An integrated mass movement monitoring system for rockslide hazard assessment at Gascons, Gaspé Peninsula, Québec: *An Overview*

J. Locat, C. Cloutier, P.-E, Lord, and P. Therrien,
Laboratoire d'études sur les risques naturels, Université Laval, Québec, Canada
C. Jacob, A. Nadeau,
Ministère des transports du Québec, Québec, Canada
D. Hébert,
Transport Canada, Ottawa, Canada,
R. Couture, F. Charbonneau., V. Singhroy, and K. Murnaghan
Natural Resources Canada, Earth Sciences Sector, Ottawa, Ontario, Canada
L. Danisch,
Measurand Inc., Fredericton, New Brunswick, Canada,
M. Jaboyedoff, A. Pedrazzini
Institute of Geomatics and Analysis of Risk, Université de Lausanne, Lausanne, Switzerland,
S. Gravel,
AcroCanada, Québec, Canada

ABSTRACT
An integrated mass movement monitoring system including ground and satellite observations has been developed for an active coastal rockslide at Gascons, in the Gaspé Peninsula, Québec, which is threatening a railroad. The monitoring system has been put in place in order to understand the various types of movements in an attempt to develop both warning criteria and risk assessment scenarios to be considered as part of a risk the management plan for the Gascons site.

RÉSUMÉ
Un projet intégré de suivi sur le terrain et par satellite a été développé pour un glissement rocheux côtier dans la région de Gascons en Gaspésie lequel présente une menace pour la voie ferrée du secteur. Le système de suivi a été mis en place afin de pouvoir comprendre les mouvements du massif rocheux et ainsi développer à la fois des critères d'alerte et une analyse du risque qui seront intégrés à la gestion du risque pour cette portion de la voie ferrée dans la région de Gascons.

1 INTRODUCTION

The railroad between Matapedia and Gaspé has recently been acquired by local municipalities with the financial support from Provincial and Federal governments as part of an effort to support the socio-economic development of the Gaspé Peninsula. A portion of the railroad, near Port-Daniel-Gascons (mile 30.5 of the Chandler division, Figure 1) is known to present various signs of mass movements. Previous studies at Gascons (Locat and Couture 1995a and b) revealed the presence of open fissures involving a rockslide of about 0.5 Mm^3.

The Gascons site is located along a coastline formed in sedimentary rocks of Silurian age consisting mainly of alternating beds of limestone, shale, conglomerate and less frequently sandstone (Bourque and Lachambre 1980). Most of the rockslide is taking place within the l'Anse-à-Pierre-Loiselle Formation (Fig. 1).

Mass movements observed in this sector are first caused by coastal erosion which locally triggers smaller planar and toppling failures that eventually transfer the instability to the upper part of the slope which is failing more or less along the bedding plane in a sort of rotating planar failure (see Cloutier et al. 2010 and Lord et al. 2010 for more details). It is interesting to point out here that the railroad was constructed around 1920 and little fissures are apparent on a 1933 aerial photograph of the sector above the railroad (Locat and Couture 1995a). Extensometer data obtained in 1993-1994 for the Petit-Massif (zone II in Fig. 3) indicated that the movements of a large block facing the ocean near the railroad were at about 0.3 to 0.4 mm/d which indicated that this part of the slope was about to fail in the near future (Locat and Couture 1995a). It did fail four years later in July 1998.

In order to contribute to the safe operation of the railroad, the Gascons project (2009-2013) was initiated.It has been designed using experiences at various sites in Canada such as Turtle Mountain slide (Moreno and Froese 2009), Acknes rockslide in Norway (Ganerød et al. 2008, Oppikofer et al. 2009), and rockslides in Switzerland (Sartori et al. 2003, Rouiller et al. 2004).

This paper presents the various objectives of the project, the instrumentation installed during the fall of 2009, the acquisition system and the proposed approach for slide monitoring and warning strategy. Since for most of the partners of the Gascons project the data acquisition is quite recent, many aspects will be presented with greater details at the time of the conference.

2 OBJECTIVES

2.1 Operational objectives

Operational objectives are considered here as those that will be directly implemented as the main outcome of the Gascons project. These are:

1. Setting up of a near real time monitoring system of slope movements monitoring;
2. Qualitative and quantitative analysis of various hazards and risks associated with mass movements at Gascons.

It is believe that these two objectives will help managing the risk associated to mass movements in this portion of the railroad. The monitoring system put in place to support the risk management effort has an expected life time of 20 years.

