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Emergency response Canadian Pacific Railway Canadian Main Line

Barry A. Palynchuk, PhD, McMaster University
Michael J Loehr
Robert W Badger
Robert P Conroy
Clive H Mackay
1.0 INTRODUCTION

In late June 1998, a major storm event occurred in the Adirondack Mountains in the vicinity of Keeseville, New York about 150 miles north of Albany. This storm resulted in unprecedented damage to the Canadian Pacific Railway (CPR) Canadian Mainline along the shores of Lake Champlain. The storm caused 14 major embankment failures and washouts, numerous minor failures, severe bridge foundation scour and a major mainline derailment.

This paper will describe the affected rail corridor, the details of the storm event, the resulting damage, the failure modes and analysis, impacts to the surrounding communities, and the reconstruction strategies and construction management techniques used to restore the line as quickly as possible.

In addition to the technical aspects of this project, the problem solving strategies employed by the emergency response team assembled by Canadian Pacific Railway and Clough, Harbour & Associates LLP (CHA) will also be discussed. Effective communication and teamwork were major factors in getting the job done in a timely and cost-effective manner.
A map indicating locations where the major damage occurred is shown in Figure 1.
2.0 SITE DESCRIPTION

The Canadian Mainline is CPR’s primary north-south route that carries both freight and passenger traffic between Montreal, Quebec and Albany, New York. The route is operated and maintained by its subsidiary the Delaware & Hudson Railway (D&H) which is part of the St. Lawrence & Hudson Railway and CPR rail network.

The corridor was originally constructed in the 1880’s in the mountainous terrain along the western shore of Lake Champlain that is now part of the Adirondack State Park. The distance from Albany to the Canadian border is about 150 miles. The track geometry of the line typically includes curves up to 8 degrees and the profile typically has grades greater than 1%.

Because of the dramatic topography in this region, the rail line was built through major cut and fill sections, with some embankments as high as 80 feet above original ground. These embankments were typically constructed using locally available soil materials.

The surficial geology at the southern end of the affected area is generally mapped as glacial till, described as silt and silty clay containing textured sand, gravel and boulders deposited under glacial ice.

The northern end is mapped as marine and lacustrine sand, described as well sorted sand and gravel deposited at the lake shoreline. Bedrock is also visible along the corridor.

The rugged terrain also required a significant number of cross culverts, mostly stone box and stone arch construction as large as 12 feet in diameter, as well as numerous bridges of various types in order to accommodate the intense storm runoff in this area. Prior to the storm, much of the original Canadian Mainline infrastructure was still in place and in generally good condition.
3.0 STORM DAMAGE

3.1 Derailment Site at Mile 150.2

At about 1:30 AM on the morning of June 26th a freight train traveling about 20 miles per hour was headed south from Montreal to Albany on the Canadian Main. Visibility was poor because of the intense rainfall. The crew noted that water was at or above the top of the ties between Mile 162 and 152. However, the signal at Mile 152.1 gave a clear indication and the crew continued southward.

The rails and embankment appeared intact as the train passed over a steep embankment at Mile 150.2. The railroad embankment at this location crosses a mountain stream called Little Trout Brook. The embankment is about 400 feet long and has a maximum height of about 80 feet. The 12-foot stone arch culvert under the embankment had been inspected annually and was in excellent condition prior to the derailment.

The conductor, who was sitting on the eastern side of the lead engine, actually observed the slope on the eastern side of the embankment begin to fail. Two of the three locomotives successfully made it over the embankment and came to a stop on the tracks about 350 feet south of the embankment. The third locomotive and 4 cars were carried down the steep slope as it failed. Fortunately, no one was injured.

The washout site as it looked on the afternoon of the derailment on June 26th is shown in Figures 2 and 3.
Inspection of the derailment site the following day revealed that the failure scarp on the eastern side of the embankment extended to the western crest of the embankment, undermining the tracks. The failure scarp extended over a length of about 130 feet along the tracks and was centered over the masonry arch culvert. The scarp was near vertical at the top, flattening out towards the base. Approximately 50 feet of culvert at the downstream outlet had washed away.
Inspection of the culvert inlet indicated that the water level had reached as high as about
3 feet above the crown at some point during the storm. There was no evidence of blockage of
the culvert by debris. Embankment soil exposed in the upper part of the failure scarp was moist,
but did not appear saturated.

