1.5
25 and over	2.0

Where

L_i: Total length represented by each slope class throughout the territory
L_g: Average width of a landslide

The weighting factor (K_h) accounts for the possibility of having several steep segments in the same slope (Table 37.1). The higher a slope is, the greater is the probability of it being identified as a trigger zone.

The weighting factor (K_h) has the effect of stretching the variation range of the P_{site} probability values relative to the P_i probability of occurrence of a shallow landslide. Therefore, a correction factor (K_{ci}), varying according to slope class "i", must be applied to center the average probability assigned to each site in relation to probability P_i.

$$K_{ci} = \frac{P_i}{P_i \times K_h}$$

The potential severity of the consequences (C_{site}) can be assessed for each building according to the equation:

$$C_{site} = P_S \times V \times P_T \times E_V$$

Where

P_S: Spatial probability
V: Vulnerability of threatened elements
P_T: Temporal probability
E_V: Number of exposed elements

The spatial probability (P_s) depends on the principle that the closer a vulnerable element is to the toe of the slope, the greater is the probability for it to be affected by landslide debris. This probability is obtained from the landslide inventory carried out by Perret and Bégin (1997), in which 769 landsides were identified following the torrential rains that fell in July 1996 in the Saguenay – Lac-Saint-Jean area. This inventory made it possible to draw a graph of the frequency of landslides as a function of travel distance of the debris, factored by the height of the slope (D/H).

The portion of land located between the toe of the slope and a distance equal to twice the height of the slope is divided into four classes, as identified by the histogram in Fig. 37.3. The probability assigned to each class is obtained by taking
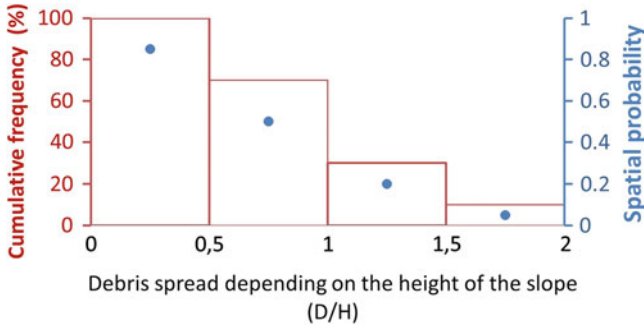
Fig. 37.3 Cumulative frequency relative to the travel distance of the debris (Modified from Perret and Bégin 1997 and Levasseur 2003). The blue dots represent the probability for each class (D/H)

the average probability of the limits of the class. Figure 37.3 shows that 100% of the debris reached or exceeded range 0–0.5H. The spatial probability for this zone is 0.85.

The vulnerability (**V**) represents the probability of mortality if people are found in a building hit by landslide debris. It is based on the damage from shallow landslides observed on different types of building.

The temporal probability (P_T) is associated with the exposure time of a person to danger. This probability varies according to the use of the building. It is admitted that residents remain in their home 16 h per day. In the case of a business or a farm, it is estimated that people work there 8 h per day.

The E_V factor corresponds to the number of vulnerable elements exposed to a shallow landslide hazard. As a preliminary estimate, an average of four people per residence, eight people per multiple-unit residential building, one person per farm building and five people per commercial building is considered in the analysis.

Mapping made it possible to target over 700 buildings directly exposed to various degrees to a shallow landslide debris hazard in the city of Saguenay only. The general risk analysis allowed quantification of the risk for each of these buildings, and thus target those with the highest risk level. Only the buildings most likely to be hit by debris were subjected to a more refined analysis. This specific analysis allowed the implementation of a risk management plan adapted to the territory studied.

37.3.2 Specific Risk Analysis

The specific risk analysis makes it possible to determine the risk level of each site, considering the worsening factors that could impair slope stability and considering the shallow landslide warning signs observed on the ground. Factors are added to the site probability (P_{Site}) determined by the general analysis.

$$P_{\text{Specific site}} = P_{Site} \times K_D \times K_E \times K_R \times K_V \times K_S \times K_c$$

