SEVERE WEATHER WARNING LEVELS FOR GEOTECHNICAL RAILWAY HAZARDS

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Abstract
Historically ground hazards have caused periodic losses and interruptions of rail service. Case histories are cited that demonstrate that severe weather, primarily extreme precipitation events, trigger these ground hazards. Work is in progress to develop weather indices that could be used as alert criteria within the railway's operating framework. These indices would be region or site specific and specific to ground movement hazards that could potentially affect the safe operation of the track in that region. The railway industry is well suited to the application of weather warning indices and graduated-actions in response to the severity of the climatic conditions. As a result, the application of this research to the rail sector appears to provide a greater opportunity to reduce the impact of ground-movement on the railway industry, than other business and public sectors. This paper includes an update on the research activities completed to date.

Résumé
Historiquement les chemins de fer ont soutenu des pertes et des interruptions périodiques de service à la suite des dangers de sol. Les histoires de cas sur ce sujet démontre que le temps sévère, principalement les événements de précipitation extrêmes, déclenche ce type de danger de sol. Actuellement, du travail est encours afin de développer des index de temps qui pourrait être utilisé comme les critères d'alerte dans le cadre de la structure d'opération des chemins de fer. Ces index seraient établis selon des régions ou des sites spécifiques et viseraient les dangers de mouvement de sol qui pourraient affecter potentiellement l'opération sécuritaire du chemin de fer (le rail) dans cette région. L'industrie de chemin de fer est bien adaptée à l'application d'index d'avertissement de temps ainsi qu'aux actions échelonnées en réponse à la sévérité des conditions climatiques. Par conséquent, l'application de cette recherche au secteur ferroviaire semble fournir une plus grande occasion pour réduire l'impact des mouvements de sol pour l'industrie du chemin de fer, que les autres industries et les secteurs publics. Ce papier inclut une mise à jour sur les activités de recherché complété jusqu' à ce jour.

1.0 INTRODUCTION

The railway industry is exposed to a wide variety of geotechnical hazards and safety concerns. These include the hazards classified in Figure 1. A review of the records compiled over the past 122 years by Canadian Pacific Railway (CPR) indicates that at least 30% of the larger volume hazards occurred synchronous with severe weather events, most commonly prolonged periods of increased precipitation intensity. Severe weather events are defined as climatic conditions including antecedent conditions that develop over months or years that have a return period of at least 10 years. To reduce the impact of these events on the safe and reliable railway operation, CPR retains the service of a weather-information provider. This information comes in three forms: 1) synoptic reporting of current conditions, 2) forecasts of predicted conditions, and 3) Weather warnings (as defined by Environment Canada and the National Weather Service (NWS) in the US).

Chowdhury and Flentje, 1998; Cullum-Kenyon et al., 1998; Rahardjo et al., 2001 and others have investigated the relationship between weather and geotechnical hazards. Commonly this work has focused on establishing a link between specific landslides and specific meteorological events. In contrast, the railway corridor operated by CPR (see Figure 2) transects diverse climatic, geologic, and geographic conditions. Hence, it is unlikely the site specific approaches used by others would be applicable to the diverse conditions encountered by railways.

Within the railway operating-environment, raw and processed meteorological data can be compiled for a specific site or region to develop climatic indices. Initially, only those regions that are identified as problematic will be analyzed. These climatic indices will be compared to alert index criteria for the site or region that have been compiled based on historic incident and hazard reports. The current research