The western embankment slope was intact. Topographic mapping completed several
days after the failure revealed that the western slope was constructed at an average slope of about
1.5 Horizontal to 1.0 Vertical (or about 33 degrees). The slope was somewhat steeper near the
top than it was at the bottom. The eastern slope was presumably constructed to a similar
geometry.

Much of the landslide debris, including trees and vegetation, had been washed away by
the high water flow in the Little Trout Brook. Sediment was deposited over the banks of the
Brook between the embankment and the shore of the Lake Champlain. Initially, the rail cars at
the base of the embankment were mostly inundated, with only the upper parts of the cars
extending above water. Water levels receded during the day.

3.2 Embankment Failure at Port Kent at Mile 154.5

Later in the day on June 26th it was also discovered that several major washouts had
occurred to the north at Port Kent near Mile 154.5. These included complete washouts of two
stone box culverts, leaving the tracks hanging unsupported over the washouts.

One of the washouts also destroyed the small Amtrak Passenger Station at Port Kent, and
the resulting debris was found in the gully under the hanging tracks and in Lake Champlain.

The stone box culverts were completely destroyed. In addition, a major slump occurred
along the east embankment slope just to the south of the washouts, partially undermining the
tracks and a third stone box culvert was severely damaged.
Visual evidence indicated that the railroad embankment was overtopped, resulting in the washouts. These failures appeared to have occurred after the derailment at Mile 150.2.

The storm also rendered the road leading to Port Kent impassable. This road damage cut off access to the railroad and also to the ferry at Port Kent, New York that crosses Lake Champlain to Burlington, Vermont. The washouts at Port Kent are shown on Figures 4 and 5.

Figure 4

Figure 5
3.3 Embankment Failure at Mile 147.3

As the investigations continued, it was soon found that still another washout had occurred to the south at Mile 147.3. At this location, the track was supported on a rock fill embankment over a narrow ravine. The rock fill had washed out leaving the track hanging unsupported over the ravine. This section originally constructed as a blind drain with water flowing under the embankment through the rock fill. After the storm, this culvert was missing and had apparently washed into Lake Champlain. The washout at Mile 147.3 is shown on Figure 6.

3.4 Other Embankment Failures

Continuing rain on the night of June 26th resulted in additional failures to the north of the culvert at Mile 150.2. An additional 20 feet of culvert was destroyed in this failure, and another rail car was carried down the embankment. This secondary failure appeared to have been initiated by surface water from the ditch on the eastern side of the tracks, north of the derailment.
Another failure of the east embankment slope occurred some time later at Mile 150.1 just south of the derailment site. This failure occurred during reconstruction at the derailment site, and the failure mass “flowed” eastward several hundred feet, carrying a section of track with it. A small “island” of embankment remained intact between the two failures.

Numerous smaller washouts and slumps of the railroad embankment occurred over a 10-mile area between Mile 157 and Mile 147. Most of the sites were at remote locations with difficult access. This difficulty was exacerbated by the washouts, making travel along the track impossible except by foot.

Finally, a helicopter was hired on June 27th to review the magnitude and extent of the damage over the entire 10-mile corridor. These inspections revealed numerous major and minor washouts and side slope slumps. Many of these other failures partially or completely undermined the tracks. Most of the side slope slumps occurred along the eastern side of the railroad embankment, in some cases extending right to the shore of Lake Champlain, further complicating access.

3.5 Bridge Scour at Mile 176.9

After water in levels in the local rivers and streams receded sufficiently to inspect bridge substructures, it was found that the railroad bridge over the Little Chazy River at Mile 176.9 was severely undermined.