Table 37.2 Weight assigned to the each factor

Factors	Ranges	Weight
Cutting (K_D)	D/H >1/3	2
	1/3 > D/H >1/5	1.5
	1/5 > D/H	1.2
	Nil	1
Water concentration (K_E)	Yes	1.5
	No	1
Height of the stiffest section (K_R)	Base	0.8
	Middle	1
	Top	1.5
Vegetation (K_V)	Denuded	1.5
	Shrubs	1
	Trees	0.8
Revealing signs of instability (K_S)	Nil	1
	Loss of plant cover	1.5
	Minor cracks	2
	Cracks with vertical shift	5

Where

K_D: Factor for the cut section

K_E: Water concentration factor

K_R: Factor for the position of the stiffest position in the slope

K_V: Factor for the type of vegetation found on the slope

K_S: Factor for the presence of revealing signs of instability

K_c: Correction factor

Weights were assigned to the different factors (Table 37.2). Their importance is based on field observations and expert judgement. As in the general analysis, a weight factor (K_P) was considered to recenter the probabilities on the average.

In the case of the risk analysis performed in the La Baie borough, a specific risk analysis was applied to approximately 350 buildings. The risk is presented in the form of a logarithmic graph based on the one produced by the Geotechnical Engineering Office (1998). The graph was divided into five risk classes, thus allowing each site to be classified according to a risk scale (Fig. 37.4a). The results shown in the graph are then transferred to the risk map (Fig. 37.4b).

37.4 Risk Treatment

In the territory of the La Baie borough of the city of Saguenay, the risk analysis revealed that several homes are exposed to shallow landslide hazard. As mitigation works could not be performed on all the sites, due to the high cost of such an
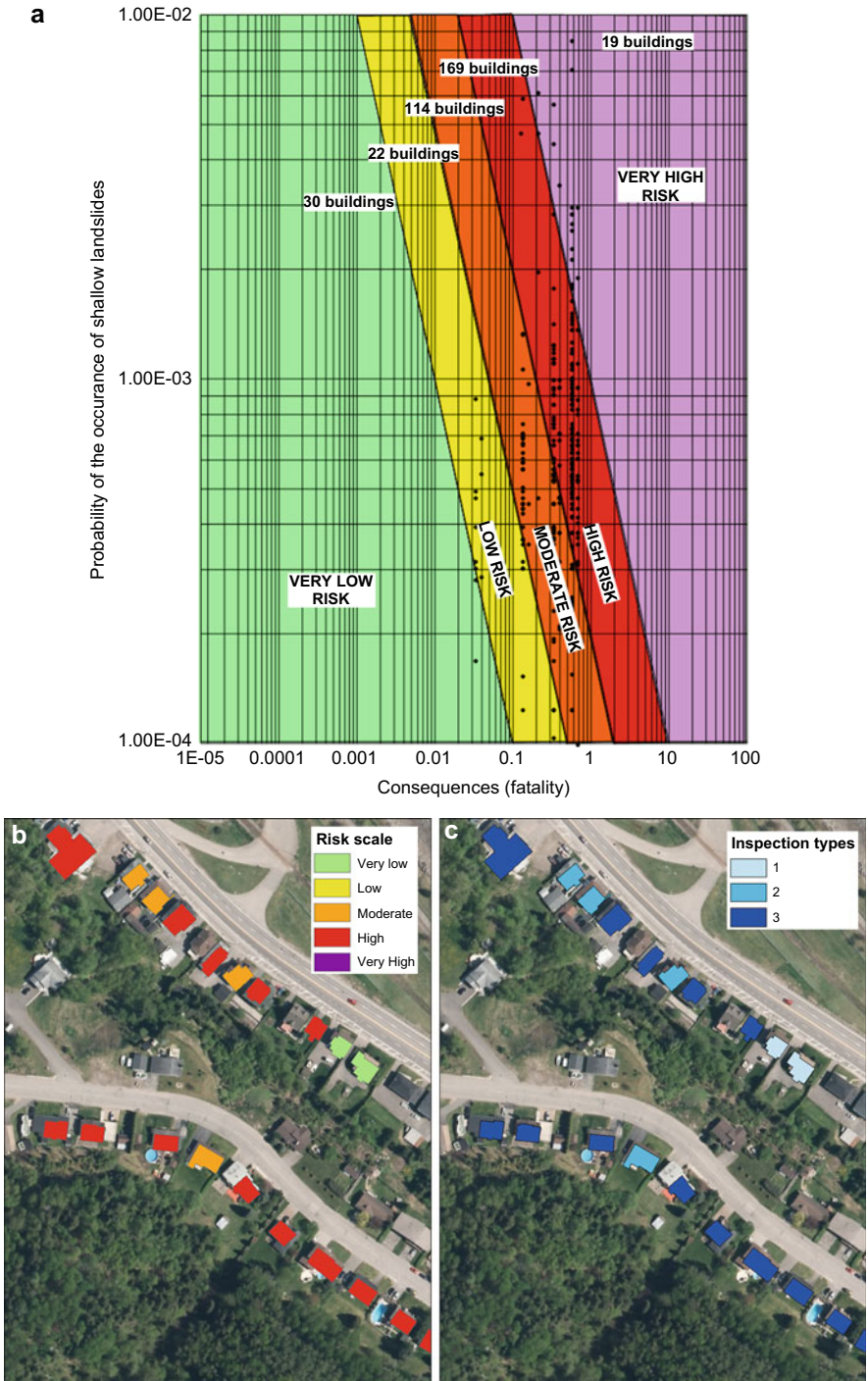
Fig. 37.4 (**a**) Graph of the specific risk analysis for the shallow landslide hazard; (**b**) Risk map example; (**c**) Inspection map example
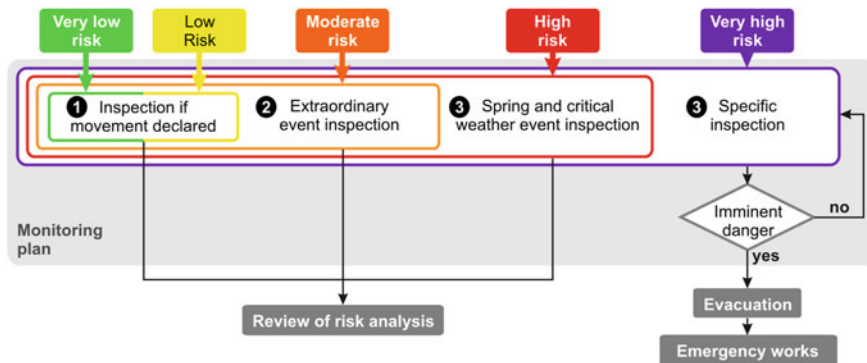
Fig. 37.5 Monitoring plan for areas exposed to shallow landslides