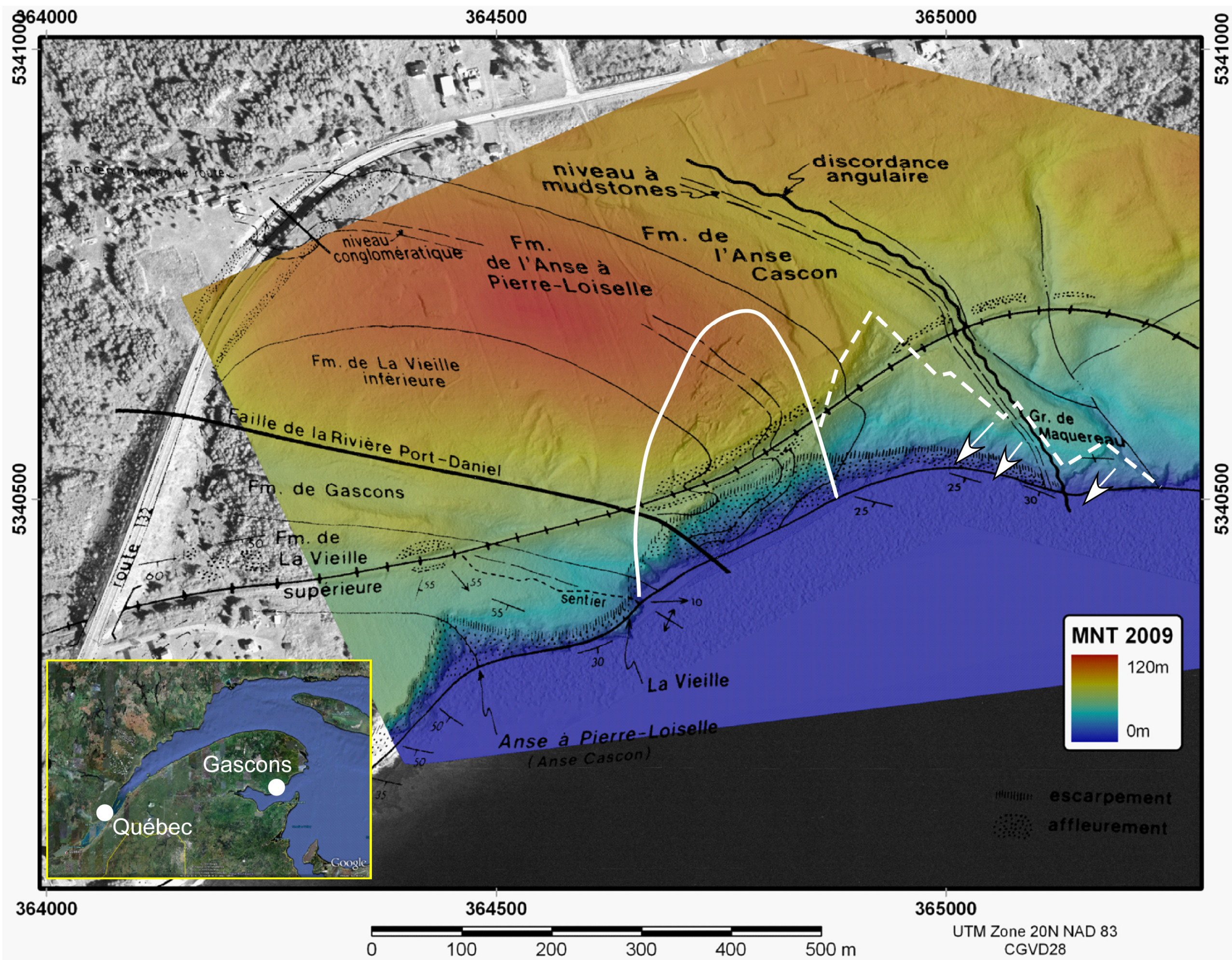

Figure 1. The Gascons study area showing the active slide sector (white line) and an older (dashed line) mass movement sector including more recent events shown by the white arrows. The geological information is from Bourque and Lachambre (1980). Here, the 2009 aerial LiDAR image has been draped over an aerial photograph.

2.2 Scientific objectives

In addition to the operational objectives mentioned above, the Gascons project offers a unique opportunity to address the following scientific objectives:

1. Validate the use of the *Shape Accel Array* (SAA) method for monitoring rock mass movements and railroad ballast deformations;
2. Develop warning criteria (displacement, speed, acceleration) adapted to the Gascons site;

3. Develop an integrated monitoring system of a rockslide as a tool for real time assessment of causes and consequences of mass movements;
4. Integrate slope deformation monitoring by coupling crackmeter/extensometer data, SAA method, InSAR and LiDAR (terrestrial) using a digital elevation model based on LiDAR surveys (both aerial and terrestrial);
5. Understand the kinematics of the rockslide considering that the main causes of instability are related to coastal erosion, response to groundwater regime changes, and possibly karst development and human activities;
6. Help in the qualitative and quantitative evaluation of the causes and consequences of mass movements in this region using methods developed by Fell et al. (2005) and Keegan (2007); and
7. Develop an evolutive approach for hazard assessment applied to rockslides which takes into account field observations and their evolution in space and time.