Since this bridge was located some distance to the north of the main failure areas, it had originally been open to local freight traffic. However, discovery of the scour resulted in the emergency closure of the bridge until adequate repairs could be made.
4.0 INITIAL EMERGENCY RESPONSE

D&H personnel responded immediately to the derailment site arriving before daybreak on June 26th. Of immediate concern was the safety of the site and adjacent residents.

A contractor was mobilized to begin clean up of spilled diesel fuel from the derailed locomotive. The contractor set up absorbent booms along the shore of the lake to contain the leaking diesel fuel. Some of the derailed cars also carried ethanol (whisky). This also created a potential hazard at the site and had to be removed to create a safer work site. Another contractor was also mobilized to remove the derailed cars and locomotive. In the interim, a local contractor began to clear an access road through dense woods to the derailment site.

CPR then contacted CHA to provide technical expertise and field support in trying to assess the damage and make the best possible engineering decisions in trying to reconstruct the main line. CHA personnel arrived the afternoon of June 26th and remained on site continuously, around the clock, to support CPR staff until the entire cleanup was completed two months later.

5.0 EMERGENCY RESPONSE MANAGEMENT

The goal of the emergency response team was to restore rail service as soon as possible. CPR quickly assembled a highly qualified team of engineers, construction managers, contractors, and suppliers. A “War Room” was then established at a local motel as a base of operations, setting up telephone, fax, and e-mail links. The War Room was manned around the clock for the duration of the project. Personnel were equipped with cell phone and beepers, allowing communication between widely spaced failure areas as the work progressed. Communication was essential for the successful completion of this project, since key decision-makers were also based in varied locations including Toronto, Calgary, and Albany.
The first task was to identify the numerous failure areas. The likely cause of each failure was also determined. Topographic surveys were made of the major failure areas to document conditions after the failures to aid in designing and quantifying repairs. Hydraulic analyses were then performed for sites requiring replacement culverts to verify sizes of the replacement pipes.

Locally available soil materials were investigated by inspecting existing sand and gravel mines and other potential sources. The investigation revealed that there were two primary types of materials available for embankment reconstruction: sand or bank run sand and gravel. Since the sand was considerably more economical, it was used for most of the reconstruction. Shot rock was also available either by truck or rail, but was the most costly material.

Appropriate repairs were then developed for each failure based on site conditions. Site specific repairs were selected considering accessibility of the site, speed of construction, available materials, available equipment, safety and cost. A critical path schedule was then developed to identify those sites requiring immediate action and sites requiring around the clock reconstruction. This critical path also identified embankment repairs that would quickly restore the track for work train access to critical sites. Considerable effort went into planning and scheduling repairs to restore service as quickly and economically as possible.

The management team also identified sites requiring surveys and other documentation. This included topographic surveys of the major failure areas and cross sections at most of the larger slump failures. The failure areas were also documented with extensive photographs. Soil test borings were made at select failure sites to evaluate subsurface conditions in the embankment and foundation soils. Laboratory index testing was performed on representative samples to document classification of soil samples. This data and hydraulic analyses were then summarized in a 3-volume binder of the storm damage in the corridor for future reference.
The reconstruction efforts were then divided into three sections: Zone 1 covered from the derailment site south, Zone 2 covered from the derailment site north to Port Kent, and Zone 3 covered from Port Kent north. Key CPR personnel managed work within each zone and the overall construction was managed through the War Room. Project meetings were held in the War Room every morning and evening throughout the project. These meetings were essential in tracking the project and coordinating personnel, equipment, and materials to the varied sites. The project schedule and critical path were continuously updated as the project progressed.

Another important function of the project management team was community relations. CPR personnel met with homeowners and attended local town meetings to discuss problems and potential solutions. For example, since the heavy truck traffic associated with the reconstruction effort resulted in damage to local roads, CPR paid for roadway repairs following the completion of the project.

6.0 STORM ANALYSIS

The storm event that was responsible for the catastrophic damage was analyzed in detail in order to understand the events leading up to the failures. CPR hired CHA and a climatologist, Dr. Arthur T. DeGaetano of Cornell University, to perform a forensic analysis of the rainfall data and assess the potential contribution of the storm runoff to the railroad embankment failures.