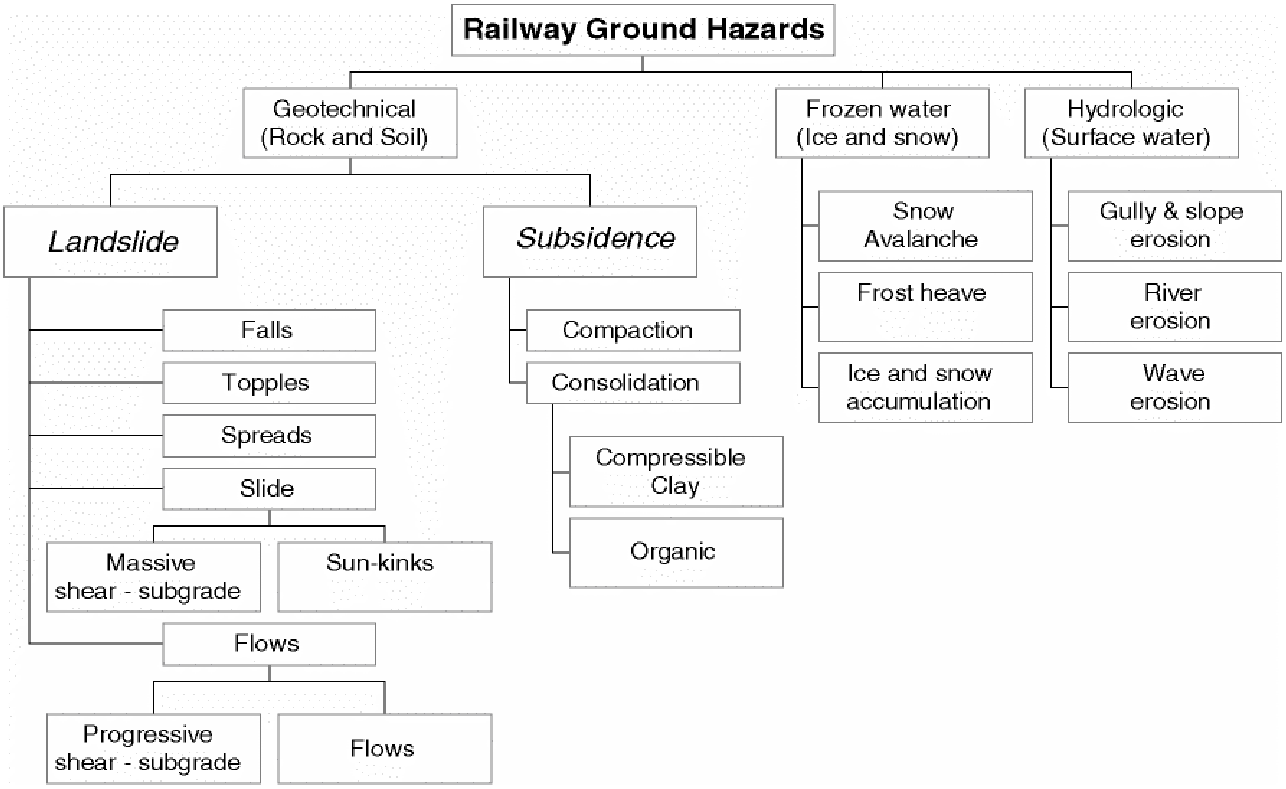

Figure 1: Railway ground hazards classification warrants response by the railway (after Keegan, 2003, pers. comm.). The indices will be developed for use throughout most of North America's mid latitude climatic and geographic regions.