In order to achieve the above objectives, a scientific team has been put together. Preliminary results of the team effort ae summarized in papers presented at this conference (Cloutier et al, 2010; Couture et al. 2010; Danisch et al. 2010; Lord et al. 2010).

Table 1. Type, model, dimensions and location of instruments and boreholes (Roman numbers are for each zone shown in Figure 3).

Type	Model	Length (m)	I	II	III	IV	Remarks
Inclinometer	Roctest/Telemac DIS-500	60			1		GEO-LOK 70 mm tubing
Extensometer rods	-	-var	17	-	19		Grouted in place
Tape extensometer	Convex-Ealey	30					
Corner reflectors	Tripod	-	2	1	2	3	See Couture et al. 2010
Piezometers	Geokon 4500	-	3	-	3	3	Vibrating wire
SAA-H, Measurand	SAAF	60			1		50cm spacing for SAA
SAA-V, Measurand	SAAF	48 and 52	1		1		50cm spacing for SAA
Crackmeters	Geokon 4420	0.15 - 0.3		5	1		Vibrating wire, max. extension
Bi-axial tiltmeter	Geokon 6160				1		MEMS
Weather station:							
Rain/snow gauge	Met One 385					1	
Barometer	Met One 092					1	
Relative humidity and temperature	Campbell Scientific HMP45C-10					1	
Wind	Met One 014A					1	Wind is only for speed
Boreholes			2	-	3	1	Diamond drilling
Data acquisition	CR-1000						Using Logger Net

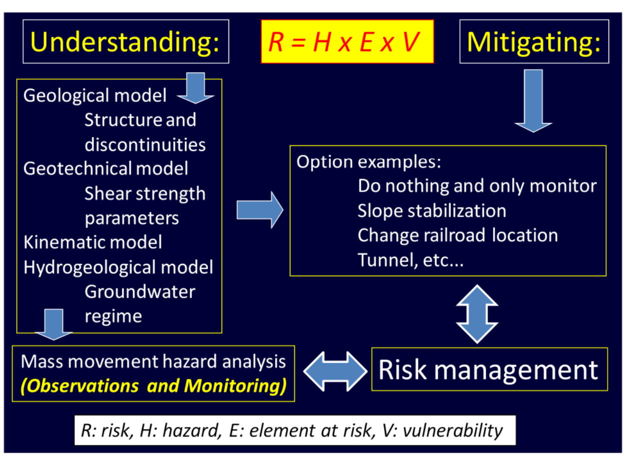

Figure 2. Overall approach for risk management proposed for the Gascons project.

3 APPROACH

The approach used for the Gascons project is quite typical of many other similar projects (e.g. Turtle Mountain, Froese and Moreno 2007). It is basically addressing two main aspects: (1) understanding and (2) mitigating (Fig. 2), the mitigation components being part of risk management decisions.

Developing an understanding of the various aspects of mass movements requires the development of various models tested against field observations and data analysis. The models are: geological, geotechnical, hydrogeological and kinematic.

The development of the various models requires the best available digital terrain model. To achieve this, the Gascons project involved both aerial and terrestrial LiDAR surveys. The terrestrial survey was conducted in July 2009 while the aerial survey could only be carried out in late October 2009 (Lord et al. 2010). Both surveys were proven to be very significant contributions to our understanding of the morphology of the Gascons site.

Since the Gascons site is an active landslide (i.e. Factor of Safety <1), analytical methods based on static equilibrium analysis are not as relevant for the hazard assessment. Therefore, the analysis must be based on knowledge generated by field techniques providing information on: the stratigraphy, the position of the failure surface, the types of mass movements involved, the role of groundwater and the displacements of the various blocks involved in the slide. This is why the various in situ instruments are put in place not to evaluate the factor of safety of the slope but to understand what affect its kinematics in order to be able to develop warning criteria based on displacement observations and their response to the various contributing factors such as erosion and pore pressure variations.

4 INSTRUMENTATION

The instrumentation selected for this project is summarized in Table 1. The instrumentation has been deployed according to zones of interest. Zone I is located above the railroad right of way and the main interest is to look at the large planar-like rockslide. Zone II corresponds to the active sea cliff under erosion and where rockfalls occurred in 1998 (Cloutier et al. 2010). Zone III corresponds to the area more or less included within the railroad right of way and zone IV includes the area outside the active slide. These zones of interest and the instrumentation selected also reflect the necessity to be able to track both the short and long term slope movements which velocity will vary greatly as it can be expected by considering the overall slope slow planar failure or local more frequent rockfalls along the cliff.

The position of the various instruments is shown in Figure 3. Most of the instrumentation has been concentrated on the western side where fissures are very well developed and also in the active part of the cliff which has been modified by a local slide in 1998 (Cloutier et al. 2010). In some cases, putting in place the instrumentation required drilling which was also helpful to describe the local stratigraphy and determine local variations in RQD values across the rock mass.