The rainfall amounts for the derailment area were not actually measured at the site, but deduced from measurements taken at nearby weather stations. The nearest weather station to the affected area is located in Peru, New York about 7 miles northwest of the derailment site. Based on observations at the Peru station, a total of 2.3 inches of rain fell on June 25th and an additional 4.1 inches fell on June 26th for a two-day total of 6.4 inches.
This amount exceeded the 100-year return period for a two-day event by more than an inch. Precipitation measured in Peru for the 10 day period prior to June 26th totaled 8.0 inches, also exceeding the 100-year, 10-day precipitation accumulation by 2.8 inches.

The drainage area for the critical culvert that carried Little Trout Brook under the Canadian Main was estimated to be about 5 square miles. The main channel of the brook has a slope of about 5 percent. Land usage within the watershed is mostly undeveloped, consisting of dense woodland. Impervious soil conditions within the watershed along with steep slopes promote rapid runoff.

A hydraulic analysis was then performed using this data. It is estimated that the flow volumes in Little Trout Brook reached about 1,625 cubic feet per second and the flow velocities reached over 20 feet per second, both far above the 100-year storm levels.

Other weather stations in the area also recorded total precipitation well above normal during the weeks prior to the failures. The average total rainfall recorded from June 1st to June 24th at six weather stations located within 20 miles was 5.1 inches. This rain over an extended period of time saturated the ground surface and exacerbated runoff during the major storm event.

Other contributing factors included the major ice storm damage that occurred the previous winter. It is likely that dead wood debris from the ice storm contributed to the railroad failures by washing into drainage courses. Another factor was the possible breach of a beaver dam upstream of the derailment site that would have further increased runoff flow volumes.

Based on the cumulative effect of the above factors, the climatology report concluded that the rainfall from this storm definitely exceeded the 100-year event and caused the extensive damage to the rail corridor by exceeding the design capacity of the system. Therefore, the event was ruled a “natural disaster”, not a maintenance failure or industrial accident.
This was an important factor when CPR went before the Federal Railroad Administration (FRA), New York State Department of Environmental Conservation (NYSDEC) and Adirondack Park Agency (APA) to demonstrate that the railroad was not negligent in any of its responsibilities and had always maintained the line to industry standards. The climatology report was a key piece of evidence in establishing the railroad’s credibility on this issue.

As a result, CPR was able to avoid stiff fines and settle insurance claims to help cover some of the costs of the storm damage.

7.0 FAILURE ANALYSIS

A failure analysis for the derailment site was also performed in order to determine the most probable cause. Two possible failure modes were considered. The first scenario assumed that the embankment failed first due to the elevated groundwater levels saturating the soils and the embankment failure (under load) then destroyed the downstream end of the culvert. The second scenario assumed that the downstream end of the culvert failed first due to the high runoff flows, and the culvert failure then resulted in the failure of the entire embankment.

The embankment stability analysis was performed in two steps. First, the probable range of soil strength parameters was established as well as the position of the water table within the embankment at the time of the failure, when the safety factor of the east slope was known to have a value of 1.0. Second, the factor of safety is computed when the water table is near the invert of the culvert, representing normal conditions.

The first analysis indicated that if the water table rose to a height of 14 to 16 feet at the 12-foot stone arch culvert on the western side of the embankment, the safety factor would drop below 1.0 and the eastern slope would fail.
The hydraulic model also indicated that the water would be about 7-feet deep at the outlet, flowing at nearly 20 feet per second. Based on the characteristics of the natural streambed, these flow rates would have been highly erosive, possibly undermining the downstream toe of the embankment, thereby adding to the instability of the embankment.

This scenario corresponds closely with visual observations and physical evidence in the field that indicated that the water level on the upstream side had risen to about 3 feet above the culvert crown at some point during the storm. It was also consistent with observations that no visible seepage flowed from the exposed upper portion of the embankment.

The analysis of the second scenario indicated that the safety factor of the slope under normal conditions, with water levels near the culvert invert, would still be about 1.3. Train loading was also considered in this analysis. It was found that these loads only had minor effect on side slope safety factor since live loads are transferred and dissipated more widely on high embankments.