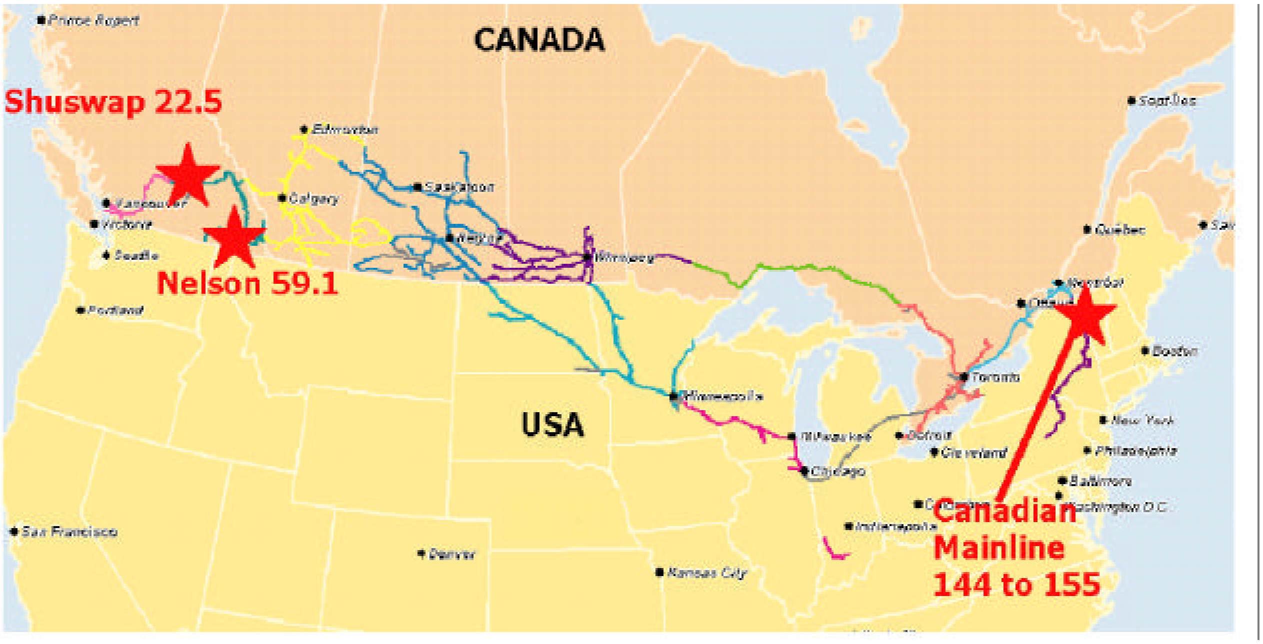

Figure 2. Map of North America showing CPR's track and sites discussed in the paper

will establish what indices are appropriate for a specific region and what criteria for each index warrants response by the railway. The indices will be developed for use throughout most of North America's mid latitude climatic and geographic regions.

2.0 CURRENT USE OF WEATHER INFORMATION BY RAILWAYS

Class 1 railways in North America use weather information in numerous ways. Temperature information is used to limit train speed during severe cold and hot conditions to reduce the potential for broken rail and rail sun-kinks, respectively. During winter, snow and road conditions may limit train and maintenance crew movements on highways. Despite the use of switch heaters clearing switches of snow and ice is required to assure switches operate correctly during winter months.

The track, bridge, and structures maintenance personnel also use weather information, such as rainfall amounts, to predict increased potential for damage to the track and structures. Heavy rainfall forecasts frequently prompt increased track and structure inspections. In rare cases trains have been slowed over tens-of-miles of track in response to high rainfall conditions and forecasts. At present, the use of this information, by these individuals, is non-systematic, and empirical.

One of the more common scenarios is prolonged, intense rain in a specific area where the antecedent soil moisture is already elevated due to previous precipitation or snow melt events. Under these conditions, small-scale erosion and sluffing of steeper slopes become relatively common and ditches become blocked with debris. Track maintenance personnel often work around the clock clearing debris from culverts and inspecting the track for debris. The maintenance personnel are empowered to invoke multi-mile slow orders or provided increased access to track time to complete inspections. However, they often need additional climatic information to support their observations and cause for concern. Furthermore, maintenance personnel are not equipped with any means of quantifying or communicating the hazard level. At same time, the Transportation group (and the Network Control Centre or NMC) within CPR that controls train movements is not informed as to the severity of the hazard along the track. As a result, these severe climatic events are not always responded to in a proactive manner.

Less common, but of generally more impact, are events like the 4-month period in the spring of 1997 in British Columbia. Unusual high accumulations of snow in late 1996 combined with prolonged mild and wet spring conditions resulted in high soil moisture conditions throughout southern BC (TRB 1998). During this period CPR experienced slope movement in numerous locations, including:

1. Heavy snow caused numerous avalanches, debris slides and rock falls ranging in volume from less than 0.1 to 1,000 m^3 in the Fraser Canyon between Hope and Spences Bridge. This resulted in a five-day closure of the CPR tracks in the Thompson and Fraser valleys in late February 1997.

2. Thirteen massive-shear subgrade-failures in fill ranging from 20 to 2,000 m^3 occurred between Mile 71.3 and Mile 77.8, 10 km northwest of Salmon Arm during early March 4, 1997. Track settlement resulted and slow orders were imposed.

3. Four massive-shear subgrade landslides of 1,500 to 10,000 m^3 occurred 3 miles east of Cranbrook, BC between March 19, 1997 and April 1997. The track was left unsupported over a length of 20 m above one failure. The track bed settled up to 100 mm and the embankment shoulder dropped 0.1 to 3.0 m over an additional length of several 100 metres.