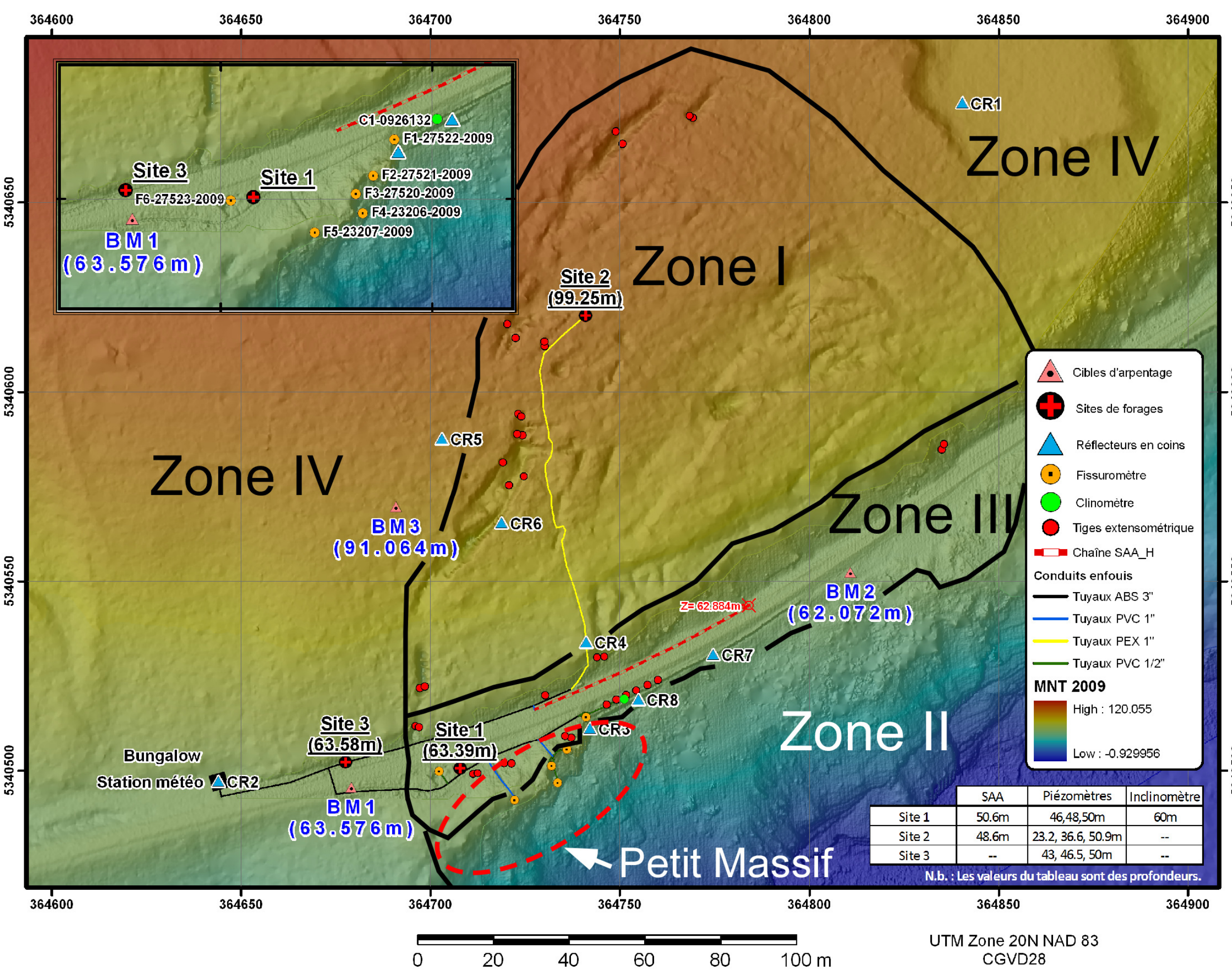

Figure 3. Instrumentation deployed for the Gascons site in the various zones. The insert shows the location of instruments near the cliff and the dashed red ellipse indicates the Petit-Massif area. The terrain model presented here is a combination of both terrestrial and aerial LiDAR surveys in 2009.

Site selection for the various instruments was done using available information on the slide (Locat and Couture 1995a) and also from a site visit in June 2009 (most of the instruments were put in place in late in October 2009). The LiDAR survey could only be done in late October so it was not available at the time when planning and installation of instruments took place.

Figure 4. Emplacement of a 52m long vertical string of SAA sensors at site 1 in zone III (note the required curvature radius needed for inserting the string).