This finding also supports the idea that the first scenario was the likely failure mode. Since the train loading and associated vibrations would have only had a minor effect on the failure, then the embankment must have already been in a saturated state when the train passed over it. In fact, it was likely that the embankment would have failed anyway at some point during the storm, regardless of whether the train had passed over the embankment or not.

Although both failure mechanisms are physically possible, the analysis indicates that the failure of the embankment’s eastern slope was due to the elevated water levels on the upstream side and the derailment occurred as a result of this failure.

Figures 7 and 8 graphically represent the analysis of this scenario.
8.0 EMERGENCY REPAIRS

8.1 Derailment Site at Mile 150.2

Initial plans to repair the embankment at the derailment site included extending the remaining stone arch culvert with a 12’ diameter Corrugated Metal Pipe (CMP), using a concrete collar to create a transition between the two sections. For safety, the upper part of the embankment would be removed to protect personnel working below. Because of continuing rainy weather, it was planned to reconstruct the embankment with rock fill so it could be placed rapidly regardless of weather conditions and would provide a steep, stable embankment slope.

This initial reconstruction plan was based on the assumption that the remaining culvert was in satisfactory condition. Because of the continued storms and high flows it was not possible to inspect the interior of the culvert for about a week after the derailment. During the inspection, it was discovered that much of the culvert sidewalls were undermined and that sections of the walls were severely damaged.

Based on this information, it was concluded that the only practical option left was to completely replace the entire culvert with 12’ CMP and reconstruct the embankment. The new culvert would also be realigned slightly to better accept the flow of Little Trout Brook. This realignment also allowed the original stone arch to carry stream flows during reconstruction.

Several options were also considered for embankment material. The existing soils at the site were wet and silty, making poor fill material. Because of uncertain weather, the use of this material may have resulted in unacceptable delays. The use of quick lime as an additive to dry the existing soils was also considered, but was rejected as impractical and costly. Locally available sand was the most economical fill material. However, sand would have required a slope flatter than the original 1.5H:1V to achieve an unacceptable stability safety factor.
Flattening the slope would have required extending the embankment toe beyond the right-of-way limits and would have required a longer 12’ CMP. In addition, a flatter slope would have required more fill material, increasing construction time and delaying the reopening of the rail line. Because of these concerns, the use of the sand fill was rejected.

Other options included the use of more costly rock fill or bank run sand and gravel, which could have been used to reconstruct the embankment at a steeper slope with an adequate safety factor. However, both of these materials were considerably more costly than the locally available sand.

Finally, a design option was developed that would use the sand soil to save on the cost, but reinforce it with plastic geogrids to provide a steeper, more stable slope with an adequate safety factor. Rock fill was also included along the toe of the embankment to protect it against failure during future storm events. This was judged to be the most economical option that could be constructed quickly, with minimal delays due to poor weather.

Photos of the reconstruction are shown in Figures 9, 10, and 11 (note scale of workers).
8.2 Embankment Failure at Port Kent at Mile 154.5

The Port Kent repairs included the installation of new culverts (CMP) and reconstructing the embankments using locally available sand. The embankment at this location extends to the edge of the Lake, and rock fill was used along the toe of the eastern side slope as protection against wave action. A connecting channel was constructed between the two washed out culverts on the upstream side to provide some redundancy in the drainage system.
A major slump also occurred along the eastern side slope just to the south of this location. Fortunately, the embankment was wide at this site, with areas to the west of the track previously used as a railroad yard and currently used as parking for the Amtrak station. This allowed a slight realignment of the track to the west, shifting it away from the crest of the slope and enhancing long term stability. The slump was repaired by installing a rockfill toe along the shore and reconstructing the side slope using the locally available sand fill.

8.3 Embankment Failure at Mile 147.3

The steep gradient of the stream channel and the large flow of water complicated repair of the rockfill embankment at this location. It was elected to reconstruct the embankment by placing large stone fill along the base of the channel under the embankment, thereby creating a blind drain to carry the flows. This allowed reconstruction of the upper embankment in the dry. The remaining embankment was constructed using progressively smaller size rock fill.