4. A massive shear failure landslide of 35,000 m^3 caused track settlement of approximately 100 mm at Mile 74.8 of the Nelson Sub, 13 km north of Creston, BC on April 16, 1997.

5. Ten landslides of 300 to 3,000 m^3 occurred between Mile 60.6 and 61.7 of the Shuswap Sub, 2.5 km northeast of Salmon Arm around April 27, 1997. In some cases debris reached the track and blocked rail traffic.

6. A 10-million m^3 landslide was partially remobilized at Mile 99.6, 22 km east of Revelstoke in May of 1997. About 100 m of track settled 50 to 200 mm.

During these types of multi-month events, maintenance personnel often use the predictive capacity of public weather information services to identify periods of severe weather that may trigger additional geologic or hydrologic hazards. To assist these personnel and allow scheduling to reduce the impact of severe weather many railways subscribe to weather information services to provide weather information and pass on severe weather warnings referenced to track location. CPR utilizes one of these services. Upon notification of severe weather the CPR responds with staged responses called the Severe Weather Alert Levels or SWAL's.

CPR SWAL SYSTEM

Since the early 1990's, CPR has enlisted the service of a weather information provider. The SWAL system is briefly described in Figure 3. Historically the SWAL process was restricted to wintertime and was known as the Winter Alert Level (WAL) but since 1999, a year round process has been adopted.

The area of the SWAL system of most relevant to this work is the box labeled "Compare against area specific criteria". The determination of the many of the area specific criteria is the responsibility of the geotechnical group within Engineering Services at CPR. At present, CPR uses the return period of a given event as a proxy as to the severity of the impact on the infrastructure. The logic being that the less frequently an event has occurred the more likely that event is to cause damage given that the infrastructure is rarely exposed to such an event. This system is in place for short term less than 24-hour events. Due to the untested nature of the antecedent indices and to reduce unnecessary false alarms, the return period assessment has not been utilized for antecedent conditions to date.

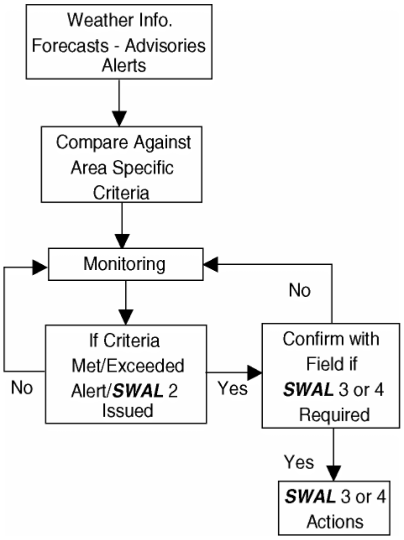

Figure 3: CPR Severe Weather Alert Level (*SWAL*) system process map.

To evaluate the antecedent warning system a non-standardized process has been periodically tested to determine it efficacy. Two notable examples of how the severe antecedent warning system has worked are described below.

In the spring of 2002, the area of BC around Hope was being inundated by severe precipitation. Both CN and CPR received notification of the elevated antecedent precipitation condition by their weather information provider. The track and structures maintenance crews were notified. No damage was experienced on the CPR, however, had a railway ground hazard occurred the heightened awareness is expected to have reduced the consequences of the damage. During this period, the Trans-Canada Highway was blocked by a debris slide west of Hope.

In the spring of 2001, a series of storms moved across the Kenora area of western Ontario. Several heavy rainstorms occurred over several days and a wide spread slow order was imposed. Stream erosion damaged a culvert and the subgrade 5 miles west of Kenora, Ontario. A minor derailment occurred as a train crossed the area. Had the train been at traveling normal track speed the derailment could have been significantly worse.

It is apparent that the opportunity exists to provide the maintenance personnel and NMC more regionally and hazard specific information on which to act. It also includes the potential to become more prescriptive in the actions that are warranted in relation to the severity of climatic event. The research activities are intended to address this need.