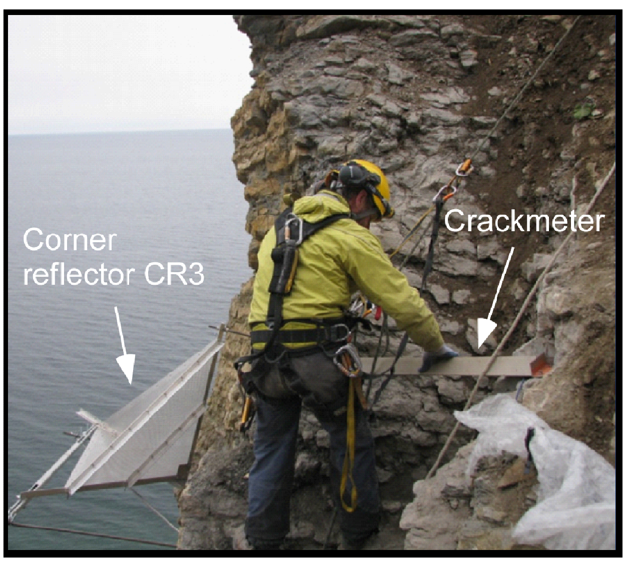

Figure 5. Installation of a protective cover on a crackmeter in Zone II (Petit-Massif).

Another strategic aspect was to make sure that instruments would be installed within and outside the slide area so that the mass movement characteristics could be best captured.

All the electrical instruments were wired up or down to the utility bunker (bungalow in Fig. 3) via a series of PVC and ABS tubes buried about 20cm below the ground surface (see below Fig. 8) to avoid any damage from animals and surface human activities.

4.1 Zone I

Zone I is a partly forested area where very large fissures and depressions are visible on the ground and also from the LiDAR survey (Fig. 3). In this zone, at site 2, in one borehole, three piezometers (depth of 23.2, 36.6, and 50.9m) were installed next to another borehole where a vertical string of SAA was deployed (e.g. Fig. 4; Danisch et al. 2010). Both boreholes reached a depth of about 50m. The cables connecting these instruments were carried down to the utility bunker (see yellow line in Fig. 3).

In addition, 17 extensometers rods where installed across eight fissures or depressions in Zone I (see also Lord et al. 2010) along with two corner reflectors (CR4 and CR6; see Couture et al. 2010 for more details).

4.2 Zone II

Zone II is the area of active coastal erosion leaving a steep (40° to 60°) and barren slope. Although not easily seen on the LiDAR map, this area is cut by many open fissures that delineate major blocks within the rock mass where rockfall and toppling failures are expected around the Petit-Massif (Fig. 3; Cloutier et al. 2010; Lord et al. 2010). For this reason, a total of four crackmeters were installed across as many fissures which define various block (e.g. Fig. 5) and few more will be put in place during the summer of 2010. In this zone, it has been possible to install one corner reflector (CR3, Fig. 5). Zone II has also been almost totally covered by ground LiDAR in June 2009 (Lord et al. 2010).

Figure 6. Installation of the 60m horizontal SAA string along the railroad track in zone III.

4.3 Zone III

Zone III is a very intensively instrumented area because of its proximity to the railroad and to zone II. Site 1 is located in this zone where three boreholes were drilled. The first one contains three piezometers at depths of 46, 48, and 50m; the second is for the inclinometer reaching a depth of 60 m, and third one was used for placing a 52m long vertical string of SAA sensors (Fig. 4). In this zone, a 60m long horizontal string of SAA sensors has also been put in place next to the wood caisson supporting the railroad ballast (Fig. 6) and in the same area that has been impacted by the 1998 rockfall. Also along the retaining wall, one tiltmeter (Fig. 7) and two corner reflectors have been installed (CR7 and CR8).

In zone III, a total of 19 extensometer rods were installed, mostly below the railroad and some close to the two crackmeters installed in that zone (Fig. 3).

4.4 Zone IV

Zone IV comprises all the area surrounding the active slide. Instruments used here were mostly intended to provide a ‘stable’ reference to reveal differences in the behaviour (movement or pore pressure) within the slide area (zone I, II and III) compared to the outside stable area.