Large size rock fill was used to line the channel downstream of the culvert outlet. Slush grout was used along the surface of the downstream channel to handle future storm flows.

Rock fill was brought to this remote site by train using side discharge air dumps. The air dumps unloaded the stone fill just to the south of the washout, and the fill was then placed in the embankment using a rail mounted crane operating from the south side of the failure.

8.4 Bridge Scour at Mile 176.9

The scour under the substructures of the railroad bridge over the Little Chazy River was repaired by installing grout filled bags under the substructures. Placing riprap around the substructures provided additional scour protection.
8.5 Other Repairs

Side slope repairs typically made by placing rock fill in the slumped areas. At locations accessible to work trains, the rock fill was typically placed using side dump cars. Elsewhere, the rock fill was trucked in and placed with excavators. At locations where the railroad embankment straddled the shoreline, excavators and other equipment were mobilized using barges.

Other sites were repaired by installing new culverts either by pipe jacking or open cut methods and then reconstructing the embankments with suitable materials brought to the site.

9.0 ENVIRONMENTAL ISSUES

As part of the corridor restoration effort, CPR also had to comply with New York State Department of Environmental Conservation (NYSDEC) and Adirondack Park Agency (APA) regulations.

In addition to the emergency cleanup of ethanol and spilled diesel fuel from the derailed locomotive, a major environmental consideration was the deposition of sediment along downstream properties and in Lake Champlain. Sediment originating from storm flows and the washed out embankments created small “islands” just offshore in the Lake.

The embankments were also seeded with a wildflower seed mix in accordance with Adirondack Park Agency requirements.

Final plans for the cleanup of the sedimentation are still being negotiated with the NYSDEC and Adirondack Park Agency. These plans include removal of sediment, restoration of wetlands, and stream channel improvements for fish.

Figure 12 shows a typical culvert outlet with natural rock treatments and stream grading.
10.0 SUMMARY

The washouts forced the closure of CPR’s Canadian Mainline for about 7 weeks. This required the rerouting of all rail traffic between Albany and Montreal until the line was reopened in mid-August. Amtrak passenger service between Albany and Montreal was also stopped. Passengers were bussed during the shutdown resulting in lost revenue from Amtrak. This not only meant loss of revenues, but a significant cost to reroute traffic. The estimated cost of the repairs alone was about $8 million.

The storms also had adverse impacts on local residents. The construction effort extended round the clock, seven days a week, including the 4th of July holiday weekend. This coincided with peak tourist season in the area, disrupting the normal quiet neighborhoods along the lakeshore.
Traffic was finally restored on August 13th, 1998. A photograph of the first train crossing the derailment site at Mile 150.2 is shown on Figure 13.

11.0 ACKNOWLEDGEMENTS

This project was completed through the dedication and hard work of many talented individuals that came together as a team with a common goal. Not only did they work around the clock seven days a week, many worked through the Fourth of July and Labor Day holidays in order to complete the job.
In particular, the following individuals also deserve special recognition:

*Hal Langpap, Canadian Pacific Railway – Chief Construction Engineer*

*Richard Bovee, P.E., Clough, Harbour & Associates LLP – Chief Project Engineer*

*Warren Harris, P.E., Clough, Harbour & Associates LLP – Senior Field Engineer*

*Mike Miller, P.E., Clough, Harbour & Associates LLP – Senior Hydraulic Engineer*

*John E. Quinn, P.L.S., Clough, Harbour & Associates LLP – Chief Surveyor*

This project also won the American Consulting Engineers Council (ACEC) Gold Medal in 1999 for Transportation Projects in New York State. The project was recognized for its innovation and ingenuity in assessing the damages quickly and implementing a cost-effective reconstruction program over a large area in a remote region in real time. It was a true demonstration of how to apply time tested engineering principles to help make informed decisions that can guide and facilitate enormous and complex field construction efforts.