3.0 CASE STUDIES

The following three case studies demonstrate the need for longer-term antecedent conditions criteria for issuance of SWAL alerts. The locations of the case study events are provided in Figure 2. As will become apparent in the case studies, different severe weather criteria will be required to warn of increased hazard potential depending on the geology, climate, topography, and hazard type.

Case 1 - Shuswap Sub, Mile 22.6, June 13, 1990

At 17:20 on June 13, 1990 a debris flow of 5000 m^3 inundated the tracks at Mile 22.5 of the Shuswap Subdivision, 29 km west of Revelstoke, BC. The debris flow apparently hit a passing train derailing the 4th to 17th cars. The debris flow originated as a landslide of 200 to 600 m^3 of colluvium over bedrock. It entered the streambed about 2.2 km upstream of the track. The gradient of the creek is on the order of 16 degrees. The slide appears to have been triggered by a combination of erosion at the toe slope and saturation of the soil.

The landslide and subsequent debris flow was triggered by severe rainfall as recorded at Malakwa 13 km west of the site and Revelstoke 29 km east. The 70 years of records for Malakwa indicate that this area received normal rainfall for several days prior to June 13, 1990. However, over 230 mm of rain fell on the area in the prior 30-days. This 30 day antecedent rainfall has a return period estimated at 34 years. Furthermore, the preceding 120-day rain and snowmelt of 630 mm of precipitation is expected to occur less than once every 80 years. Despite the rarity of the climatic conditions leading up to June 13, 1990, a debris flow damaged a neighbouring property in the spring of 1999 (Figure 4). The spring 1999 event had little impact on the railway but it filled the fish hatchery ponds with debris and sediment. The antecedent and precipitation conditions prior to the 1999 event have not been investigated at this time.

Figure 4. Oblique aerial photo of Shuswap Sub, Mile 22.6 on April 4, 1999 following a debris slide into the Fish Hatchery during the spring of 1999. This event did not affect the railway or highway. The June 13, 1990 debris flow inundated the track immediately east (right) of the radio tower.

Case 2 - Nelson Sub, Mile 59.1 May 31, 1998

During May of 1998 the area surrounding Creston in southeast BC received more that 179 mm of rain. The resulting runoff triggered a massive shear subgrade landslide of 2200 m^3 of the CPR side hill fill embankment and natural ground at Mile 59.1 of the Nelson Subdivision in the early morning hours of May 31, 1998. Later that morning three locomotive locomotives and four cars derailed as they passed over the 30 m section of track left unsupported by the failure. Fortunately the locomotive operators escaped with only minor injuries (TSB 1999).

The track traverses the south slope of the Goat River valley wall about 25 m above the flood plain. The average slope angle above and below the track is 30 to 38 degrees. The soil consists of 1 to 2 m thick well-graded granular fill over glacial and colluvial deposits. Although glacial lacustrine deposits are present within 1 km west of the site no silts were identified in the back scarp of the failure or test pitting investigation.

Analysis of the climatic conditions indicates that the May 1998 was one of the wettest periods on record. The extreme value analysis of the precipitation information is also included in Table 1.

Table 1. Extreme value return period analysis of May 1998 rainfall for Creston, BC

Antecedent period	**Cumulative Rainfall (mm)**	**Return period (years)[1]**
4 days	70.6	50
7 day	105	99
14 day	147.4	~100
15 day	168	> 170
30 days	179	52
120 days	305	10

1 - Based on 82 years of record

Case 3 - Canadian Mainline, Mile 143.85 to Mile 155.30, June 26, 1998

Over the course of several days in June 1999, a section of the Canadian Mainline south of Plattsburg, New York endured a severe weather condition resulting in numerous landslides and areas of erosion. This eight-mile section of track was located between Port Douglas and Port Kent on the west side of Lake Champlain. Damage at 34 sites between Mile 143.85 and 155.3 consisted of hydraulic gully and slope erosion, seepage erosion, debris flows, and massive-shear subgrade landslides (Figure 5). Landslide and erosion volumes ranged from ten to several thousand cubic metres. At the largest event, the destruction of a culvert, at Mile 150.17 near Port Douglas, caused the derailment of a train. Fortunately, the operators escaped with minor injuries, however, the railway incurred significant losses and was out of service for 6 weeks.