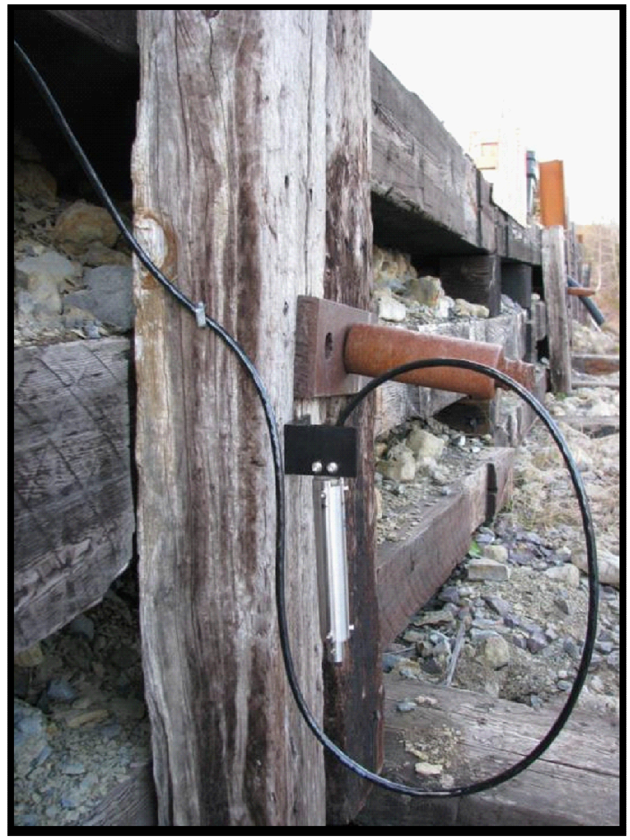

Figure 7. Tiltmeter installed on the wood retaining wall in zone III.

In zone IV, one borehole was drilled (site 3 in Fig. 3) to install a nest of three piezometers at depths of 43, 46.5, and. 50m. It is also in this area that the utility bunker (Fig. 8), built to house the data acquisition system. The weather station and a corner reflector (CR2) were installed on the roof of the bunker. Corner reflector CR1 and CR5 have also been placed in zone IV.

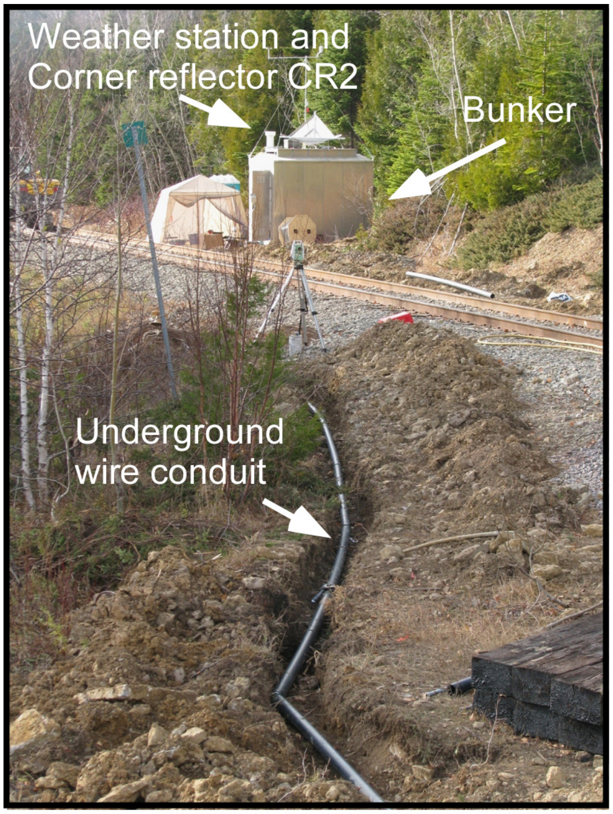

Figure 8. View of the utility bunker housing the data acquisition system, the weather station and a corner reflector. This photograph also shows the excavation required to burry all wires in an underground conduit (ABS system).

5 DATA ACQUISITION AND MANAGEMENT

The data acquisition is under the control of a Campbell Scientific CR1000 data logger for all powered instruments. As indicated above, all wires from all instruments converge towards the utility bunker where the data acquisition and transmission system is hosted. Because of service proximity, all the wired instruments are powered by electricity and the data are transmitted via a phone line. Other non powered instruments are read at each visit (six at the time of writing) and this is for the inclinometer (two surveys), extensometers (six surveys) while the corner reflectors are surveyed every 24 days by RadarSat II satellite (Couture et al. 2010).

The CR1000 is programmed to acquire data from all instruments in the following sequence: crackmeters, tiltmeter and weather station every hour, while SAA strings and piezometers are read once a day. At the time of writing this paper, the data are manually downloaded weekly via the phone line into the data base at Université Laval. Work is in progress for establishing an internet connection and remote control of the data. As of now, we are planning to adopt a strategy similar to what has been developed in Switzerland by the Centre de Recherches en Environnement Alpin (CREALP, Rouiller et al. 2004.

The expected flow of information is shown in Figure 9 where it is integrated in a proposed scheme for data management and emergency response.

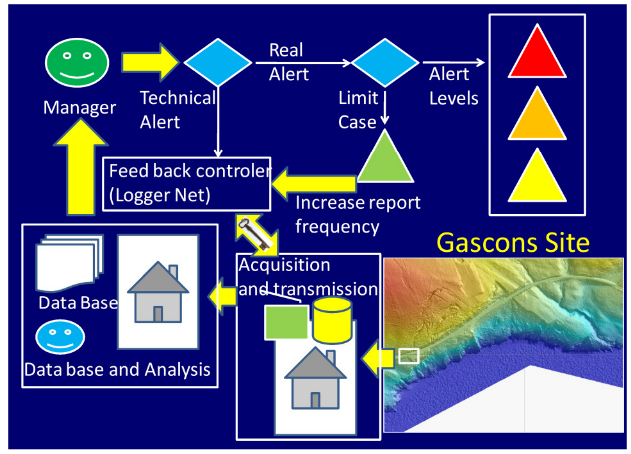

Figure 9. Proposed flow chart of data and alert process. Triangles indicate alarm level from none (green) to high (red).