endeavor, preventive measures were therefore implemented. Thus, the municipal by-laws allow control of interventions that could impair slope stability. Moreover, the deployment of a slope monitoring plan makes it possible to reduce the likelyhood of disasters. Slope inspections are conducted at a certain frequency, based on the computed risk level, in order to identify early signs of instability (cracks in the slope or at its top, bulge in the ground at the foot of the slope, degradation of retaining walls, etc.) which have developed or worsened since the previous inspection. Figure 37.5 presents the monitoring plan for the areas exposed to shallow landslides in the city of Saguenay. Inspection maps can be drawn to facilitate the work of the municipal and government stakeholders (Fig. 37.4c). These maps take the information from the risk maps and transpose it into inspection types (1, 2 and 3) for each building. In the case of La Baie borough, 182 buildings are inspected annually. Over the past few years, the city of Saguenay has extended its monitoring plan to all its boroughs, using the same framework.

Since 2007, this innovative approach has allowed to detect about ten sites where danger became imminent. Interventions, totally or partially funded by the government, were carried out to avoid potential deaths and major property damage (Ministère de la Sécurité publique 2013a). Interventions made can seek to reduce the probability of occurence, by stabilizing the slope, for example, or to reduce the severity of the consequences, by building a protective wall, for example.

37.5   Conclusion

The approach described in this article is part of the Prevention Framework for Disasters adopted by the Government of Quebec in 2007 and renewed in 2013 (Ministère de la Sécurité publique 2013b). It allows implementation of management measures adapted to the magnitude of the risk and optimization of the preventive interventions to significantly reduce risks associated with shallow landslides. Its

success is linked to the political will and the cooperation of the authorities concerned, primarily on the municipal level. Communication and consultation among government authorities, geotechnical engineers, municipal authorities and the public is a key success factor in such an approach. This approach used by the city of Saguenay served as a model and remains to this day a reference in landslides risk management in Quebec Province.

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