Figure 5. Oblique aerial photo of one of the many massive-shear subgrade landslides and seepage erosion sites near Port Kent (north of Port Douglas, NY.

Along this section of west shore of Lake Champlain the track is located 20 to 45 m above the lake shore. It traverses bedrock outcrops; colluvial and dense till side slopes; alluvial sand and silt terraces; and the lacustrine silt and clay deposits. The track damage was primarily in the areas of erodible silt and sand fills and natural silt and sand deposits; and in the areas of interbedded lacustrine silts and clays. At the failure sites, natural slopes are at the or slightly above the angle of repose due to gully, slope, and lake-shore wave-erosion.

The precipitation records, before June 26, 1998, of several weather stations near Port Douglas and Port Kent, NY were analyzed. The closest weather stations to the damage were located 12 km to the northwest and 16 km to the south and east. Peru, the station to the northwest, recorded precipitation in excess of the 50 year return period for 24 hour duration, and in excess of the 100 year return period for the 2, 10 and 30 day accumulation periods. The stations to the south and east were in the 10-year return period range for the same rainfall durations.

To investigate why the 11.5 miles of track between Mile 155.3 and 143.8 was so heavily damaged the available weather radar data was analyzed. The results of this analysis are illustrated in Figure 6 and shows that the precipitation in the area of interest ranged from 0 inches in the northeast to 8 inches in localized areas. The plot is consistent with the lower rainfalls in Willsboro and Burlington and the higher amounts in Peru, but it also shows the dramatic spatial variability across the region and along the CPR track. Notably, the area of damage did not directly receive as much rainfall as other areas of the track. However, the drainage basin to the west of the damage area did receive intense rainfall and likely contributed to the concentration of damage in this region.

4.0 CLIMATE CHANGE

Although, the specific effects of climate change on precipitation are poorly quantified at this time CPR recognizes that climate change may affect the application of return-period type indices. Although untested at this time the expectation is that by re-assessing the return period of given events using a sliding 30 year data sample it should be possible to identify climate change trends in the severity of mid to long return period events. However, the higher frequency and increased severity of extreme weather events, predicted by some as being a product of climate change, will test the robustness of the railway infrastructure. As such, it is likely that the affects of climate change, if realized, will test the weather information system.

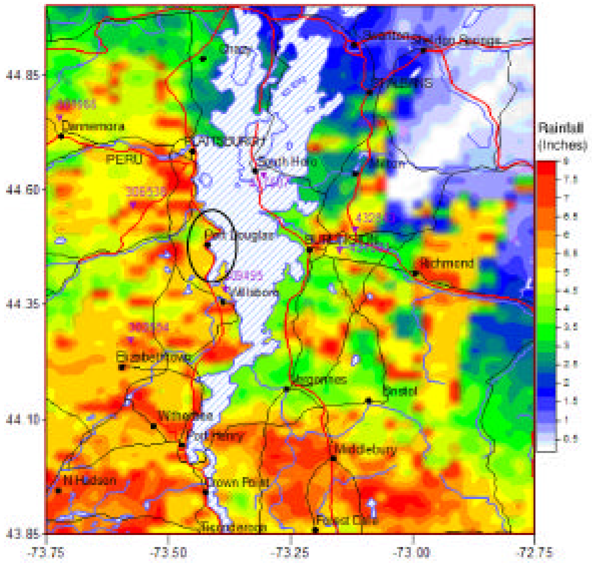

Figure 6: Lake Champlain, NY weather radar precipitation for the month of June 1998 with the track in red along the west shore and an ellipse around the area of damage.

5.0 CONCLUSIONS

The cited examples indicate that severe weather, primarily extreme precipitation events, can trigger natural hazards that influence the safety and reliability of a railway's operation. The value of weather radar has been demonstrated in assessing the conditions at specific locations along the rail corridor and within the drainage basin upstream of the corridor. Furthermore, it should be possible to identify specific criteria that can be used to warn the railways that the potential for a specific hazard is elevated and that proactive measures are warranted to reduce losses. Had these indices been available to the railway in each of the cited case, and the railway had invoked preventative measures the safety of personnel and equipment could have been increased and the loss to the railway could have been reduced.

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