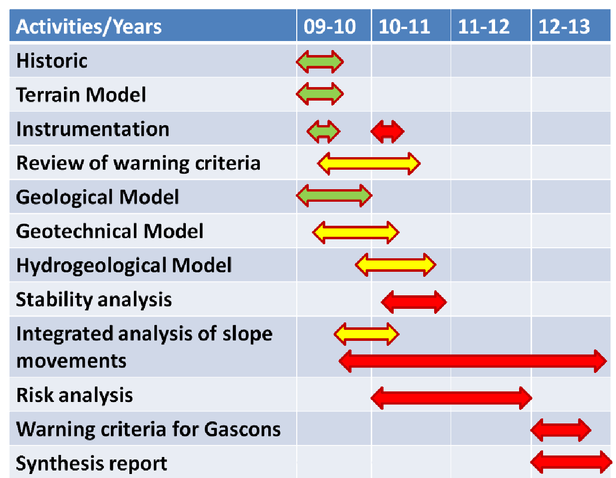

Figure 10. Calendar of activities for the Gascons project. The green, yellow and red colors are respectively for work completed, in progress or forthcoming.

As planned at this time, the local utility bunker hosting the data acquisition system will also include two computers responsible for the quasi-real time monitoring of all the sensors. For example, a possible scenario could be as follows. The sampling rate will be tested and set at the maximum and the flow of data from the utility bunker at the site is to be done on an hourly basis so that it is continuously assembled into a general data base. At the same time, the monitoring system would provide a visual report of the data and of potential alarms to the manager (likely a geotechnical engineer) that will analyse the observations and initiate an alert if necessary. If the manager considers that the alarms is due to technical reasons (i.e. false or a technical alarm, Fig. 9) he will be able to interrogate directly the on-site data acquisition system to identify the problem and call for repairs if needed. If it is a real alarm, action will be taken according to the critical levels (still to be determined). Depending on the situation, the reporting of the data to the manager could be increased but still one must also consider the time to carry a proper analysis of the data. Any relevant alarm information shall also be directed automatically to the few people involved in the chain of responsibility but they shall wait for the manager request before taking any action.

6 CONCLUDING REMARKS

The Gascons project was officially launched June 1st 2009 and it will last until March 2013. The research team is just starting to capture field observations and the work required to integrate and develop a practical understanding of the situation.

The initial calendar of activities is given in Figure 10 to show the remaining steps. As for any project of this nature, initial plans evolve with time as it is for our understanding of the situation.

For example, the acquisition of the LiDAR data provided an unexpected view of the terrain with very much improvement on the location of the various fissures, and also revealed a significant old rockslide features just to the east of the active slide (see Cloutier et al. 2010 for more details). Along the same line, the morphology of the sea floor facing the Gascons study site will be revealed by a multibeam (or sonar interferometry) survey of about 2 km^2 of the bay off the slide area to look at potential older slide debris or evidence of any groundwater springs. This survey is planned for the summer of 2010.

Having now the instrumentation in place and operating, assessing warning criteria can began but the kinematics of the slide will need to be understood before any relevant warning criteria be proposed. Extensometer measurements across large fissures revealed that the upper part of the slide is moving few millimetres per month, at a similar rate than the large blocks in zone II.

The hazard assessment is forthcoming and will consider the various types of failures and their conditioning, i.e. how to link displacement rates or pore pressure changes to increase instability and the response of the kinematic model.

As part of the planning of the project, some funds were kept to add few more instruments in 2010 based on our improved understanding of the Gascons slide. As of now, we are planning to install four or five new crackmeters in zone II and few more extensometer rods in the eastern part of zone I which has been better defined by the aerial LiDAR survey. In addition, 6 to 8 corner reflectors will be added in October 2010 in other parts of the Gascons slide and its surrounding.

The use of all the data is being illustrated in the various papers that have been proposed for this conference. These papers show the developing integration of the data in an inter-active remotely operated monitoring system. Altogether, the initiation of the Gascons project as required an intense team effort to be able to put in place the monitoring infrastructure. The next few years shall enable a much improve understanding of the Gascons rockslide while providing a unique site for developing and/or testing new technologies like SAA sensors and InSAR.

ACKNOWLEDGEMENTS

The writers would like to acknowledge the support of the Ministère des transports du Québec, Transport Canada, the Ministère de l'éducation des loisirs et des sports du Québec, and the Canadian Space Agency. We also acknowledge the contribution of the Earth Science Sector (No. 20100060). We also wish to thank Vincent Fournier and Associates for their contribution related to drilling and borehole installation of various instruments. We also acknowledge the discussions and advices of Stéphane-Eric Thivierge of GKM Consultants. Thanks also to the Chemin de fer de la Gaspésie for their logistical support. Finally we would like to thank Geneviève Cauchon-Voyer, Luc Boisvert and Andrée-Anne Fortin-Rhéaume from Université Laval for their help in the field. We also thank Wendy Sladen (Earth Science Sector) for her review of the paper.

REFERENCES

Bourque, P.-A., and Lachambre, G. 1980. *Stratigraphie du Silurien et du Dévonien basal du sud de la Gaspésie, Rapport ES-30*, Direction de la géologie, Direction générale de la recherche géologique et minérale. Ministère de l'énergie et des ressources du Québec, Canada.

Cloutier, C., Locat, J., Lord, P.-E., and Couture, R., 2010, Caractérisation des instabilités côtières dans le secteur de Port-Daniel-Gascons, Gaspésie, Québec. *Proceedings of the 63rd Canadian Geotechnical Conference*, This volume.

Couture, R., Charbonneau, F., Murnaghan, K., Singhroy, V., , Lord, P.-E., and Locat, J., 2010. PTA-InSAR rock slope monitoring at the Gascons site, Gaspe Peninsula, Quebec. *Proceedings of the 63rd Canadian Geotechnical Conference*. This Volume.

Danisch, L., Patterson T., Cloutier, C., Lord, P.-E., Locat, J., and Bond, J., 2010. Integration of SAA technology for coastal rock slope movement monitoring at Gascons, Gaspé Peninsula, Québec, Canada. *Proceedings of the 63rd Canadian Geotechnical Conference* . This Volume.

Fell, R., Ho, K.K.S., Lacasse, S., and Leroi, E., 2005. A framework for landslide risk assessment and management. *In: Landslide Risk Management*, Hungr, Fell, Couture and Eberhardt, Ed., Taylor and Francis, pp.: 3-25.

Froese, C.R. and Moreno, F. 2007. Turtle Mountain Field Laboratory (TMFL): Part 1—overview and activities. In V.R. Schaefer, R.L. Schuster & A.K. Turner (eds), Conference Presentations: 1st North American Landslide Conference, AEG Special Publication 23: 971–980. Vail, Colorado: Assoc. of Engineering Geologists.

Ganerød, G.V., Grøneng G., Rønning, J.S., Dalsegg, E., Elvebakk, H., Tønnesen, J.F., Kveldsvik, V., Eiken, T., Blikra, L.H., and Braathen, A. 2008. Geological model of the Åknes rockslide, western Norway. *Engineering Geology* 102: 1–18.

Keegan, T. 2007. Methodology for risk analysis of railway ground hazards. Ph.D. thesis, Geotechnical Engineering, University of Alberta. 485 pages

Locat, J., and Couture, R., 1995a. Analyse de la stabilité du massif rocheux au millage 30.5, Division Chandler, Anse-aux-Gascons, Gaspésie, Québec. Groupe de recherche en environnement et en géo-ingénierie, Département de géologie et de génie géologique, Université Laval, Rapport GREGI 95-01, 85p.

Locat, J., and Couture, R., 1995b. Analyse de la stabilité d'un talus rocheux à l'Anse-aux-Gascons, Gaspésie, Québec. *Proc. 48th Canadian Geotechnical Conference*, Vancouver,: 885-892.

Lord, P.-E., Locat, J., Cloutier, C., and Pedrazzini, A., 2010. Analyse des mouvements de terrains au site de Gascons, Gaspésie, par couplage d'observations aéroportées et terrestres. *Proceedings of the 63rd Canadian Geotechnical Conference* . This Volume

Moreno, F. and Froese, C.R. 2009. ERCB/AGS system manual for the Turtle Mountain Monitoring Project, Alberta; *Energy Resources Conservation Board, ERCB/AGS* Open File Report 2009-14, 87 p.

Oppikofer, T., Jaboyedoff, M., Blikra, L., Derron, M.-H., and Metzger. R. 2009. Characterization and monitoring of the Aknes rockslide using terrestrial laser scanning. *Nat. Hazards Earth Syst. Sci.*, 9: 1003–1019.

Rouiller, J.-D., Ornstein, P., and Délèze, J.-Y., 2004. Guardaval : un système de télésurveillance adapté aux régions de montagne. *Proceedings of the 57th Canadian Geotechnical Conference*, Session 3C: 25-30.

Sartori, M., Baillifard, F., Jaboyedoff, M., and Rouiller, J.-D., 2003, Kinematics of the 1991 Randa rockslides (Valais, Switzerland). *Natural Hazards and Earth System Sciences* 3: 423–433